Faculty of
Bioscience Engineering

HANS DE STEUR

# MARKET POTENTIAL OF
# FOLATE BIOFORTIFIED RICE IN CHINA

Thesis submitted in fulfillment of the requirements
for the degree of Doctor (PhD) in Applied Biological Sciences

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# Acknowledgments

*It's my third week at Nanjing Agricultural University. Tomorrow I am off to Beijing, the last stop before the Shanxi 'adventure' really starts. I was putting the final (!?) touches to my research design, while making my mind up about the upcoming To-Do's – actually writing this PhD was the biggest to-do –, when I got interrupted by this reggae singer Jimmy Cliff, singing: "You can get it if you really want, but you must try, try and try, try and try, you'll succeed at last". Still recovering from this line (and the fact that I actually own this record), his lyrics hit me another time: "Rome was not built in a day. Opposition will come your way. But the harder the battle you see, is the sweeter the victory, now".*
*Without knowing, I believe he exactly summarized how I experienced the process of my PhD.*

Indeed. My PhD wasn't built in a day. Today, it's my 1 882$^{nd}$ day as a researcher of the Department of Agricultural Economics at Ghent University. I must say, as a sociologist, being a white raven has not always been an advantage. Fortunately, I had the opportunity to work on various topics, before *I got what I really want.* I could do a PhD about an extremely interesting and multidisciplinary project, which deals with nutrition, health, genetics, birth defects, consumer studies and economic (e)valuations. As such, everyone in this project was a white raven to some extent. And, I must admit, I had the honor to work with the best 'ravens'. Now the time has come to thank them and the people who supported me, stood by me, in research or anti-research purposes, in times of crisis or stress (often in combination), in the office, in China, at home or from above, this one's for you.

First of all, I want to thank two people for giving me the opportunity to work at this department, which is more easily said than done. My promoter, Prof. Xavier Gellynck. If there would exist such a thing as a 'typical' professor or PhD student, I don't think we would be elected. While I could work independently on this PhD, you were there to take action when it was really needed. Not only with respect to work, e.g. the first paragraph above would be fiction without your support, but also, and above all, to health and family. Prof. Viaene, you have guided me successfully during the project years, and helped me to form the foundation of this thesis. I am grateful for having the chance to learn from you as a highly experienced, renowned agricultural economist. I cannot recall any significant disagreement between us, and I am sure this contributed to the publication of our first FBR articles.
When talking about the FBR project, I cannot, may not and will not forget to thank Prof. Van Der Straeten and Prof. Willy Lambert. I must admit, the endless devotion you have shown in this project consortium was extremely contagious. On top of that, you have continuously motivated me to contribute. Dominique, your optimistic reaction to the 10-page comments letter not only surprised me, but also convinced me to *try and try*, and finally, publish in Nature Biotechnology. Also Sergei and Dieter of your FPB team, and Ge Liqun of Liaoning Academy of Agricultural Sciences deserve their spot. A particular thanks to Dieter, for not giving up on me to learn me the basics in the wonderful world of genetics. Although the difference with *Chinese* was sometimes thin (e.g. an e-mail about GTPCHI and phosphomannose isomerase ☺), there is not a doubt that your transferred knowledge definitely contributed to this thesis. If I would pile up all the replies to my never-ending biotech questions and the advice from all four of you, the seven hills of Rome would fall short.
Regarding the recent PHD work, I have to thank Prof. Verbeke, Pieter Rutsaert[1] and dr. Nicole Hellyer (auctions), and Prof. Matin Qaim (multi-biofortification). Prof. Qaim, what started as a 10-hours drive to Göttingen, ended up in a A1 publication that addresses ex ante one of the key novelties in biofortification research. It was my privilege to work, talk, discuss and learn from one of the world experts in economic evaluations of GM crops.

But working at the department was much more than writing this PhD. I want to thank all the people that helped me in one way or another, particularly the (ex-)colleagues from my office!
A special appreciation to the head of fun (Jozef) and my personal PhD crisis manager (Bianka).

[1] Pieter, I guess you're the first who really paid for a spot in this section. Although I accepted your offer (we're still economists right ?), your help in designing and analyzing the auctions would have been already enough to be cited!

Many thanks go to the members of my Reading and Examination Committee, Prof. dr. ir. Frank Devlieghere, Prof. dr. Godelieve Gheysen, Prof. dr. ir. Dominique Van Der Straeten, Prof. dr. ir. Wim Verbeke, Em. Prof. dr. ir. Jacques Viaene, Prof. dr. Eric Wailes (University of Arkansas) and Prof. dr. Shi Xiaoping (Nanjing Agricultural University) for their fruitful comments and suggestions which significantly improved the quality of this dissertation. It was my honor having you all on my jury.

Of course, there would be no PhD without China. Besides IMRD (Marie-Paule) and the China platform of Ghent University (Isabelle and Mieke, and Isabelle in Beijing), I want to express my gratitude to Prof. Shi Xiaoping and Prof. Feng Shuyi, who invited and guided me in Nanjing Agricultural University. The way they both supported me to conduct my research and to get integrated definitely contributed to the success of this trip. I recommend every researcher to take such an opportunity when it comes along. However, I would suggest to first explore the potential involvement of future pregnancies when booking a seven weeks ("seven weeks??") trip. Furthermore, I thank the office colleagues in Nanjing, Lei and Xianlei, who made me feel like it was my office, the practical organizer Liu, and last but not least, Kun and Hong, aka the best experimental auctioneers one could ask for. Their commitment during the auctions was an example for all master students I have ever worked with. I admire the tremendous work you have done. Neither will I forget the family dinners (服务员!), the sightseeing (平遥古城), the karaoke (and, luckily, 青島啤酒), and the talks.
Every trip needs a decent laptop. My brother Wim, thanks for borrowing your laptop for almost a year! And Bjorn, the last-minute IT hero who made it work. Indeed, the police became my friend.

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And not to forget my own editors. My brother Wim, your help was priceless! Therefore, I will not pay you ☺. And what to say about Gretchen. We have met only once in Budapest during the IAMA conference, but still it did not hold you back from editing my PhD. Although I am certainly prejudiced, this is again the proof that the Americans I have met, are anything but superficial. Gretchen, I truly hope to reward you another time, but then in person.

My friends, I hope I can stop quoting the former Californian governor anytime soon!
My brothers, Peter and Wim. The little one must have grown old! The Wonder Years ® finally pay off!
My mom and dad. This thesis demonstrates your life-time support in whatever I do. However, it vanishes compared to what you have done for me. And if this book makes you proud, it's because you deserve nothing less.
And my final lines are left to thank the one who actually deserves the next 17 765 lines: **Pieternel**. You and only you know what is really behind these pages, this study and me. As Rome was founded by two people, this thesis would not have been possible without you, your support, and your love. This thesis is nothing more than another proof of how we can manage everything, if we're together!
And there is one big difference with Romelus and Remus … We do have a happy ending! Merlijn!

And to the reader, I would say, enjoy or good luck! [2]

*Hans De Steur*

Ps: It took Rome 870 years[3]. *26 November 2011, Wetteren*

[2] Delete as appropriate.
[3] These references to Ancient Rome must have something to do with my Latin background.

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# List of abbreviations

| | |
|---|---|
| ADB | Asian Development Bank |
| AL | attribution level |
| BDM | Becker-Degroot-Marschak auction |
| CAAS | Chinese Academy of Agricultural Sciences |
| CC | Copenhagen Consensus |
| CB | biofortification using conventional methods (conventional biofortification) |
| CBA | cost-benefit analysis |
| cba | childbearing age |
| CDC | Centers for Disease Control and Prevention |
| CDPF | Chinese Disabled Person Federation |
| CEA | cost-effectiveness analysis |
| CGIAR | Consultative Group on International Agricultural Research |
| CIAT | International Center for Tropical Agriculture |
| CIP | Country Investment Plan |
| CMA | cost-minimization analysis |
| CNGOIC | China's National Grain and Oils Information Center |
| COI | cost-of illness analysis |
| CRA | Comparative Risk Factor Assessment |
| CV(M) | contingent valuation (method) |
| DALE | disability-adjusted life expectancy |
| DALY | disability-adjusted life year |
| DC | dichotomous choice contingent valuation |
| DCP | Disease Control Priorities in Developing Countries |
| EAR | Estimated Average Requirements |
| ESCAP | United Nations Economic and Social Commission for Asia and the Pacific |
| EU | European Union |
| FAO | Food and Agriculture Organization of the United Nations |
| FAR | folic acid pills + rice ('rice supplemented with folic acid pills') |
| FBR | folate biofortified rice |
| FD | folate deficiency |
| FFI | Flour Fortification Initiative |
| GAIN | Global Alliance for Improvement of Nutrition |
| GDB | Global Burden of Disease |
| GDP | Gross domestic product |
| GLM | General Linear Model |
| GM | genetic modification/ genetically modified |
| GR | Golden Rice |
| ha. | hectares |
| HALY | health-adjusted life years |
| HUMBO | Golden Rice Humanitarian Board |
| HUTT | Humanitarian Use Technology Transfer |
| IFIC | International Food Information Council |
| IFPRI | International Food Policy Research Institute |
| IIASA | International Institute for Applied Systems Analysis |
| IMNIP | India Micronutrient National Investment Plan |
| IMRD | International Master in Rural Development |
| ILSI | International Life Sciences Institute |
| IPR | Intellectual Property Rights |
| ISAAA | International Service of the Acquisition of Agri-biotech Applications |
| iWTP | indirect willingness-to-pay |
| IZINCG | International Zinc Nutrition Consultative Group |
| LAC | Latin America and the Caribbean |
| MBR | Multi-biofortified rice (folate, vitamin A, zinc and iron) |
| MDG | Millennium Development Goals |
| mg | milligram |
| mi. | million |
| MI | Micronutrient Initiative |
| MIL | micronutrient intake level |
| MM | micronutrient malnutrition |
| MoA | Chinese Ministry of Agriculture |
| MoH | Chinese Ministry of Health |
| MOST | Chinese Ministry of Science & Technology |
| MT | metric ton |
| NA | not applicable |
| NCBP | National Committee on Biosafety of the Philippines |
| ND | no data |
| n.d. | no date |
| NGO | Non-Governmental Organization |
| NTD | neural-tube defect |
| ID | iron deficiency |
| IDA | iron deficiency anemia |
| IOD | iodine deficiency |
| OE | open-ended contingent valuation |
| QALY | Quality-Adjusted Life Years |
| R&D | research and development |
| RNI | recommended (daily) nutrient intake |
| RQ | research question |
| SDB | social desirability bias |
| SEPA | State Environmental Protection Administration |
| SPSS | Statistical Package for the Social Sciences |
| sWTP | stated willingness-to-pay |
| TB | biofortification using transgenic methods |
| UK | United Kingdom |
| UL | tolerable upper level |
| UN | United Nations |
| UNICEF | United Nations International Children's Emergency Fund |
| US | United States |
| USDA | United States Department of Agriculture |
| VAD | vitamin A deficiency |
| WHO | World Health Organization |
| WHO CHOICE | Choosing Interventions that are Cost-Effective |
| WTA | willingness-to-accept |
| WTP | willingness-to-pay |
| ¥ | Yuan |
| ZD | zinc deficiency |

# 1 General Introduction: framework, research questions & outline of the thesis

Adapted from:

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## *Preface*

This PhD dissertation is prepared within the framework of the Special Research Fund – Concerted Research Action (2004 – 2009) project, entitled "*Enhancement of folate content in rice: an analytical-molecular and economic study*" (BOF-GOA 1251204), financed by Ghent University. Both the Laboratory of Functional Plant Biology of Department of Physiology, led by Prof. dr. ir. Dominique Van Der Straeten, and the Laboratory of Toxicology of the Department of Bioanalysis, led by Prof dr. apr. Willy Lambert, were involved in the biotechnological and analytical part of this study, which aimed to develop rice with high folate content through genetic engineering. This PhD dissertation reports the results of the third part of the research, conducted by the division of Agri-food Marketing of the Department of Agricultural Economics. This part encompasses research activities to explore the market potential of folate biofortified rice (FBR) in China and Shanxi Province specifically, with a focus on the level of consumer acceptance and the potential health impact.

In 2011, I received financial support through the IMRD (International Master in Rural Development) staff exchange program, to set up a collaboration with Nanjing Agricultural University, in order to investigate the willingness-to-pay (WTP) for FBR with experimental auctions in Shanxi Province.

## *1.1. General introduction*

Worldwide, micronutrient malnutrition or a chronic lack of essential vitamins and minerals affects over two billion people, particularly pregnant women and children in less developed regions (Micronutrient Initiative, 2009). Due to its far-reaching consequences for global health and development, international organizations have set specific nutritional goals in the 1990 World Summit for Children (Sanghvi et al., 2007) as well as the 2015 UN millennium development goals (MDG)(UN, 2004). Presently, despite the progress made towards eliminating the global burden of this 'hidden hunger', these goals are far from being reached (UNICEF, 2006; UN, 2010), necessitating an increase in efforts to support, develop, introduce or improve micronutritional interventions (Mason et al., 2001; Dalziel and Segal, 2007).

In addition to the current policy tools to address micronutrient malnutrition, e.g. supplementation, fortification and dietary diversification, biofortification has been explored and advocated as a novel, potential strategy (Horton et al., 2008; Mayer et al., 2008), at both the policy and research level (Johns and Eyzaguirre, 2007). By enriching the natural micronutrient content of staple crops, such as rice, wheat or potatoes, biofortification aims to alleviate the burden of micronutrient deficiencies, in particular for the people who need it the most (Qaim et al., 2007). In this respect, folate biofortified rice (FBR) was recently developed through genetic engineering in order to tackle folate deficiency (Storozhenko et al., 2007). As a consequence, FBR is considered a Genetically Modified (GM)[4] food product with health benefits.

[4]Although several proponents of GM food avoid the term 'GM', due to the controversy it already generated (Novotorova and Mazzocco, 2009), and prefer the more neutral term 'biotechnology' (Brooks, 2010), this thesis consequently refers to the term 'GM' as this is the concept to which people are more likely familiar with.

Due to the controversial nature of this micronutrient enriched staple crop, governments, decision-makers and health planners are interested in the consumer reactions to this product as well as the benefits and costs of introducing it as an alternative health intervention. In order to justify the allocated resources of setting FBR as a priority to address folate deficiency, stakeholders should have access to information about the importance of this micronutrient deficiency on the one hand, and understand how FBR would contribute to reduce its burden on the other. Information on the burden of disease is considered an essential factor for a successful implementation of micronutrient interventions, in addition to a supportive government (Faillace et al., 2008). As the asynchronous approval of currently available GM foods demonstrates, consumer acceptance and intention will also play an important factor in political support and farmer adoption. Not surprisingly, market failure of novel products or technologies is often caused by a lack of, or inadequate consumer market research (Davidson, 1988; Lusk and Norwood, 2006). Because FBR is not (yet) available in the marketplace, it is deemed crucial to explore ex-ante its market potential.

Even though field trials of Vitamin A biofortified 'Golden' rice have recently started in the Philippines (Serapio, 2010; NCBP, 2011), the commercialization of GM biofortified crops as such has not proceeded. As transgenic crops like FBR are still under development, little is known about the acceptance (Gonzalez et al., 2009), purchase intentions (Lusk, 2003) and public health impacts (Stein, 2006) of such 2$^{nd}$ generation GM crops. However, due to China's recent approval of the first GM rice crop (Wang and Johnston, 2007b; Waltz, 2010), the future commercialization of GM biofortified crops is likely to happen (James, 2009b). This thesis anticipates these events.

This PhD dissertation is a compilation of research papers that investigate ex-ante the market potential of FBR in China and Shanxi Province, a poor, rural, less developed, and high-risk region in Northern China. This province is characterized by one of the highest prevalence rates of maternal folate deficiency (Ren et al., 2007) and neural-tube defects (NTDs)(Gu et al., 2007). Despite large efforts to tackle folate deficiency in this province, the currently existing folate strategies are less successful, e.g. folic acid supplements (Ren et al., 2006), or less feasible, e.g. folic acid fortified rice (Alavi et al., 2008; Bertebos Foundation, 2008).

In section 1.2, the rationale behind the relation between the topic and the research location is described from a practical point of view. Section 1.3 presents the conceptual framework and the underlying theories and methods. The research questions are outlined in section 1.4, followed by a discussion about the contributions of this dissertation and the policy relevance of the findings (section 1.5). In section 1.6, I outline the research design and the structure of the thesis.

## 1.2. Scope and relevance of the topic and the research location

The objective of this thesis is to evaluate the market potential of FBR in China and Shanxi Province in particular. The scope of the research will follow three main lines of inquiry: acceptance, WTP and cost-effectiveness. While the former two examine the market potential of FBR by focusing on the consumer, the latter investigates its potential as a public health intervention (see section 1.3).

The rationale behind this research scope is closely related to the scope of the topic, i.e. FBR as both a novel, controversial good with consumer/health benefits and a micronutrient intervention, and the research location, i.e. China and Shanxi Province in particular.

Figure 1 illustrates the link between the topic and the research location.

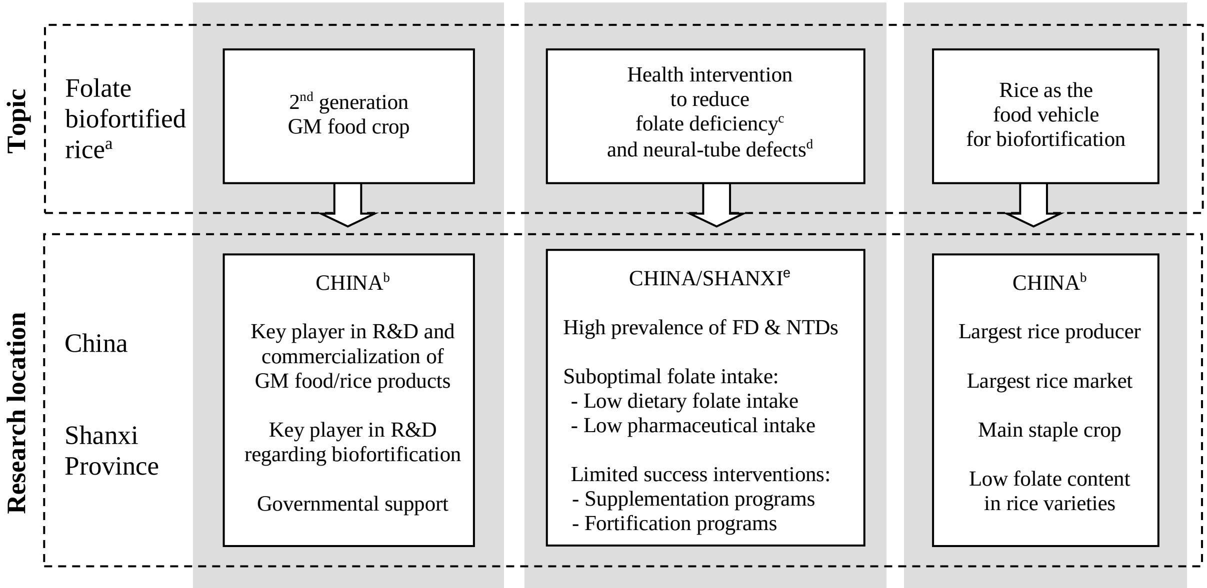


Figure 1 Focus of the PhD dissertation

FD, folate deficiency; GM, Genetically Modified; NTD, neural-tube defect
[a]See section 2.4.4; [b]See section 2.5; [c]See section 2.2 (micronutrient malnutrition) and section 2.3.2.1 (folate deficiency); [d]See section 2.3.3; [e]See section 2.4 (folate interventions).

*Topic*

This study focuses on folate enriched rice as a novel, non-market good, which makes this thesis an ex-ante evaluation study. Due to its significantly higher concentrations of natural folate or vitamin $B_9$, FBR is categorized as a biofortified food product, i.e. a staple crop of which the micronutrient content is enhanced (Storozhenko et al., 2007). It is currently the most advanced folate biofortified crop (see section 2.4.4). Compared to conventional biofortification, FBR is based on transgenic technology. Therefore, it is considered as a GM biofortified crop and, thus, belongs to the 2nd generation of GM food products[5]. While the first generation led to substantial farmer benefits by improving agronomic traits, the focus here is on consumer benefits through increasing the micronutrient content of staple crops (Engel et al., 2002)[6]. In the case of FBR, the higher folate content is beneficial as it reduces the

[5] Throughout this dissertation, the terms "transgenic" and "GM" will be interchangeably used. In other words, transgenic crops are considered the same as GM crops. Thus, FBR is based on GM or transgenic breeding techniques to increase the micronutritional level, i.e. transgenic or GM biofortification. In that way, FBR is opposed to rice based on conventional breeding, i.e. non-GM or non-transgenic rice.

[6] However, first generation crops, such as Bt cotton (Huang et al., 2002) and Bt rice (Huang et al., 2005b), are assumed to be also beneficial to health due to the reduced farmers' sickness, saved labor days and decreasing health costs, which are associated with the lower levels of pesticide use. On the other

occurrence of several folate deficiency related diseases, of which the risk of having a baby with an NTD is the most important (Berry, et al., 1999; see section 2.3).

In this way, FBR can also be considered as a novel, agriculture-based, health intervention to tackle folate deficiency. In health literature, an *intervention* is defined as: *"an activity using human, physical, and financial resources in a deliberate attempt to improve health by reducing the risk, duration, or severity of a health problem"* (Musgrove and Fox-Rushby, 2006, p. 273). At the population level, three intervention types can be distinguished: those promoting to change personal behavior, those aiming to control environmental hazard and (mass)-medical interventions. Regarding folate deficiency, there are currently three policy interventions[7] that could be implemented in order to increase folate intake levels: folic acid supplementation, folic acid fortification and dietary diversification. While the former two refer to a 'medical' intervention, the latter aims to alter the dietary habits of the population. Although some of these folate interventions will be included in this thesis, e.g. the provision of folic acid supplements as an auction design characteristic in the study to elicit WTP for FBR (see section 1.3.2.2), or discussed, e.g. costs of folic acid supplementation and fortification (see section 1.3.3.3), FBR remains the key focus. By using the world's most consumed crop as the food vehicle for biofortification, the aim is to maximize the potential health benefits of folate biofortification and, as a consequence, help to further alleviate the burden of folate deficiency and micronutrient malnutrition.

Besides the focus on FBR as a potential alternative to these three existing folate interventions, this thesis will also address multi-biofortification of rice (MBR), by which not only folate, but also zinc, iron and vitamin A deficiency can be tackled (see section 2.4.4.3). This will be done in the cost-effectiveness study of chapter 5. An overview of the different folate interventions, including multi-biofortification, their characteristics, advantages and shortcomings, their applicability and feasibility in China and the link with the Chinese policy context, is extensively described in section 2.4.

*Research location*

The potential of FBR is investigated by focusing on Shanxi Province, and China as a whole. Broadly three reasons can be cited for the selection of this research location. First, China is one of the key players in research, development and production of GM crops, and rice in particular (Huang et al., 2004; Jia et al., 2004; Wang and Johnston, 2007b). It is the sixth largest GM producer of the world (James, 2010) and will likely be the first to commercialize GM rice (Xiong, 2004; Waltz, 2010). Due to the governmental support towards biotechnology (Biosafety Clearinghouse of China, 2004; Xi and Harris, 2006) and reducing malnutrition (Micronutrient Initiative, 2011b), it is one of the main actors in conventional (HarvestPlus China, 2009, 2011) and GM biofortification research (Campos-Bowers and Wittenmyer, 2007; Pray and Huang, 2007).

Second, China is characterized by a high prevalence of folate deficiency, with about 20 % of its population being folate deficient (see section 2.3.2.1), and a high NTD rate (12.2 per 10000 births, see section 2.3.2.2). The reason to improve folate consumption is even more relevant in Shanxi Province,

---

hand, biofortification itself might address agronomic traits as well, such as the improvement of disease resistance (Welch and Graham, 2004). Nevertheless, the focus throughout this thesis will be solely on the health benefits of biofortification.

[7] When dealing with interventions to tackle folate deficiency, the terms 'policy', 'micronutrient' and 'health' interventions will be interchangeably used.

where suboptimal folate intake levels occur in 43.8 % of all pregnant women, leading to one of the world's highest numbers of NTDs per year, i.e. between 0.3 (Dai et al., 2002) and 1 NTD per 50 births (Gu et al., 2007). This is confirmed by the currently low (correct) use of folic acid supplements and the low dietary folate intake in China (Zhao et al., 2009) and Shanxi Province (Ren et al., 2006; Zhang et al., 2008). Moreover, past folic acid supplementation programs were not successful, at least not in the long term (see section 2.4.1.2), and folic acid fortification is less feasible when aiming to tackle poor, developing regions, like Shanxi Province (see section 2.4.2.2).
Third, biofortifying rice would be particularly relevant for China, as it is the world leader in rice production and has the largest rice consumer market (see also Figure 22). In 2007, China was responsible for a rice production of 185.5 million tons or a world share of 28.5 % (FAOSTAT Database, 2008).

The relevance of this topic and research location is extensively described in Chapter 2. In that chapter, the main concepts related to FBR and folate deficiency are defined and discussed in relation to the broader (policy) context, in China as well as in the world. In this way, chapter 2 encompasses the rationale of this PhD dissertation and provides a foundation for the research chapters on acceptance (chapter 3), WTP (chapter 4) and cost-effectiveness (chapter 5).

## *1.3. Conceptual framework*

Consumer market research is considered a crucial factor to successfully introduce a novel, controversial good, such as GM food (Davidson, 1998; Lusk and Hudson, 2004; Lusk and Norwood, 2006). Despite the large number of developed biofortified crops, knowledge on consumer acceptance of, and WTP for these products is scarce (Lusk, 2003), especially in high-risk regions. Therefore, this thesis obtains insight in the way consumers accept and value FBR in a folate deficient region, i.e. Shanxi Province. But an agricultural innovation like FBR can also be perceived as a health strategy that aims to contribute to public health by tackling micronutrient malnutrition, i.e. folate deficiency. From a policy point of view, knowledge of the importance of the micronutrient deficiency (ADB, 2004b; Faillace et al., 2008) and an economic evaluation is needed to assess whether this health intervention is worthwhile to undertake (Laxminarayan et al., 2006; Musgrove and Fox-Rushby, 2006). As previous burden of disease studies solely focused on the three main micronutrients (vitamin A, zinc and iron), this thesis addresses this knowledge gap by conducting a disease burden study of folate deficiency and an ex-ante health impact analysis of FBR.

Figure 2 presents the conceptual framework that will be applied to analyze the market potential of FBR in China. The different components of the conceptual framework and the rationale to investigate them will be discussed in the subsequent sections. Thereby, emphasis is put on the three different research domains, i.e. acceptance (see section 1.3.1), WTP (see section 1.3.2) and cost-effectiveness (see section 1.3.3). Each of these topics refers to a specific chapter in this PhD dissertation and can be categorized based on the level of analysis, micro versus macro. While acceptance of, and WTP for

FBR are examined at the level of the individual consumer (micro), the macro-level looks at the potential health benefits of FBR, and MBR, for the society as a whole, as well as the potential cost-effectiveness of introducing this policy intervention in China (macro). Also the research location differs according to this level: at micro-level, the consumer studies are conducted with rice consumers from Shanxi Province; at macro-level, FBR as a policy intervention is evaluated from the point of view of the broad society, i.e. China and its regions (see also section 1.2).

Regarding the micro-level, broadly two consumer studies can be distinguished. The study on acceptance of FBR consists of three main parts. The determinants of FBR acceptance are investigated, including objective GM knowledge and subjective GM rice knowledge, consumer perceptions of GM food (benefits, risks, safety and price impact) and socio-demographic indicators (see section 1.3.1.1); a segmentation analysis is conducted to further define the market of FBR (not presented, see section 1.3.1.2); and the influence of negative changes of the regular product characteristics, such as taste and appearance, on FBR acceptance is explored (see section 1.3.1.3). The second micro-level analysis examines WTP for FBR, by which two value elicitation studies are compared, i.e. WTP as stated preferences and WTP values derived from experimental auctions (see section 1.3.2.1). Regarding the latter, the effect of GM food acceptance, knowledge (e.g. folate benefits), socio-demographic indicators and auction design characteristics (e.g. provision of a folate substitute, timing, auction size) on WTP in different information rounds is determined. Moreover, the effect of the provision of specific information related to the folate content, the folate benefits, the application of GM technology, including conflicting GM information and information about the link between FBR and the research location, is analyzed in the auctions (see section 1.3.2.2) .

The macro-level study analyzes the cost-effectiveness of FBR in China and its regions, based on three subsequent steps[8]. First, the current burden of the micronutrient deficiency in China and its regions is quantified (see section 1.3.3.1). Second, the health gap between a situation with and without biofortified rice is assessed. By comparing both burdens, the health benefits can be estimated (see section 1.3.3.2). Third, the cost-effectiveness of this health intervention are estimated by juxtaposing the intervention costs and the potential health impacts (see section 1.3.3.3).

It is important to note that this conceptual framework provides an overview of the key concepts in this thesis. In the following subsections, reference will be made to related concepts, e.g. the DALY concept as a health impact measure, or concepts will be defined according to the investigated research topic, e.g. GM food knowledge versus knowledge of folate benefits. The main contributions of this conceptual framework will be described separately in section 1.5.1.

[8] A similar approach is taken to evaluate the potential cost-effectiveness of MBR in China. Here, the micronutrient deficiency refers to the lack of folate, vitamin A, zinc and iron.

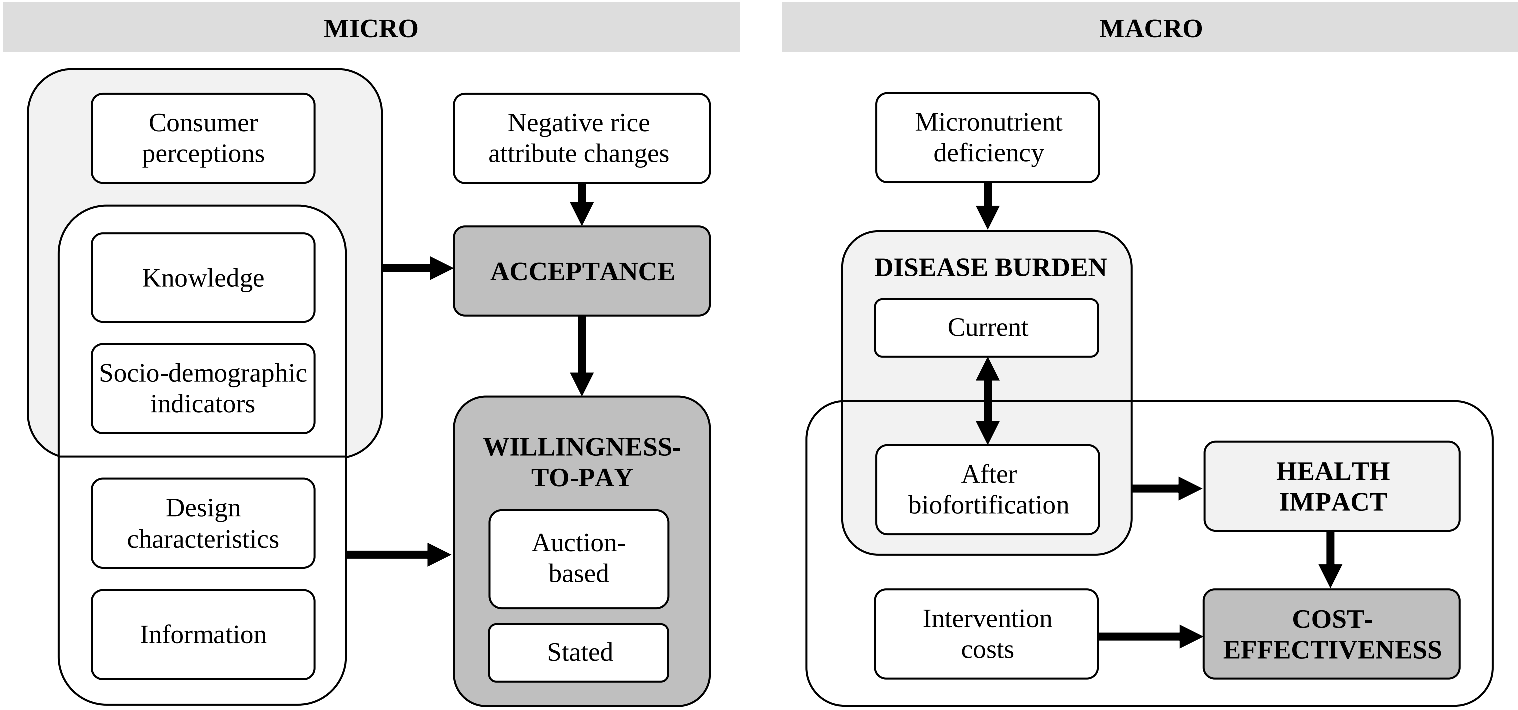


Figure 2 Conceptual framework

Source: Own compilation

### 1.3.1. Acceptance (Chapter 3)

The analysis of FBR acceptance as a GM food product with health benefits addresses three challenging issues in GM food consumer research. First, the main determinants of a biofortified crop as a GM food product in a high-risk region are investigated. Second, the variance of consumer and information characteristics regarding GM food is segmented in order to define target groups for FBR in China. Third, the trade-off between consumer oriented benefits and potential negative attribute changes of biofortification is examined. Below, each of these aspects is elaborated with reference to the concepts of the conceptual framework, theory and research literature.

#### *1.3.1.1. Determinants of GM food acceptance*

In this study, the concept of *acceptance* measures whether a consumer is favorable, indifferent or unfavorable to FBR as a GM food product with health benefits. Due to its health benefits, this GM food product of the second generation is expected to be more appreciated than its first generation counterparts and may be able to compensate for the negative perception that might be associated with the GM food technology (Frewer et al., 1997a; Lähteenmäki et al., 2002; Hossain et al., 2003; Lusk et al., 2005; O'Conner et al., 2005; Anand et al., 2007; Schnettler et al., 2008a). Scientific research to underpin the larger GM food acceptance when health benefits are present, is scarce (Lusk, 2003), but steadily growing. Among these GM food products that are explored in consumer preference studies, are dairy spread (O'Conner et al., 2005), beer (Burton and Pearse, 2002), oil seed (Cox et al., 2008), cheese (Frewer et al., 1997a; Lähteenmäki et al., 2002), grains (Onyango and Nayga, 2004; Zhang et al., 2010) or a combination of products (Magnusson and Koivisto Hursti, 2002). Although they did not mention the term 'biofortification', the latter three studies (partially) focused on the acceptance of nutritionally enriched GM foods. As expected, they found large support for this health oriented application of GM technology, especially in comparison with other GM applications. However, these authors investigated consumer reaction towards the use of GM technology to increase the nutritional content of crops in general. To date, only two studies examined consumer acceptance of a specific biofortified food crop, i.e. conventionally bred provitamin A enriched maize (De Groote and Kimenju, 2008; Stevens and Winter-Nelson, 2008). Except for a qualitative study on Golden Rice (GR) which reported high farmer acceptance rates in the Philippines (Chong, 2003) and few valuation elicitation studies on vitamin A enriched crops (see chapter 4), consumer research on acceptance of transgenic biofortified crops is lacking. Section 3.3.2 addresses this by identifying the factors that influence consumer reaction towards FBR in a problematic region in terms of folate intake.

In the aforementioned conceptual framework (Figure 2), the analysis of consumer acceptance of FBR focuses on different concepts derived from the explanatory GM food acceptance model (Costa-Font et al., 2008) and scientific evidence on acceptance of GM and/or biofortified food crops. In their review of consumer acceptance studies of GM food, Costa-Font et al. (2008) developed a framework that builds on the attitude model of Bredahl et al. (1998) and Fishbein's multi-attribute theory (Fishbein, 1963). It considers GM food attitudes and acceptance as complex constructs, which are determined by consumer perceptions of benefits and risks, general attitudes, knowledge and socio-demographic factors. In line with previous research (Hamstra, 1995; Verdurme and Viaene, 2003; Pope et al., 2004), the focus in the FBR acceptance study in this thesis will be on the role of the two GM related concepts, namely knowledge and consumer perceptions of GM food.

*Knowledge* is one of the most important determinants of food acceptance (Chen and Li, 2007; Costa-Font and Mossialos, 2007) and plays an important role in the framework. However, the direction of this effect remains a topic for discussion (Hamstra, 1995; House et al., 2004; Kassardjian et al., 2005). Here, GM food knowledge is split up into a subjective and an objective component. This approach is based on previous studies where objective knowledge is found to be significantly lower than subjective knowledge (Li et al., 2002; Verdurme et al., 2003b; House et al., 2004; Ganiere et al., 2006; Ho et al., 2006; Costa-Font et al., 2008). Besides GM food knowledge, subjective or perceived knowledge of GM rice is also explored.

Cognitive variables such as *consumer perceptions* regarding GM food have an important influence on consumer acceptance (Bredahl et al., 1998; Baker and Burnham, 2001; Li et al., 2002), especially benefits and risks (Frewer and Shepherd, 1995; Hamstra, 1995; 2005; Costa-Font et al., 2008). Several studies used a multi-item scale to measure consumer perceptions towards GM food, containing knowledge, labeling and trust issues (Pope et al., 2004); health risks, environmental risks, benefits, trust and safety (Verdurme et al., 2003b); or process-related and product-related beliefs (Bredahl et al., 1998). Such GM food perceptions are closely related to beliefs towards an object (Fishbein and Ajzen, 1975) in that they measure how people evaluate specific attributes of GM food, such as its capability of lowering environmental pollution. In line with Verdurme et al. (2001), consumer perceptions in the conceptual framework deal with risks, benefits, safety and price impact.

In addition, there is a need to further explore the influence of *socio-demographic indicators*, such as age, gender, income, education and residence, which generated mixed and inconclusive results in the past (Costa-Font et al., 2008). While several studies conclude that socio-demographic variables (alone) do not have a strong explanatory power to predict acceptance of GM food products (Bredahl et al., 1998; Baker and Burnham, 2001; Li et al., 2002; Kontoleon and Yabe, 2006; Anand et al., 2007), other studies found several socio-demographic differences in GM food acceptance (Hoban, 1998; Chen and Li, 2007). For example, women (Siegrist et al., 2000; Moerbeek and Casimir, 2005), older people (Ganiere et al., 2006) and those with a low education (Hoban, 1998; Traill et al., 2004) or a low income level (Wachenheim et al., 2008; Yee et al., 2008) are generally more skeptical of GM food. However, there is still discussion about the strength and the sign of these determinants (Costa-Font et al., 2008). Therefore, socio-demographic factors are included in the conceptual framework. Given that the consumer study on FBR acceptance will be conducted in a poor, rural region of China (see section 3.2.1), residence (rural/urban), education and income level of the respondents are integrated in the analysis. Gender, age and family-related indicators (family size, number of children and age of the youngest child) are included due to the specific relationship between maternal folate deficiency and the risk of giving birth to a baby with an NTD. Another relevant variable, farmer status (farmer/non-farmer), is added because small farmers operate on both supply and demand side for home consumption. The inclusion of consumer characteristics is further supported by their influence on the acceptance of conventional biofortification, as shown by De Grootte and Kimenju (2008).

#### *1.3.1.2. Reviewing GM food segmentation studies*

Due to the global, persistent controversy about GM food, consumer segmentation is often used to further analyze the variance of consumer reactions to GM food. As this is a technique that will be used to further explore the market of FBR, based on the main concepts of the previous section, rather than a concept as such, it is not presented in the conceptual framework. This section will present the results of a review on GM food studies that segmented the market for GM food in general, or specific GM food products in particular, as a foundation for, and the rationale to conduct a segmentation analysis.

Table 1 summarizes the results of this literature review. The studies mainly focus on improved agronomic traits and, in a few cases, consumer oriented traits, such as GM dairy spread and GM oil seed. While almost all consumer research on GM food acceptance can be understood as a binary segmentation analysis, where a group of accepting consumers is compared with a segment that refuses GM food, this table goes beyond these studies. Therefore, this overview only includes segmentation analyses that discovered more than two groups of consumers, who also differ from each other with respect to underlying determinants of GM food acceptance.

Table 1 Overview of market segmentation studies on GM food, per product category, research location, name and size (% of sample) of the identified clusters, and source

| **Product category** | **Location** | **Identified clusters** (% respondents) | **Source** |
|---|---|---|---|
| GM food | EU-15 | 1 - Trade-off (18 %)<br>2 - Relaxed (14 %)<br>3 - Sceptical (62 %)<br>4 - Uninterested (6 %) | 4th Eurobarometer Survey[b] (Gaskell et al., 2004) |
| | EU-15; EU-25; EU-27 | # - *Cluster name (EU-15; EU-25; EU-27)*<br>1 - Optimistic (22%; 27%; 23%)<br>2 - Pessimistic (50 %; 54%; 61%)<br>3 - Undecided (28 %[c]; 16%; 16 %) | 5th, 6th & 7th Eurobarometer Surveys[b] (Gaskell et al., 2003; Gaskell et al., 2006; Gaskell et al., 2010) |
| | Belgium | 1 - Halfhearted (34.5 %)<br>2 - Enthusiasts (23.5 %)<br>3 - Balancers (26.5 %)<br>4 - Green opponents (15.5 %) | Verdurme and Viaene, 2003 |
| | China | 1 - Neutral (46.5 %)<br>2 - Knowledgeable (18.1 %)<br>3 - Biotechnology learners (26.9 %)<br>4 - Price-conscious (8.5 %) | Li et al., 2003 |
| | China | 1 - Food safety (31 %)<br>2 - Nutritional technologist (14 %)<br>3 - GM Skepticism (26 %)<br>4 - GM for non-food promoter (29 %) | Zhang et al., 2010 |
| | Germany | 1 - Supporters (25 %)<br>2 - Indifferent (47 %)<br>3 - Opponents (28 %) | Christophe et al., 2008 |

Table 1 Continued

| Product category | Location | Identified clusters (% respondents) | Source |
|---|---|---|---|
| GM food | Greece | 1 - Opposition (38 %)<br>2 - Potential (10.8 %)<br>3 - Early adopter (41.3 %)<br>4 - Extreme opposition (9.8 %) | Arvanitoyannis and Krystallis, 2005 |
| | South Korea | 1 - Open mindedness (29 %)<br>2 - Convenience/familiarity seekers (47 %)<br>3 - Biotechnology opponents (24 %) | Onyango et al., 2006 |
| | United States | 1 - Proponents (4.7 %)<br>2 - Non-opponents (61.0 %)<br>3 - Moderate opponents (22.7 %)<br>4 - Extreme opponents (11.7 %) | Ganiere et al., 2006 |
| GM apples | New Zealand | 1 - Price sensitive (15.3 %)<br>2 - True believing (13.0 %)<br>3 - Appreciative (23.3 %)<br>4 - Middle of the road (18.3 %)<br>5 - Opposed (16.3 %)<br>6 - Concerned (13.7 %) | Kaye-Blake et al., 2007 |
| GM chocolate & GM tomatoes | New Zealand | 1 - Price sensitive (c: 7 %; t: 13%)<br>2 - Price and technology sensitive (c: 40%; t: 25 %)<br>3 - Anti-GM, not price/benefit sensitive (c: 30 %; t: 21 %)<br>4 - Neophobic (c: 12 %; t: 11 %) | Gamble et al., 2000 [d] |
| GM corn flakes | United States | 1 - Brand buyers (40.5 %)<br>2 - Safety seekers (30.3 %)<br>3 - Price pickers (29.2 %) | Baker and Burnham, 2001 |
| GM dairy spread[a] | Ireland | 1 - Pro-2nd generation (29.4 %)<br>2 - Anti-2nd generation (24.4 %)<br>3 - 2nd generation accepters (14.4 %)<br>4 - 2nd generation rejecters (31.8 %) | O'Conner et al., 2005 |
| GM derived animal foods | UK | 1 - Opponents (7.6 %)<br>2 - Cautious (41.3 %)<br>3 - Optimists (51.1 %) | Kontoleon and Yabe, 2006 |
| GM maize | South Africa | 1 - Anti-GM, brand aware (35 %)<br>2 - Brand unaware, farmer sympathetic (20 %)<br>3 - GM consumer benefit, brand aware (25 %)<br>4 - Brand aware, Pro-GM (20 %) | Vermeulen et al., 2005 |
| GM oil seed[a] | Australia | 1 - Conservatives (28 %)<br>2 - Confident protectors (51 %)<br>3 - Anti-GM (20 %) | Cox et al., 2008 |
| GM tofu | Taiwan | 1 - Conventional Buyer (45 %)<br>2 - GMO Buyer (32 %)<br>3 - Non-GMO buyer (23 %) | Jan et al., 2007 |

*Note:* c = chocolate; t = tomato
[a]To our knowledge these are the only segmentation studies solely focusing on GM products with consumer benefits, the so-called 2nd generation GM products; [b]4th, 5th, 6th and 7th Eurobarometer Surveys are conducted in 1999, 2002, 2005 and 2010, respectively; [c]In the 5th Eurobarometer 'undecided' is replaced by 'risk-tolerant'; [d]Although the authors discovered three additional, smaller segments with respect to GM tomatoes, only the common clusters are shown.

According to the review of Costa-Font et al. (2008), the consumer's reaction towards GM food can be generally classified into three groups: 'pessimistic', 'risk-tolerant' or 'information searchers', and 'optimistic'. In respect of the European Union, the last four Eurobarometer Surveys confirm the large, growing European opposition or skepticism towards GM food (Gaskell et al., 2003; Gaskell et al., 2004; Gaskell et al., 2006; Gaskell et al., 2010). When focusing on the GM food perceptions in specific

European countries, studies discovered three German (Christophe et al., 2008), four Greek (Arvanitoyannis and Krystallis, 2005) and four Belgian consumer segments (Verdurme and Viaene, 2003). The latter study, for instance, identified the following clusters: 'halfhearted' and 'green opponents', both reluctant, versus 'balancers' and 'enthusiasts'. Except for the large indifferent segment in Germany, these studies follow the trend of the Eurobarometer, by which the size of the opposed cluster is about two times as large as the optimistic segment. In the United States, such a reluctant segment is less represented, as Ganiere et al. (2006) demonstrated, with about 34.4 % (moderate) refusing consumers.

Several segmentation studies focus on specific GM food products, such as GM apples (Kaye-Blake et al., 2007), GM chocolate and tomatoes in New Zealand (Gamble et al., 2000), foods derived from animals fed with GM feed in the United Kingdom (Kontoleon and Yabe, 2006), GM corn flakes in the United States (Baker and Burnham, 2001) and GM maize in South Africa (Vermeulen et al., 2005). All authors analyzed the market potential for products with improved agricultural traits, except for O'Conner et al. (2005) and Cox et al. (2008). These two studies focus on GM food products with consumer benefits, respectively GM oil seed as a source of omega-3 fatty acids and cholesterol reducing GM dairy spread.

Only a few GM food segmentation studies have been conducted in Asia. Onyango et al. (2006) pointed out the existence of three South Korean segments, denoted as 'open mindedness', 'convenience seekers' and 'biotechnology opponents'. Another study generated three distinct clusters regarding GM tofu in Taiwan: 'GMO buyer', 'Non-GMO buyer' and the indifferent 'conventional buyer' in between. In China, Li et al. (2003) identified four consumer segments: "neutral", 'knowledgeable', 'biotechnology learners' and 'price-conscious'. Recently, four distinct urban consumer segments were discovered in China: 'food safety', 'nutritional technologist', 'GM skepticism' and 'GM for non-food promoter' (Zhang et al., 2010). They demonstrated that there is a significant group of Chinese consumers (14 %) who attaches importance to improved nutrition of GM rice products, i.e. biofortification. So far, these are the only Chinese studies that segmented consumers' reactions to GM food. I have no knowledge of market segmentation studies of specific GM food products in China. Nevertheless, there is a great variance in acceptance of GM food products between Chinese consumers (Huang et al., 2006b) resulting in different segments (Li et al., 2003; Zhang et al., 2010), which supports the importance to segment the potential interest of Shanxi rice consumers in GM food and FBR. In the end, as Onyango and Nayga (2004) stated, market segmentation strategies will be required to efficiently target the consumer in the market of GM food products with tangible consumer benefits. Identifying consumer segments is a prerequisite to reach this goal.

Consumer or market segmentation identifies potential consumer segments based on socio-demographic, attitudinal and behavioral differences (Kotler, 2001). GM food segmentation studies typically also include important determinants of GM food acceptance, such as knowledge and consumer perceptions (Verdurme and Viaene, 2003; Christophe et al., 2008; Zhang et al., 2010). The segmentation study in this thesis does not only focus on these two GM food related concepts but additionally incorporates trust in information channels and sources to identify distinct consumer segments in Shanxi Province. *Trustworthiness* of information sources or channels are expected to account for differences in GM food knowledge (Chen and Li, 2007), consumer perceptions (Siegrist, 2000) and acceptance of the GM technology (Frewer et al., 1998; Govindasamy et al., 2008). When consumers evaluate GM technologies, they usually depend on knowledge derived from information sources/channels (Frewer et al., 2003; James, 2003; Meijnders et al., 2009). Moreover, to successfully disseminate information regarding GM food, one needs to discover the appropriate information channels and sources, given the targeted market segment (Hovland et al., 1953). Currently, information acquisition and trustworthiness of information sources and channels are largely neglected when segmenting the market for GM food (see Table 1). Due to the inclusion of trust levels and GM food related variables, differences among the segments in FBR acceptance and information acquisition are examined in this thesis.

#### *1.3.1.3. GM food attributes and consumer acceptance*

People evaluate GM food products by the attribute changes caused by the GM technology, rather than the technology itself (Ganiere et al., 2006). When linking Fishbeins' Multi-attribute theory to GM food, acceptance not only depends on knowledge and consumer perceptions of the benefits and risks of GM food, but also on the consumer perceptions of its specific product attributes (Bredahl et al., 1998; Rimal et al., 2007; Siegrist, 2008). According to Lancaster (1966), consumers maximize utility through the combination of product attributes. By improving nutritive, sensory and other product attributes, consumers are more likely to acknowledge the advantage of GM crops (Bourn and Prescott, 2002; Engel et al., 2002; Verdurme et al., 2003a; Siegrist, 2008). As a consequence, acceptance studies on 2$^{nd}$ generation GM food products mainly focused on the evaluation of the product-enhancing attributes of GM food, such as the nutritional benefits in section 3.3.2. Although biofortification was initially applied to improve the micronutritional content of staple crops, it may involve other product attribute changes, such as an undesired taste and appearance (Bouis et al., 2000). Furthermore, the characteristics of the introduction of a biofortified crop could negatively affect its availability, cultivation potential and price. As consumers are often not accustomed to these new properties, these traits may be important deterrents to consumer acceptance, regardless of the consumers' evaluation of the technology, and reduce the potential impact of biofortification. When targeting folate biofortification of rice, a consumer could be in favor of its improved health benefits, but may become reluctant if other rice attributes would be negatively affected. Below, evidence of the impact of the most relevant product attributes of GM and/or biofortified food, such as appearance and taste, is described.

Differences in *external appearance*, for instance, could be useful to distinguish a biofortified product from the conventional product, especially when targeting specific risk groups (Bouis et al., 2000). Nevertheless, there is scientific evidence that a GM food product is more likely to be accepted if it resembles the natural product (Onyango et al., 2004; Tenbült et al., 2005; Siegrist, 2008). The impact of color changes due to fortification of rice depends on its nutritional components (Porasuphatana et al., 2008). Fortifying rice with iron, for instance, intensifies its yellow color, which negatively affected consumer acceptance in Bangladesh and Thailand (Prom-u-thai et al., 2009). Another well known

example is the yellowish GR, biofortified in order to tackle vitamin A deficiency. Although the visible difference is recognized as a potential constraint of consumer acceptance of GR, it is still not scientifically proven. According to Brooks (2010), the yellow color of this rice variant is likely to be perceived as an indicator of being a too long stored product and thus of a lower quality than regular rice. Two other studies investigated the impact of color on the acceptance of provitamin A enriched maize in Kenya (De Groote and Kimenju, 2008) and Mozambique (Stevens and Winter-Nelson, 2008). Both authors found a preference for white unfortified maize over the yellow-orange biofortified maize, which is reflected in the consumers' WTP (De Groote et al., 2011).
Genetic modification sometimes intensified the sensory properties of food products, such as *taste*. The "Flavr Savr" tomato, for instance, was primarily intended to increase its shelf life, but is also characterized by an improved flavor (Kramer and Redenbaugh, 1994). Also iron fortification of rice can change the initial flavor and chewiness (Prom-u-thai et al., 2009). According to the International Food Information Council (IFIC) study in 2001, about 58% of US consumers indicated that they would like to purchase products which have been modified to taste better (IFIC/Wirthlin, 2001). As taste as such is not an objective of biofortification, there is little evidence of sensory differences between biofortified and conventional staple crops (Engel et al., 2002). Stevens and Winter-Nelson (2008) however, found negative reactions to the flavor and aroma of provitamin A-biofortified maize, which is expected to influence consumer acceptance (Hossain et al., 2003). Product attributes related to preserving and processing GM food, such as the shelf life, and the duration and the sensory quality of cooking, could also play a role (Bonti-Ankomah and Yiridoe, 2006; De Groote and Kimenju, 2008; Prom-u-thai et al., 2009).
Although folate biofortification is not expected to change taste and visual product attributes (Bekaert et al., 2008), contrary to folic acid fortified rice (Shrestha et al., 2003), the impact of both attributes are included. One of the main reasons is that the product is still under development and the rice attributes might be altered depending on the rice varieties that will be selected. For instance, if the folate trait would be inserted in another biofortified rice crop, such as MBR, there is evidence that the higher vitamin A content would alter the color and flavor.

Other attributes, such as the *availability, the cultivation potential, and the environmental and price impact*, mainly refer to market features related to the production or the distribution. For example, if the availability is hampered, consumers are less likely to switch from the conventional to the GM food product (Foster et al., 2003; Verdurme et al., 2003a). Furthermore, the cultivation potential of GM food or biofortified staple crops may influence especially farmer's opinion, but also consumers in China as they are often subsistence farmers and grow and mill rice themselves (Gale et al., 2002).

Based on this literature review, section 3.3.4 analyzes the potential impact of a negative change in six rice attributes on the acceptance of FBR in Shanxi Province: taste, external appearance, availability, cultivation potential, price impact and environmental impact.

### 1.3.2. Willingness-to-pay (Chapter 4)

Following acceptance, the next step to determine the market potential of novel goods is to analyze consumers' WTP. When evaluating the potential demand for novel products, whether it is an environmental issue (Hanemann, 1984; Hanley et al., 2006), an agricultural product (Lusk and Hudson, 2004), such as organic products (Bonti-Ankomah and Yiridoe, 2006), or controversial technologies in food, like irradiation (Fox et al., 2002), insecticide use (Roosen et al., 1998), GM food (Bredahl, 2001; Lusk et al., 2005) and biofortified crops (Chowdhury et al., 2009), the aim is determine their economic value.

As the economic value of a good refers to the value consumers place on it, i.e. what this product is worth to consumers (Pearce and Özdemiroglu, 2002), WTP for a GM food product is understood as a subjective trade-off, namely the highest amount a consumer is prepared to pay to exchange a GM food product for another, or vice versa. This exchange or preference can be also defined as the lowest compensation a consumer is prepared to accept to sell a product, i.e. willingness-to-accept (WTA)[9]. Because FBR is not commercialized, the value elicitation study in the conceptual framework estimates the monetary value of this non-market product. FBR is clearly beneficial to consumers, unlike 1st generation GM crops, by which the aim is to determine the premium for this GM rice product rather than discount.

Several other reasons can be outlined to underpin the appropriateness of determining WTP over WTA. First, endowing an existing, familiar product and asking if people want to pay more for an improved alternative is in accordance to what consumers are facing in a real market situation. Second, WTP and WTA measures should theoretically generate similar results (Hanemann, 1991), but in practice there is often a clear divergence with substantially higher WTA values (Lusk et al., 2005; Moon et al., 2007), especially when used in a non-repeated auction design (Shogren et al., 2001a). Another difficulty of using WTA is to define at what value someone becomes opposed, because reluctance in the compensation approach will be reflected by huge monetary values (Jaeger et al., 2004).

Despite the large body of scientific studies on WTP and purchase intentions of GM food (Lusk et al., 2005), biofortified crops with proven health benefits received little attention thus far (Chowdhury et al., 2009). Valuation studies focused solely on provitamin A enriched products, such as maize in Kenya (De Groote et al., 2011), cassava in Brazil (Gonzalez et al., 2009), or Golden Rice in India (Deodhar et al., 2008), the Philippines (Depositario et al., 2009a) and the United States (Lusk, 2003). Moreover, 2nd generation GM food products are a relatively new research topic in value elicitation experiments (Rousu et al., 2005). However, in both cases, there is scientific evidence that the improved health benefits lead to higher WTP values compared to GM food products that are not directly oriented towards the consumer. Given the optimistic consumer reactions to GM rice in China (Li et al., 2002; Liu, 2009), one could expect similar increases in WTP valuations of FBR in a Chinese high-risk region.

[9] This price-determining concept differs from the previously mentioned variable 'acceptance' (see section 1.3.1 or chapter 3).

In the following subsections, the concepts and the rationale behind the part of the conceptual framework that aims to study WTP for FBR in Shanxi Province are discussed. While section 1.3.2.1 focuses on conceptualization of WTP, section 1.3.2.2 deals with the determinants of WTP.

#### *1.3.2.1. Conceptualization of WTP*

There are several approaches to define the concept of WTP which can be broadly categorized into stated or revealed values or preferences, where economic values are directly or indirectly measured (Blamires, 1997; Balistreri et al., 2001; Pearce and Özdemiroglu, 2002; Hanley et al., 2006; Lusk and Shogren, 2007).

Table 2 classifies the most commonly used WTP values, namely stated, revealed and auction-based WTP. These concepts are defined by the technique that is applied to measure WTP, i.e. the value elicitation method. In theory, they should all obtain the same WTP value. However, a discrepancy between different WTP values is often observed in practice (Balistreri et al., 2001). According to Lusk et al. (2005), the value elicitation method is a crucial factor that accounts for differences in WTP values between GM food studies.

Although the difference between the two selected WTP values, i.e. stated and auction-based WTP, is based on the way they are measured, respectively through open-ended contingent-valuation (CV) and (laboratory) experimental auctions, these two concepts are included in the conceptual framework. This is because the WTP study in this PhD dissertation will investigate the difference between these two WTP values. Below the table, both concepts and value elicitation methods are discussed and the rationale to compare them is provided. In addition, indirect WTP values will be examined during the experimental auctions as a depersonalized alternative to the auction-based values.

Table 2 Overview of the main types of WTP values, based on the applied value elicitation method

| WTP value | Value elicitation method | Specific types/examples |
|---|---|---|
| **Stated WTP** | Stated preference methods | |
| | **Contingent valuation** (CV, survey-based[10]) | **open-ended (OE)**; closed-ended, e.g. dichotomous choice (DC); payment card; bidding game |
| | Choice modeling | conjoint analysis; contingent ranking |
| **Revealed WTP** | Revealed preference methods | |
| | Market data analysis | panel data analysis, store scanner data analysis |
| | Travel cost | recreational value of places of interest |
| | Hedonic pricing | house pricing |
| **Auction-based WTP** | **Experimental auctions** | **laboratory experiment**; field experiment |

*Source:* Own compilation, based on Bateman et al. (2002), Breidert et al. (2006), Venkachalam (2004) and the Competition Commission report (2010).
*Note:* Bold indicates the focus of the PhD dissertation. Although experimental auctions are sometimes categorized as revealed preference methods, they actually combine the strengths of both revealed and stated preference methods.

*Stated WTP (sWTP)*

Stated WTP is derived from stated preference methods. It is the most investigated WTP value in GM food studies, especially when the survey-based contingent valuation (CV) method is applied to find out if consumers prefer a premium or a discount for GM food products (Lusk et al., 2005). Other stated

[10] These methods are typically build upon consumer estimations. One could also attempt to investigate WTP through expert estimates, e.g. sale managers' assessment of WTP values.

preference methods, such as choice-based conjoint analysis, are often less applicable to estimate economic values of novel food products, due to its complexity, the limited possibility of including important determinants of buying behavior (Lusk and Hudson, 2004), or because of the low explained variation (Lusk and Shogren, 2007), but are generally accepted as multi-attribute modeling tools to measure trade-offs between various factors (Lucking-Reiley, 2000; Lusk and Shogren, 2007; De Groote et al., 2010).

The most important CV approach is built upon an open-ended (OE) or a single or double-bounded dichotomous choice (DC) format (Bishop and Heberlein, 1979; Hanemann, 1984)[11]. While the former directly measures the amount one is willing to pay, the latter includes a take-it-or-leave-it bid in advance, with (double) or without (single) follow-up (Langford and Bateman, 1993). As the WTP values are built on different CV-based approaches, they are likely to be different (Hanemann and Kanninen, 1999). As Venkatachalam (2004) stated, the choice of the applied CV technique depends on different factors, including the nature of the investigated product, the characteristics of the targeted sample, the applied statistical technique and the cost of the survey. Regarding our stated WTP valuation study, an open-ended WTP value is determined. The reasons to measure this type of stated preferences are described in the methodology section of chapter 4 (see section 4.2.1).

Although direct survey-based stated values are still widely used in economic valuation studies about GM food (Lusk et al., 2005), inferring stated preferences for novel products has been shown to lead to substantially higher values than the auction-based WTP values, partially due to the absence of a market situation which attaches monetary consequences to the participant’s responses (Johannesson et al., 1998; Balistreri et al., 2001; List and Gallet, 2001; Huffman et al., 2007), by which bidding truthfully is not a (weakly) dominant strategy (Wertenbroch and Skiera, 2002). This ‘hypothetical bias’, is defined as the difference between consumers’ stated (saying) and the real WTP (doing), by which stated values overestimate the WTP values in experimental auctions. It is considered one of the key shortcomings of stated value elicitation methods (Lusk, 2003; Hanley et al., 2006). Other relevant biases which might occur, are method bias (e.g. differences in elicitation mechanisms)(Völckner, 2005), information biases (e.g. hidden value-clues to consumers, impact of the relevance of the information, confirmation bias)(Ajzen et al., 1996; Schulz-Hardt et al., 2000), negativity (Rozin and Royzman, 2001) or optimism bias (Lee and Job, 1995)(respectively over- or underestimating negative information), strategic bias (e.g. stating high values to influence expected actions based on the research findings)(Mitchell and Carson, 1989; Lusk et al., 2007), starting point bias (e.g. influence of benchmark price, see Herriges and Shogren, 1996; Ready et al., 1996; or the offered bid in DC-CV formats, see Venkatachalam, 2004), operational bias (e.g. wrong interpretation of information), and social desirability bias (Fisher, 1993; Lusk and Norwood, 2009). The methodology to measure sWTP for FBR is presented in section 4.2.1.

[11] Other contingent valuation techniques include the bidding game and payment card (Boyle et al., 1996), but are less popular stated preference methods regarding GM food valuation studies (Lusk et al., 2005). While in the bidding game a participant is offered several times a hypothetical bid to which he reacts, until he becomes reluctant, the payment card presents a list of potential values out of which participants select the one near their WTP (Venkatachalam, 2004).

*Auction-based WTP (WTP)*

The auction-based WTP is the value that is obtained through experimental auctions, a non-hypothetical value-elicitation method. Experimental auctions became increasingly popular as an alternative method to elicit consumer valuations for novel, non-market products, i.e. homegrown, auction-based values. Originated five decades ago (Becker et al., 1964), experimental auctions address the shortcomings of the stated (e.g. hypothetical bias) and revealed preference methods (e.g. indirectly deducting WTP from empirical patterns) while improving the conventional contingent valuation approach (Lusk and Shogren, 2007). First, the simulation of an active market with real products and money implies that people have an incentive to state their true value, especially when the responses differ from the true values (Klemperer, 1999; Milgrom, 2004). Second, the created market environment allows the researcher to conduct non-hypothetical research on non-market products while controlling the setting in order to assess the effect of potential determinants of interest. In that way, experimental auctions are promoted as a convenient tool to stimulate consumers to put forth cognitive effort to their stated preferences for novel products (Fox, 1995). As a consequence, auction-based values are typically lower than the values obtained through hypothetical contingent valuation methods (Balistreri et al., 2001; Chern and Chang, 2009). Due to the aforementioned hypothetical bias, hypothetical bids generally exceeded auction values by a factor of 1.65 (Balistreri et al., 2001) to 3 (List and Gallet, 2001).

In the respective methodology section of chapter 4, the different steps, the selected procedures and the assumptions regarding the development and organization of the experimental auction design are thoroughly described and justified with reference to auction theory and research literature. The study will adopt a 2$^{nd}$ price auction mechanism that is based on several procedures, such as the endowment approach, single binding and sealed bidding procedures, inclusion of trial auctions and an auction survey (section 4.3).

*Indirect WTP (iWTP)*

The aforementioned WTP values are generally based on self-reported statements that refer to the participants' own valuation. For example, in this thesis the respondents have to state the highest amount they are willing to pay for FBR (sWTP, see section 4.2) or to exchange the endowed rice bag with FBR (auction-based WTP, see section 4.3). Such personal statements may lead to auction fever, i.e. high bidding to win the auction, and social desirability bias (SDB), a tendency to please the interviewer or experimental monitor by submitting high bids. Although there is evidence of SDB in hypothetical value elicitation studies (Leggett et al., 2003; Lusk and Norwood, 2009; Olynk et al., 2010), SDB is not explored in a non-hypothetical research setting. However, given the characteristics of our experimental auctions, e.g. female consumers, a controversial good and a controlled setting, it is important to take into account the risk of social desirable behavior. One of the strategies to measure SDB is the indirect valuation method, by which the personal character of bidding, i.e. self-reported bids, is detached from the valuation exercise (Lusk and Norwood, 2006). As such, 'indirect' refers to the elicitation of consumers' estimation of the valuation of other consumers, e.g. the typical consumer. This differs from the meaning of 'indirect' in comparing stated and revealed preferences, where the

former are based on direct statements and the latter refers to the indirect method of deducting WTP from price-related behavioral patterns.
In the experimental auctions of this study, indirect WTP refers to the consumer's stated estimation of the WTP of the average female rice consumer in Shanxi Province. Instead of switching completely to indirect valuation, our auction design obtains revealed, personalized bids during the bidding rounds and asks for a stated, indirect, depersonalized WTP value in the auction survey (see also section 4.3.2.1).

As a consequence, three types of valuations are analyzed and compared in this study: sWTP and iWTP as direct and indirect survey-based values, respectively, and auction-based WTP. The objective is then to explore hypothetical bias (sWTP versus WTP) and SDB (WTP and iWTP) in economic valuation studies.

#### *1.3.2.2. WTP determinants and information effects*

The conceptual framework of this line of inquiry further aims to investigate the determinants of WTP for FBR and explores the role of information (see Figure 2).

*Determinants of WTP*
In line with the study about FBR acceptance (see section 1.3.1.1), WTP for a GM product is expected to be influenced by GM food knowledge, consumer perceptions, and socio-demographic indicators (Bredahl et al., 1998; Verdurme et al., 2003b; House et al., 2004; Ajzen, 2005; Han and Harrison, 2006; Lin et al., 2006; Costa-Font et al., 2008; De Groote and Kimenju, 2008), although research regarding the effect of the latter is inconclusive (Lusk et al., 2001a; Umberger and Feuz, 2004). The importance of these determinants are investigated for the stated WTP, which is based on the survey that is used to explain FBR acceptance (see section 3.2.2).

In the case of the experimental auctions, the determinants of the auction-based WTP are measured in the third information round of the auction (an overview of the auction design is presented in Figure 13). In this round, consumers were aware of the higher folate content (round 1) and the benefits of FBR (round 2), and were informed about the GM technology that is applied. In this way, the WTP values reflects consumer's valuation of the impact of being aware of the GM nature of FBR. Therefore, two GM related variables were entered, objective GM knowledge and GM food acceptance. Rather than including FBR acceptance, specific attention is paid to the importance of GM food acceptance as a potential determinant of WTP (and in relation to information provision, see below). Previous studies showed a positive effect on the WTP values for GM technologies (Colson and Huffman, 2009) or GM food products (Kassardjian et al., 2005).
Due to the auction design, by which two specific target groups are involved, namely female students versus women of childbearing age, the target group variable was considered as a proxy for socio-demographic differences. Therefore, only residence (rural/urban) and farmer family (i.e. involvement in farming) are explored as potential determinants. The inclusion of the target group as a design

characteristic makes it possible to analyze WTP between student versus non-student samples. Based on the current auction literature on GM food products, both subsamples are expected to generate similar WTP values (Lusk et al., 2005; Depositario et al., 2009b).
Another potential determinant related to the design characteristics is the impact of the presence of an auctioned substitute, which is currently lacking in GM food auctions (Kassardjian et al., 2005; Corrigan et al., 2009). Given that FBR is a GM rice crop with folate benefits, half of the participants could opt for a non-GM folate product, i.e. rice sold together with free folic acid pills. In this way, two folate interventions are brought into the experiment, FBR and folic acid supplementation. The aim is then to measure the effect of the auction type, i.e. having the option to bid on a GM-free product or not.
Other design characteristics refer to the timing (i.e. time and day), and the size of the auction. Previous research demonstrated that the auction sample size is positively associated with higher values (Umberger and Feuz, 2004), whereas WTP values are higher during morning sessions (Rutsaert et al., 2009; De Groote et al., 2010), known as the time-of-the-day effect (Hoffman et al., 1993). Furthermore, conducting experiments during working hours may exhibit a sampling bias, leading to higher rates of unemployed people (Wang and McCluskey, 2010), which may affect the results of the study.

*Information effects*

With respect to the auction-based WTP values, additional attention is devoted to the effect of information. As the focus is on the provision of different information treatments, the experimental auctions were designed in such a way that they allow the isolation of information effects on the obtained WTP values. A detailed overview of the five information treatments/auction rounds in the design of the experimental auctions is shown in Figure 13 (see section 4.3.4).

Information about the improved folate concentrations and the associated benefits might increase WTP for FBR, as is the case with conventional biofortified crops (De Groote et al., 2011), but may be negatively affected when consumers are aware of the GM technology that is implemented (Depositario et al., 2009a). In this WTP study, information about the folate content, the folate benefits and the GM nature of the product is provided through separate information rounds. In other words, the study compares FBR as if it would be perceived as a conventional or a GM biofortified crop. As a consequence, the auction survey was administered in between the information rounds, so that the measurement of information-related determinants preceded the respective treatment. For example, the GM related determinants (i.e. objective GM knowledge, GM food acceptance) are measured before consumers learn about the applied GM technology, while the other knowledge variables, e.g. knowledge of a woman who delivered an NTD and prior knowledge of folate benefits, refer to the auction round which dealt with information about the folate benefits of FBR.

Due to the controversy surrounding the use of GM technology in food products, there is a large body of research on the role of specific GM information. In general, positive information about the GM technology increases consumers' WTP for GM food products (Tegene et al., 2003; Colson and

Huffman, 2009), in particular when potential health benefits are mentioned (Frewer et al., 1996; Jaeger et al., 2004; Lusk et al., 2004b; Kassardjian et al., 2005; Hobbs et al., 2006). However, when providing conflicting information treatments, i.e. both positive and negative statements about GM food, there is less consensus about the information effect on WTP (Parkhurst et al., 2004; Rousu et al., 2004b; Hu et al., 2006; Colson and Huffman, 2009; Corrigan et al., 2009; Depositario et al., 2009a). A similar discussion is being held in valuation experiments with other controversial foods, such as irradiated meat (Fox et al., 2002; Parkhurst et al., 2004). The study on WTP for FBR further investigates the impact of different types of GM information, namely single, two-sided (positive, negative) or combined GM information treatments (positive, negative, objective). In addition, information order effects are measured in the two-sided treatments to identify the presence of a primacy or recency effect. According to these cognitive biases, a message that is presented first will be more (primacy) or less (recency) effective than the last presented information (Haugtvedt and Wegener, 1994).

The last information effect, as measured in the experimental auctions, is closely related to the characteristics of the study location. Since the study was conducted in a high-risk region of folate deficiency (Shanxi Province), it is also examined how consumers value FBR after being informed about the current situation in their region, i.e. the high prevalence and burden of folate deficiency.

### 1.3.3. Health impact and cost-effectiveness (Chapter 5)

While the study on consumer acceptance and WTP provides insight in the consumer reactions to FBR, one needs to realize that FBR as a health intervention may only be supported and implemented when the generated health effects verify the allocated resources. An economic evaluation is an essential tool to evaluate whether FBR is worthwhile to consider and should be given priority as a means to alleviate the burden of folate deficiency. In this study, the widely used Disability-Adjusted Life Year (DALY) approach is applied as the framework to evaluate the current burden of folate deficiency in China on the one hand and to determine the potential health benefits of this intervention on the other. Given the costs incurred for the development and introduction of this GM rice variant, its cost-effectiveness can be assessed and benchmarked against other health interventions or standardized cut-off levels. The DALY approach is also applied to MBR in China, which not only addresses folate deficiency, but also inadequate iron, zinc and vitamin A levels.

#### *1.3.3.1. Burden of disease*

When evaluating the impact of health interventions that aim to tackle a specific disease in a society, like biofortification intends to do with micronutrient malnutrition, and to adequately inform decision-makers and health planners about the potential of such strategies, it is essential to analyze the current status of the targeted disease, i.e. the 'burden of disease'. According to the World Health Organization (WHO) definition (Lopez et al., 2006) this concept is defined as the overall impact of, or the economic costs associated with, the disease and its outcomes at the individual or societal levels. It represents the health gap between the (current) health status and a hypothetical, ideal situation without diseases. One of the key objectives of estimating the burden of disease is to inform stakeholders involved in setting the health agenda and formulating priorities. In their Global Burden of Disease (GBD) reports, WHO estimates the global burden of a large set of diseases and injuries, in terms of age-, sex- and region-specific mortality and morbidity. Since the first study in 1990 (Murray et al., 1994), WHO published updated versions in 1996, 2000, 2004 (Murray and Lopez, 1996; WHO, 2002; Lopez et al., 2006; WHO, 2008a) and, upcoming, in 2010 (http://www.globalburden.org/). Together with their Comparative Risk Factor Assessment (CRA) reports (WHO, 2009a, 2011c), which provide evidence of the impact of 26 global health risk factors, the GBD series serve as one of the most comprehensive datasets of the current health situation.

In their World Development Report, WHO and the World Bank introduced the Disability-Adjusted Life Year (DALY) concept to assess the burden of disease (World Bank, 1993). Since then, the DALY framework is considered as the standard measurement tool in disease burden studies and has been used to compare the (cost-)effectiveness of health interventions, e.g. the Disease Control Priorities in Developing Countries (DCP) reports of the World Bank initiative (Jamison, 2006; Musgrove and Fox-Rushby, 2006), as shown in the next sections. The DALY framework quantifies the burden of a disease as a single index, i.e. the number of DALYs lost. This number reflects both deaths and disabilities that can be attributed to the disease and its functional outcomes, in particular. As a consequence, the concept of a DALY is a health unit, defined as the sum of years of life that are lost due to the fatal causes of a disease and the years of life that are lived with a disability. Therefore, the DALY concept, on which the DALY approach is built, is expressed by the DALY formula (Murray and Lopez, 1996; see section 5.2).

Regarding the conceptual framework of this PhD dissertation, the DALY concept is used and applied in order to assess the current burden of folate deficiency alone and of micronutrient malnutrition (folate, vitamin A, zinc and iron deficiencies) in China. Based on epidemiological and demographic data, the number of DALYs lost represents an aggregated estimate that encompasses the health impact of different functional outcomes on various target groups (see also Figure 3). Given the specific use of the DALY, some of the original methodological assumptions of the DALY framework, such as age weighting, have been adjusted or excluded. A comprehensive overview of the implications and the data assumptions of applying the DALY framework to micronutrient deficiency is presented in section 5.2. The rationale behind the selection of the DALY concept, rather than other health units of the disease burden, such as the closely related Quality-Adjusted Life Years (QALYs) framework, or cost approaches of burden, such as cost-minimization analysis (CMA), will be discussed in section 1.3.3.3.

*1.3.3.2. The health impact of interventions*

The second main purpose of the DALY approach is to determine the health benefits due to the implementation of a health intervention, i.e. the health impact.

Figure 3 shows how the DALY approach can be applied to estimate the potential health impact of biofortified staple crops as a particular type of micronutrient interventions. First, the current burden of the micronutrient deficiency is estimated, where the number of DALYs lost reflects the current health status related to a micronutrient deficiency and its functional outcomes, as discussed in the previous section. This is the scenario without biofortification (i.e. the status quo). The next step is then to estimate how biofortification can contribute to alleviate this burden. This can be done by comparing the current situation with a scenario where biofortification would be implemented. The health impact is then defined as the difference between the simulation before and after biofortification, expressed in the number of gained DALYs. The health impact of the introduction of a biofortified crop mainly depends on the product characteristics of the micronutrient enriched crop (i.e. the initial nutrient content, the nutritional losses due to processing and the bioavailability of the nutrient) and the potential coverage rate of the intervention, which refers to consumers' acceptance and access (Stein et al., 2005b). Together with the dose-response relationship, i.e. the effect of the enhanced micronutrient content on the functional outcomes, the reduction of the current burden can be determined.

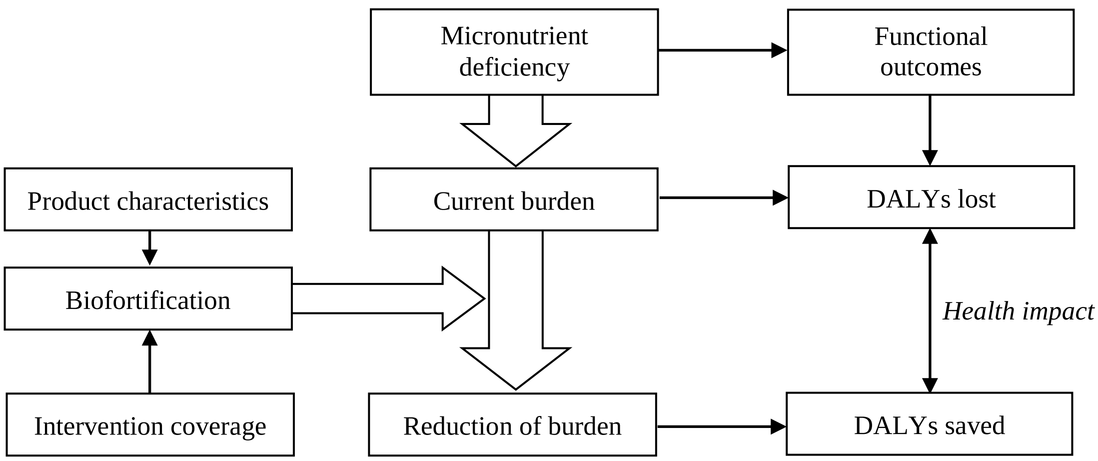


Figure 3 Ex-ante health impact assessment of biofortified crops. Application of the DALY framework
*Source*: Own compilation, based on Zimmerman and Qaim (2004) and Meenakshi et al. (2007).

The DALY framework is well recognized and recommended (Tan-Torres Edejer et al., 2003), especially for developing countries/regions (World Bank, 1994; Evans et al., 2005), and is widely applied in health impact studies with other biofortified crops (Stein et al., 2005b; Horton, 2006; Meenakshi et al., 2007; Fan et al., 2009). In the current health impact literature, the focus of micronutrient interventions was, and still is, on the main micronutrient deficiencies, i.e. iron, zinc and vitamin A deficiencies (Manyong, 2004; Zimmermann and Qaim, 2004; Horton, 2006; Meenakshi et al., 2006; Qaim et al., 2007; Fan et al., 2009; Suárez, 2010). There is currently no evidence of the health impact to tackle folate deficiency through biofortification, or the burden of folate deficiency.

Despite China's support for GM technology and biofortification (Campos-Bowers and Wittenmyer, 2007)(see section 2.5), China is a relatively new area to conduct health impact studies on biofortified staple crops (Ma et al., 2007; Fan et al., 2009). At present, no (health impact) studies focused on GM biofortification in China. Due to the regional differences in folate intake, rice consumption and NTD prevalence, the health impact of FBR is assessed for both northern and southern provinces, at regional and administrative divisional level (see also annex 1). This makes it also possible to assess the health impacts of the high-risk region of China, Shanxi Province, and compare the findings with another high-risk region in the world, Balrampur District in India, where the number of NTDs is among the world's highest (Cherian et al., 2005).

Furthermore, previous studies only examined the health impact of crops that are biofortified with single micronutrients, while poor people often suffer from multiple micronutrient deficiencies (Gwatkin and Guillot, 2000). Therefore, a country-wide analysis of the potential health benefits of rice multi-biofortification (MBR) in China is also carried out, which determines the health impact of enriching rice with folate and the three main micronutrients, i.e. zinc, iron and vitamin A. Because FBR is in a development phase and because there is no published evidence that the investigated MBR (see section 2.4.4.3) is being developed, the evaluation of the potential health benefits of both interventions are conducted prospectively.

#### *1.3.3.3. The cost-effectiveness of health interventions*

While the health impact of an intervention primarily refers to the measurement of the improved health outcomes, a full economic evaluation brings in the cost factors associated with this intervention. In principle, an economic evaluation aims to compare the consequences (e.g. health benefits) and costs of an intervention (or between different alternative interventions), in order to contribute to priority-setting and to facilitate decision-making about the resource allocation (Haddix et al., 2003; Drummond et al., 2005).

Basically, there are two main approaches in economic health literature, each built on a different economic evaluation method: cost-effectiveness analysis (CEA) and cost-benefit analysis (CBA)(see Table 3). Their objective is to identify interventions that maximizes the effectiveness per unit of cost, i.e. the (health) value for money, rather than to focus on minimizing the costs, which is done in cost-minimization analysis (CMA)(Weinstein and Stason, 1977). In the latter, also known as programmatic cost analysis, cost identification, cost outcome or consequence analysis, the total costs of the intervention are estimated and compared with other interventions that generate identical (health) outcomes (CDC, 2011). As only the costs are taken into account, this approach is useful when aiming to identify the cheapest strategy to reach the same objective, but strictly speaking is not an economic evaluation as the benefits are not incorporated (Drummond et al., 2005).

The major difference between CEA and CBA is that the former expresses cost-effectiveness in natural health units, while these health outcomes are converted into monetary values in the latter (Johannesson, 1995; Boardman et al., 2006). The most important strength of the concept of cost-effectiveness, i.e. avoiding to monetize the health effects, is often considered its main weakness and can be addressed by a cost-benefit analysis (CBA). Basically, the cost-benefit concept is concerned with a comparison of the monetary value of the health outcomes and the costs. A monetary value can be attached to a DALY or another health outcome by using, for example, country-specific annual per capita incomes (WHO, 2001b; Zimmermann and Qaim, 2004), a standardized international value for a DALY, i.e. US$ 1 000 (World Bank, 1994), a WTP value threshold for incremental risk reductions or a WTA value as a compensation for a lost health unit (Willan et al., 2001; Gyrd-Hansen, 2005). Proponents of CEA emphasize the necessity of reporting health consequences, especially when reporting health intervention evaluation results, while questioning the CBA for the attribution of a monetary value to health benefits on ethical grounds and the uncertainty regarding the level of the assigned value (Johannesson, 1995; Barbieri et al., 2001; Willan et al., 2001; Laxminarayan et al., 2006). As a consequence, economic evaluation studies of health interventions are mainly based on CEA, while the CBA is less preferred in the (environmental) health (care) sector (WHO, 2000; Grosse et al., 2007; Ngorsuraches, 2008). Although the cost-benefit concept certainly has its merits over the concept of cost-effectiveness, e.g. improved attractiveness, easier to comprehend, inclusion of non-health benefits and comparability between different sectors (Coast, 2004; Musgrove and Fox-Rushby, 2006; Stein et al., 2008b), the latter will be selected to evaluate the introduction of FBR and MBR in order to maintain the non-monetary dimension of the DALY framework, instead of using a purely economic indicator. The main objective of this approach is then to inform decision-makers whether an intervention can be considered cost-effective and which strategies provide the largest health benefits at population level, given the budgetary constraints (Gold et al., 1996; Haddix et al., 2003; Tan-Torres Edejer et al., 2003). As the cost-effectiveness in this thesis refers to an ex-ante evaluation of the costs and health benefits, the results are expected to be relevant for policy makers when deciding to promote and speed up the approval of biofortification technology.

Table 3 presents an overview of the different approaches to describe the current burden of disease and to evaluate health interventions. This overview does not aim to offer an exhaustive overview, but focuses on the most commonly used approaches in economic health literature and health impact studies, and the underlying evaluation methods. In this PhD dissertation the DALY framework is selected to analyze the current burden of folate deficiency and micronutrient malnutrition in China (see section 1.3.3.1) and to investigate whether, respectively, FBR and MBR, are cost-effective interventions to reduce these burdens.

Together with the Quality-Adjusted Life Years (QALY) framework, the DALY framework (the successor of QALYs) is one of the most applied approaches to determine the cost-effectiveness of health interventions (Tan-Torres Edejer et al., 2003; Evans et al., 2005). Both QALYs and DALYs are considered as Health-Adjusted Life Years (HALYs) methods, i.e. techniques to describe both mortality and morbidity of a health condition as a single number (Gold et al., 2002; Robberstad, 2005). Due to the inclusion of preference weights ('utilities') for the quality of life, these standardized health measures are often categorized under cost-utility analyses (CUA), an extended CEA (Ngorsuraches, 2008). When controlling for age-weighting and discounting, a QALY (health gain) is considered the opposite of a DALY (health loss). While the former uses a 'health related quality of life' weight (HRQoL), the latter uses its inverse, i.e. disability weights. Although using QALYs has its own advantages, there is evidence that it results in higher health impact, especially in the case of childhood diseases (Sassi, 2006), and may result in a different ranking of cost-effective interventions (Arioldi, 2007). The selection of the DALY approach was mainly motivated by the historical use of DALYs in World Bank (World Bank, 1993; Jamison et al., 2006) and WHO reports on developing countries (Evans et al., 2005) as well as in biofortification studies (Meenakshi et al., 2007; Meenakshi, 2008a). Although this health indicator is often criticized, e.g. less transparent to decision makers (Arnesen and Kapiriri, 2004), it is widely recognized as an economic evaluation tool without the need to attach a monetary value to a health benefit (an overview of the most relevant criticized issues is presented in section 5.1). Musgrove and Fox-Rushby (2006), for instance, argue that the DALY approach in CEA allows policy makers to underpin their investment in scarce health resources, and is an appropriate tool to identify a 'best buy' for developing countries.

Building upon the health impact study and the intervention costs (e.g. R&D costs, country-specific costs, social marketing costs and maintenance breeding costs), this thesis determines the cost-effectiveness of both FBR and MBR in China. Given the evidence on the cost-effectiveness of micronutrient interventions (World Bank, 1994; Mason et al., 1999; Mannar, 2001; Wallich et al., 2001; WHO, 2002; Baltussen et al., 2004; Horton, 2006; Fiedler et al., 2008; Klemm et al., 2009; Horton et al., 2010), including biofortification (Meenakshi et al., 2007; Meenakshi, 2008a; Qaim, 2009), both interventions are expected to be cost-effective strategies to reduce folate deficiency and micronutrient malnutrition, respectively.

The cost-effectiveness is expressed in a standardized unit, i.e. US$ per gained DALY (see also section 5.3). This implies that interventions based on CEA can only be compared when the same unit is applied. Another option is to use a fixed cut-off level to define whether this health intervention is cost-effective (Tan-Torres Edejer et al., 2003; Laxminarayan et al., 2006), such as the US$ 150-threshold of the World Bank (1993) and the per capita income levels, as proposed by the WHO (Evans et al., 2005; WHO, 2011a). To interpret the findings of this cost-effectiveness study, the results are evaluated against the World Bank cost-effectiveness threshold (see section 5.4.3) and compared with other cost-effectiveness studies on biofortified crops in developing countries (see section 5.4.4.2).

Table 3 Approaches to the estimation of disease burdens, health impact assessment and economic evaluation of interventions

| Approach | Description | Health unit | Cost unit | Examples | Selected approach/unit |
|---|---|---|---|---|---|
| ***Burden of disease*** | | | | | ***DALY Framework*** |
| Health approach, e.g. DALY framework | Estimation of the burden of a disease through health outcome measures. The DALY framework, for example, calculates the number of DALYs lost. | Natural units | / | DALYs/QALYs lost; mortality; morbidity | DALYs lost |
| Cost approach, e.g. cost-of-illness analysis (COI) | According to the COI, the importance of the disease burden is evaluated by the direct and indirect costs that are associated to the disease. | / | Monetary units | US$ | / |
| ***Intervention*** | | | | | |
| ***Health impact*** | | | | | ***DALY Framework*** |
| Health approach, e.g. DALY framework | The health impact is evaluated in terms of improved health outcomes. The DALY framework, for example, estimates the number of DALYs lost that can be averted through an intervention. | Natural units | / | DALYs/QALYs saved; deaths averted | DALYs saved |
| ***Cost analysis*** | | | | | |
| Cost approach, e.g. CMA | Cost-minimization analysis (CMA) analyzes the intervention costs in order to identify the least expensive intervention; also known as cost analysis, cost identification, programmatic cost analysis, cost outcome analysis or cost consequence analysis. | (Equal benefits) | Monetary units | US$ | / |
| ***Economic evaluation*** | | | | | ***CEA*** |
| CEA, Cost-effectiveness analysis | All costs are related to a single health index, i.e. the outcome measure, and expressed as the additional cost spent per unit of health outcome. | Natural units | Monetary units | Reduced prevalence; US$ per DALY/QALY saved | US$ per DALY saved |
| CBA, Cost-benefit analysis | Both costs and benefits are converted into monetary units and outcomes are expressed as the value of the benefits per dollars expended; sometimes referred to as benefit-cost analysis | Monetary units | Monetary units | Benefit-cost ratio (B/C) Net benefit (B-C) | / |

DALY, disability-adjusted life year; QALY, quality-adjusted life year
*Source:* Own compilation, based on Ngorsuraches (2008) and Drummond et al. (2005). Descriptions based on the CDC economic evaluation glossary index (CDC, 2011).

## *1.4. Research questions*

The objective of this PhD dissertation is to determine the market potential of FBR as a GM rice product with consumer benefits in China and a high-risk region in particular. Based on the conceptual framework to achieve this objective (Figure 2), eight key research questions are specified with respect to the three domains of interest, namely acceptance, WTP and cost-effectiveness. As most of these research questions are broadly formulated, specific sub-questions are added to test particular relations, analyze methodological issues or to put the question in the broader context. Due to the large number of sub-questions, these questions often deal with concepts that are not presented in the conceptual framework as such, but are described in the corresponding part of section 1.3. Below, a brief description of the rationale for the research (sub)questions is provided. Each question is examined in the dedicated research chapters and summarized in section 6.1 of the concluding chapter.

The research contributions that are associated with these questions will be discussed in the next section. Given the characteristics of the research design (section 1.6.1), the answers mainly refer to Shanxi Province as a poor, rural high-risk region. This is true, except for the last two research questions, where the focus is extended to China and/or an Indian high-risk region (Balrampur District).

***RQ1.*** ***Is consumer acceptance of FBR determined by socio-demographic indicators, knowledge and consumer perceptions related to GM food?***

*RQ1A.* *How do consumer perceptions of GM food affect FBR acceptance?*

*RQ1B.* *Does objective GM knowledge determine FBR acceptance?*

*RQ1C.* *How do socio-demographic variables influence FBR acceptance?*

Based on underlying theories and empirical evidence to explain GM food acceptance (see section 1.3.1.1), acceptance of FBR as a GM rice variant with health benefits is expected to be determined by GM food knowledge, consumer beliefs and socio-demographic attributes.

The appropriateness and influence of using multi-item scales of GM food consumer perceptions, which are generally recognized as determinants of 1$^{st}$ generation GM food (Bredahl et al., 1998; Verdurme and Viaene, 2001, 2003; Pope et al., 2004) is tested for this 2$^{nd}$ generation GM food product (RQ1A). GM food benefits and risks, especially the former (Hamstra, 1995), are expected to be the most determining consumer perceptions (Frewer and Shepherd, 1995; Costa-Font et al., 2008).

Although a positive relationship between knowledge and GM food acceptance is generally observed (Huang et al., 2006b; Chen and Li, 2007; Costa-Font and Mossialos, 2007), other studies countered this (Hamstra, 1995) and stress the need to further explore the effect of knowledge, especially with respect to objective GM knowledge (House et al., 2004; Kassardjian et al., 2005)(RQ1B).

Similarly, the evidence of the impact of socio-demographic variables on GM food acceptance is inconclusive. Whereas several studies question the explanatory power as such (Bredahl et al., 1998; Baker and Burnham, 2001; Li et al., 2002; Kontoleon and Yabe, 2006; Anand et al., 2007), others found significant effects of age, gender, education or income (Hoban, 1998; Siegrist et al., 2000; Traill et al., 2004; Moerbeek and Casimir, 2005; Ganiere et al., 2006; Wachenheim et al., 2008; Yee et al., 2008), but often in the opposite way (Costa-Font et al., 2008)(RQ1C). Given the objective of FBR as an agriculture-based health intervention to reduce NTDs, family-related factors and farmer status are added to the model.

The influence of these determinants on FBR acceptance is investigated in the consumer study in Shanxi Province (see section 3.3.2).

***RQ2. What kind of segments of Shanxi rice consumers can be distinguished based on GM food knowledge, consumer perceptions and trust in information sources/channels?***

The review of GM food segmentation studies in section 1.3.1.2 revealed a lack of studies on 2nd generation GM food studies and, given the applicability of market segmentation to detect distinct consumer segments as a basis for future communication, the need to incorporate the way consumers acquire GM food information and the trust levels regarding different information sources and channels.

Market segmentation is conducted to find out if Shanxi rice consumers cluster around objective GM knowledge, GM food perceptions and the trustworthiness in information channels and sources, and how these clusters differ in terms of FBR acceptance, socio-demographic indicators and GM information acquisition (see section 3.3.3).

***RQ3. Which negative changes in rice attributes would deter FBR acceptance?***

As the underlying Fishbeins' Multi-attribute theory postulates, FBR acceptance will be determined by the evaluation of its altered attributes (Bredahl et al., 1998; Ganiere et al., 2006; Siegrist, 2008). The impact of the improved health benefits of GM food (Bourn and Prescott, 2002; Engel et al., 2002; Verdurme et al., 2003a; Siegrist, 2008), i.e. the enhanced nutritional content of FBR, is explored in RQ1 (acceptance) and RQ4 (WTP). This research question reflects the need to extend such acceptance studies by determining the effect of potential negative rice attribute changes due to biofortification (Bouis et al., 2000; Stein et al., 2006).

By focusing on rice consumers who are not averse of FBR, derived from the 2008 consumer survey, section 3.3.4 deals with the reduction of FBR acceptance due to negative changes in six rice attributes (taste, external appearance, price impact, market availability, the cultivation potential and the environmental impact).

***RQ4. How much are consumers willing to pay for FBR in a high-risk region?***

*RQ4A. What determines consumers' valuation of FBR?*

*RQ4B. How does information about the applied GM technology affects WTP for FBR?*

*RQ4C. What is the effect of providing information about the regional situation on WTP for FBR?*

*RQ4D. Is there a difference between non-student and student samples in experimental auctions?*

*RQ4E. Does the provision of a non-GM substitute influence WTP for FBR?*

*RQ4F. Do design characteristics (time, day, size) matter in auctions?*

Compared to the 1st generation GM food products (Lusk et al., 2005), measuring consumers' WTP for 2nd generation GM crops, and biofortified crops in particular, is still relatively new (Chowdhury et al., 2009), especially when using experimental auctions to elicit the valuations (Rousu et al., 2005). Nevertheless, transgenic biofortification is an interesting topic to explore WTP, as consumers need to make a trade-off between the consumer benefits of biofortification and the controversial nature of the applied GM technology. Given the large premiums in previous WTP studies on GM biofortified Golden Rice (Deodhar et al., 2008; Depositario et al., 2009a; Gonzalez et al., 2009) and the supportive consumer reactions to GM rice in China (Li et al., 2002; Liu, 2009), high WTP values are expected for FBR in Shanxi Province. However, it still needs to be determined if the folate benefits are capable of mitigating negative reactions towards the application of GM technology in FBR.

Chapter 4 examines the WTP for FBR by using two main value elicitation methods: survey based contingent valuation versus experimental auctions. As the next research question deals with the difference between these methods, the focus here is on the experimental auctions that are organized with the key target group of FBR, i.e. women of childbearing age, in a poor county of Shanxi Province.

The auction design allows investigation of the determinants of WTP for FBR, based on different information rounds and the auction survey (RQ4A, see section 4.4.2.4). The difference between the folate and the 'GM technology' information rounds explores the impact of awareness of the use of GM technology in FBR on WTP, i.e. if folate benefits are capable of mitigating potential negative reactions towards the GM nature of FBR (RQ4B, see section 4.4.2.5). Stated differently, this research question compares FBR if it would have been developed by using conventional or transgenic technology. Another information effect that is examined, refers to information about the current burden of folate deficiency and the potential of FBR in the region (RQ4C). Specific GM information effects are addressed in RQ6.

The last three sub-questions investigate specific auction design characteristics in experimental auctions. First, our auction design incorporates two female target groups, a student versus a non-student subsample, to detect a target group effect (RQ4D). Although auction literature found no significant differences in valuations between student and population based auctions (Lusk et al., 2005; Depositario et al., 2009b), the involvement, the socio-demographic characteristics and the acceptance of GM food might lead to diverse bidding behavior. This is examined in various subsections of section 4.4.2., e.g. zero bidding behavior and the determinants of WTP for FBR. Second, unlike other valuation studies on biofortified crops, this study measures the effect of an additional non-GM folate substitute by auctioning rice with free folic acid supplements in half of the auctions (RQ4E). Thereby, I address the need to incorporate substitutes in GM food auctions (Corrigan, 2005; Kassardjian et al., 2005; Corrigan et al., 2009). Other design characteristics refer to the timing (i.e. time and day) and the size of the auction (2004; Rutsaert et al., 2009; De Groote et al., 2010).

***RQ5.*** ***Is there a difference between stated willingness-to-pay (sWTP) and auction-based values (WTP)?***

*RQ5A.* *Do the WTP values reveal a hypothetical bias in the stated valuation method?*

*RQ5B.* *Are the WTP values subject to a social desirability bias?*

The impact of the value elicitation method on WTP values has been widely investigated (Johannesson et al., 1998; List and Gallet, 2001; Lusk et al., 2005; Huffman et al., 2007). Generally, hypothetical valuation methods are found to generate significantly higher values than the non-hypothetical methods, a phenomenon which is mainly attributed to the lack of hypothetical bias in the latter (Balistreri et al., 2001). For example, a discrepancy is observed between hypothetical contingent valuation methods, such as open-ended stated WTP values, and the auction-based WTP values (Balistreri et al., 2001; List and Gallet, 2001; Chern and Chang, 2009). As both are incorporated in the study on WTP for FBR, the existence of hypothetical bias is examined by comparing sWTP and WTP values (RQ5A).

Despite the advantages of experimental auctions over stated preferences, the former is also criticized for stimulating social desirable behavior, especially when conducted in a laboratory setting with controversial products (see section 1.3.2.1). A novel approach to evaluate social desirability bias (SDB) in experimental auctions is indirect valuation (Lusk and Norwood, 2006). In the experimental auctions of chapter 4, indirect (iWTP) and direct valuations (WTP) are compared to analyze the presence of this bias (RQ5B).

***RQ6.*** ***To which GM information are consumers most susceptible when valuing FBR?***

*RQ6A.* *What information dominates in conflicting GM information?*

*RQ6B.* *Is there a primacy or recency effect in the evaluation of conflicting GM information?*

*RQ6C.* *Does the GM information effect differ according to consumer acceptance of GM food?*

Auction literature on WTP for 1st generation GM crops has pointed out the importance of GM related information, with higher WTP (or lower WTA) values when positive statements are provided, and vice versa (Jaeger et al., 2004; Lusk et al., 2004b; Kassardjian et al., 2005; Liu, 2009). Also the evidence on the effects of combined GM information treatments is growing (Tegene et al., 2003; Huffman et al., 2007; Colson and Huffman, 2009; Depositario et al., 2009a). Nevertheless, there is still discussion about the impact of information when dealing with two-sided treatments. First, while negative information is generally prevailing (Fox et al., 2002; Tegene et al., 2003; Parkhurst et al., 2004; Hu et al., 2006), some authors found support for the opposite (Rousu et al., 2004b; Colson and Huffman, 2009; Corrigan et al., 2009).

Second, although evidence is extremely thin, order effects in conflicting information treatments might influence WTP for GM food (Liu, 2009). When evaluating novel food products, a recency effect is expected to occur, unless the information is highly relevant to consumers (Buda and Zhang, 2000).

Third, due to the well established positive relationship between GM food acceptance and WTP values (Kassardjian et al., 2005; Colson and Huffman, 2009), its role in the effect of GM information is further explored (RQ6C). According to previous research, reluctant consumers are less susceptible to new information (Lusk et al., 2004b).

Section 4.4.2.5 of chapter 4 investigates the role of GM information in WTP for FBR, based on six, scientifically underpinned, information sheets (positive, negative, positive + negative, negative + positive, objective, all) that are randomly distributed during the 4th information round of the experimental auctions in Shanxi Province.

***RQ7.*** ***What is the current burden of folate deficiency in China and Shanxi Province?***

*RQ7A.* *What is the relative importance of folate deficiency in micronutrient malnutrition in China?*

*RQ7B.* *How large is the burden of folate deficiency in two of the most important high-risk regions, Shanxi Province (China) and Balrampur District (India)?*

In order to determine the potential health benefits of FBR in China, the current burden of folate deficiency needs to be determined. Until today, there is no evidence of studies that have calculated the health impact of folate deficiency at population level (see section 2.2). Given that Northern China (Hao et al., 2003; see also Figure 7), and Shanxi Province in particular (Ren et al., 2007), has one of the highest folate deficiency rates in the world, there is a need to estimate the current burden of this micronutritional disease at regional/provincial level.

In chapter 5, the current burden of folate deficiency in China and its 31 administrative areas, among which Shanxi Province, are assessed by applying the DALY approach. Based on epidemiological and population data, the number of DALYs lost due to fatal and non-fatal outcomes of folate deficiency is estimated (see section 5.4.1.1). To evaluate the relative importance of the burden, the results are benchmarked with evidence from other health burden studies in developing countries (see section 5.4.4.1). However, given the scope of this PhD dissertation, benchmarking the country-wide burden against the main micronutrient deficiencies (vitamin A zinc and iron) in China (RQ7A) and comparing the situation in Shanxi Province with one of the most important high-risk regions in the world, Balrampur District (Cherian et al., 2005)(RQ7B), is more appropriate.

***RQ8.*** ***How cost-effective would folate and multi-biofortified rice be when introduced in China?***

*RQ8A.* *Does the cost-effectiveness of FBR and MBR in China achieve the World Bank thresholds of highly cost-effective health interventions?*

*RQ8B.* *When compared with other biofortified crops in other developing regions, how cost-effective is FBR and MBR in China?*

*RQ8C.* *What is the health impact of FBR when introduced in the most important high-risk regions of China and India?*

The World Health Organization (WHO, 2002) emphasized the need to examine the cost-effectiveness when evaluating (novel) health interventions. Especially in Asian countries, there is an urgent need to provide information on health strategies in order to adequately and efficiently address major public health problems (Mason et al., 1999). Given the controversy surrounding GM biofortification as a novel micronutrient intervention, ex-ante cost-effectiveness studies are required to provide the stakeholders with an evaluation tool to assess its potential (Stein, 2006) and to compare it with other interventions (Klemm et al., 2009).

This research question deals with the health impact assessment and the economic evaluation of FBR and MBR in China. Improving the folate content of China's major staple crop alone or together with vitamin A, zinc and iron, is expected to have a large impact on folate related health problems. In line with other health impact studies (Stein et al., 2005b; Horton, 2006; Meenakshi et al., 2007; Fan et al., 2009), the DALY framework is applied to FBR and MBR as potential health interventions in China. Building upon a large, comprehensive literature review, the number of DALYs that can be saved through FBR and MBR, in comparison with the current burden of folate or micronutrient malnutrition (see RQ7), is estimated.

By comparing the potential health benefits and the costs of biofortification, the cost-effectiveness of both interventions is measured. To put the country-wide results in perspective, this economic valuation measure is then compared with the low (US$ 258.12 per DALY saved) and high (US$86.04 per gained DALY) World Bank thresholds (RQ8A) and compared with other cost-effectiveness studies to combat micronutrient malnutrition in developing countries (RQ8B). As in the burden analysis (RQ7), a regional scope is used to measure the health benefits of FBR in China, which allows comparison of the results of Shanxi Province with another high-risk region in India, i.e. the Balrampur District (RQ8C).

Whereas section 5.4.1 and 5.4.2 assess the potential impacts of, respectively, FBR and MBR, the cost-effectiveness of both interventions are calculated in section 5.4.3. The sub-questions are tackled in section 5.4.4.

## 1.5. Research contribution

The major research contribution of this PhD dissertation refers to:

- the originality of the investigated topic, which is the first to evaluate consumer acceptance of FBR as a GM rice with consumer/health benefits in a region where folate deficiency is considered to be a major health problem;
- the combined empirical research focus on both the micro and macro-level, by determining acceptance of, and WTP for a GM food product with health benefits in a high-risk region, while evaluating the benefits and costs of introducing it as a health intervention in China, e.g., the value elicitation methods and the targeted sampling approach for WTP, the impact of product attributes, a regional health impact study and a CEA of a multi-biofortified product;
- the methodological adaptations and improvements in the experimental auctions, e.g. comparison of valuation methods, indirect valuation, non-GM substitute and information effects (product attributes and the regional situation) and a targeted sample;
- its relevance towards the nutritional community, (health) policy makers and program planners, stakeholders in the field of (GM) biofortification, GM rice and/or birth defect prevention;
  e.g. importance of burden of folate deficiency and health intervention analysis.

### 1.5.1. Scientific contribution

This section describes how this PhD dissertation contributes to scientific research following the three lines of inquiry. These contributions are made on methodological and/or empirical level (see Table 4).

Table 4 Scientific contribution per contribution area and level of contribution

| Contribution area | Contribution level | | |
|---|---|---|---|
| | Replication | Extension | Innovation |
| *Methodological* | | | |
| Acceptance | Standardized survey | | |
| Willingness-to-pay | Stated WTP | Experimental auctions: | Experimental auctions: |
| | Experimental auctions: | In-between auction survey | Indirect valuation |
| | GM information effects | GM information order effects | Non-GM substitute effect |
| | Design effects (time, size,...) | | GM product attribute effects |
| Cost-effectiveness | DALY framework; CEA | | |
| *Empirical* | | | |
| Acceptance | GM food with health benefits | High-risk region | |
| | Determinants of acceptance | GM food market segmentation | |
| | | Impact negative attributes | |
| Willingness-to-pay | GM food with health benefits | High-risk region | Comparing interventions |
| | Determinants | Comparing 3 valuation methods | Role of (GM) information |
| | | Comparing technologies | Targeted sample |
| Cost-effectiveness | | Burden of deficiencies: | Regional/provincial focus |
| | | Folate/MM | Comparing high-risk regions |
| | | CEA of biofortification: | |
| | | Folate/multi-micronutrient | |

CEA, cost-effectiveness analysis; DALY, disability-adjusted life year; GM, genetic modification; MM, micronutrient malnutrition; WTP, Willingness-to-pay

#### *1.5.1.1. Methodological contribution*

This thesis mainly builds upon existing data collection methods, such as a standardized survey (acceptance) and experimental auctions (WTP), and uses appropriate statistical methods, such as cluster analysis, multinomial logistic regression and double hurdle model regression (an overview of the applied methods is presented in section 1.6.1.).

Regarding WTP, the study incorporates two common value elicitation methods, namely the stated preference method (sWTP) versus experimental auctions (WTP). Whereas both techniques replicate the standard methodology, the latter goes beyond current auction literature on GM food by measuring the impact of information about FBR attributes and the regional situation on WTP through distinct auction rounds, which allows the measurement of the effect of biofortification technologies, i.e. conventional versus GM biofortification. A specific auction design effect deals with the option of a GM-free substitute to explore consumers' WTP for GM food when alternative folate options are present. Other auction design effects refer to the time-of-the-day effect, the 'weekend' effect and the size of the auctions.

To examine the determinants of WTP, our auction survey was organized in-between information rounds, rather than before or after the bidding process. The auction design is based on 5 non-repeating information rounds, of which one is used to determine the role of six different GM information treatments. Hereby, specific attention is paid to the sequence of conflicting GM information in order to explore the presence of a primacy or recency bias/effect.

The bidding methodology in the experimental auctions also involved indirect valuation method in the third auction round, which is an innovative modification of the general auction methodology. Although this approach is useful when eliciting values for controversial goods, it is currently not applied to GM food. Compared to the indirect valuation method of Lusk and Norwood (2006), this thesis separates the indirect valuations from the general bidding rounds in order to measure social desirability behavior rather than to control it. Another methodological contribution refers to the adapted negative valuing approach of Parkhurst et al. (2004), by which people have the option to submit a negative bid after the 3rd auction round. As this approach was used to further investigate the reasons of zero bidding behavior, this concept is not included in the conceptual framework and the research questions. Nevertheless, this is the first to apply such as an approach in GM food auctions.

With respect to the study on cost-effectiveness, replication of the DALY framework is justified as it is the recommended CEA tool of the World Bank (Laxminarayan et al., 2006) and WHO (Tan-Torres Edejer et al., 2003; Evans et al., 2005), and because it is the common method to measure the health impact of biofortification and other micronutrient strategies (Horton, 2006; Meenakshi et al., 2007). Moreover, it also allows comparison of the results with most of the published cost-effectiveness analyses of biofortification strategies in developing countries. Nevertheless, in line with similar study approaches (Stein et al., 2005b), some of the initial assumptions of the DALY framework are relaxed or adjusted.

### 1.5.1.2. Empirical contribution

The empirical contribution of this thesis primarily lies in the nature of the investigated product and the selected research location. By exploring the market potential of a GM rice variant with health benefits, i.e. folate biofortification of rice, this dissertation focuses on a relatively new area in GM food consumer research. The main advantage of investigating consumer reactions towards second instead of first generation GM crops, is that the former is both controversial and beneficial to humans, by which consumers have to make a trade-off between its benefits and potential risks.

Although the development of biofortified crops initiated in the 1990s, a knowledge gap still exists in research on consumer acceptance and WTP (Lusk, 2003), especially in high-risk regions (Gonzalez et al., 2009), and when using experimental auctions (Rousu et al., 2005) in developing countries (Rutsaert et al., 2009).

In the field of health intervention analysis, a lot of efforts have been made to close the knowledge gap of biofortified crops (Meenakshi et al., 2006; Table 52). Still, to our knowledge all these health impact studies solely focus on one of the three key micronutrients, vitamin A, iron or zinc. The focus on folate enriched and multi-biofortified rice further closes this gap in GM biofortification research.

By combining research on both the micro (i.e. consumer studies about the acceptance of, and WTP for FBR) and macro-level (i.e. CEA of FBR), this thesis aims to address the aforementioned knowledge gaps simultaneously.

Given the product under investigation, the selection of the research locations is justified (see section 1.2.). This thesis one of the first to conduct consumer research about a 'consumer-friendly' GM food crop in a high-risk region where the need of exploiting its benefits is the highest. When reviewing Chinese consumer studies on GM food, whether the objective is to analyze acceptance (Lin et al., 2004; Ho et al., 2006; Huang et al., 2006b), conduct a segmentation study (Li et al., 2003; Zhang et al., 2010) or to investigate the WTP for GM food and rice (Li et al., 2002; Liu, 2009), or when experimental auctions are applied (Kachelmeier and Shehata, 1992; Li et al., 2002; Wang and McCluskey, 2010), the focus is solely on urban China, which further supports the selected research location.

Regarding consumer acceptance, the major contribution is to assess what determines acceptance of GM rice with health benefits in a relevant research location, i.e. a poor, rural region that lacks alternative options to obtain these health benefits. It is also the first study that describes the potential impact of negative attributes of biofortified staple crops, and one of the first market segmentation studies on a 2$^{nd}$ generation GM food crop.

Empirical novelties in the experimental auctions include the comparison of consumers' WTP for different options to increase micronutrient intake levels and, in combination with the high-risk region, a targeted sample of women of childbearing age. Furthermore, this thesis seeks to obtain scientific insight in the role of five different types of information, related to the product characteristics (GM technology, folate content, folate benefits, …) or the link with the region, when explaining WTP for FBR.

The CEA is the first to assess the burden of folate deficiency (and micronutrient malnutrition in China), and the potential cost-effectiveness of both FBR and MBR, respectively. It contributes to a wider understanding of the phenomenon of folate deficiency and anticipates multi-biofortification as the next phase in GM biofortification research. Whereas previous health impact studies on biofortification strategies focus on national estimates, this thesis also includes a regional and provincial comparison of the burden and health impacts of folate biofortification in China. As a consequence, the results of the most important risk region, Shanxi Province, can be compared with a similar problem area in India, Balrampur District. The potential impact of MBR is only investigated at the national level, but a distinction is made according to the applied GM technology.

### 1.5.2. Policy and stakeholder relevance

This PhD dissertation also seeks to be of practical relevance for policy makers (health and agriculture) and other stakeholders in the field of biofortification, folate interventions and birth defect programs, such as health planners and aid agencies. It broadly addresses the need to evaluate ex-ante biofortification strategies by determining the market potential of FBR on consumer side and evaluating the impacts of this health strategy for the society as a whole. The practical contributions are twofold.

Firstly, governments are faced with restricted resources to address competing public health problems. They are seeking a process for deciding the best way to invest their funds for public health. A first step to assist decision makers in setting a strategic health agenda and formulating priorities is to investigate the current status of the targeted disease, i.e. the ‘burden of disease’ (Lopez et al., 2006). This thesis is the first to provide information about the importance of folate deficiency as a particular type of micronutrient malnutrition (see section 2.2). The lack of adequate knowledge of the importance and prevalence of micronutrient deficiencies is considered one of the main bottlenecks to successfully introduce micronutrient health interventions (ADB, 2004b; Faillace et al., 2008). Although the focus is limited to China, the low folate intake levels and high prevalence of NTDs, and the regional differences in folate intake and rice consumption further support the need to identify its impact at the regional and national level.
The second step is then to obtain ex-ante information on how folate biofortification could contribute to alleviate this burden. CEA is largely acknowledged as an essential tool to adequately evaluate the potential gains of a health strategy, given the budgetary constraints (Gold et al., 1996; Haddix et al., 2003; Tan-Torres Edejer et al., 2003). When conducted ex-ante, highly cost-effective interventions that policy makers are hesitating to support or even not aware of, can be discovered (Laxminarayan et al., 2006). Stein (2006, p. 3) formulates the social and policy relevance of bringing cost-effectiveness into biofortification research as follows: “*Filling this knowledge gap regarding the possible impact of biofortification is both vital and urgent: neglecting a potentially effective intervention and any delays in its implementation may literally cost lives*”. Given that biofortification technology is moving towards a multi-biofortification approach of product development (Naqvi et al., 2009), I anticipate this trend by investigating if adding vitamin A, zinc and iron to FBR would be still cost-effective in China.

Notwithstanding the focus on China and rice biofortification, the results are assumed to be relevant for developing (rice consuming) countries or regions. As such, this thesis aims to increase the awareness of the burden of folate deficiency and micronutrient malnutrition on the one hand, and offers potential stakeholders insight in FBR and MBR as alternative micronutrient interventions. Not only the nutritional community, but also agricultural policy makers can benefit from the results in this study, as they will be responsible for evaluating the potential of introducing biofortification by taking into account the explored advantages and disadvantages, e.g. health and cost consequences, and consumers' evaluation of FBR in regions at high risk of folate deficiency.

Secondly, even if folate biofortification would be considered as highly cost-effective, this health intervention is based on a controversial technology. As public acceptance is often a precursor of governmental efforts to support the development and introduction of GM food, governments are interested in the voice of the consumer, i.e. the potential demand for non-market goods (Boardman et al., 2006). Future commercialization of FBR is less feasible when consumers are not willing to buy it. Due to the recent history and the specific nature of GM biofortification, which combines health benefits and GM technology, stakeholders from different related fields, such as the biotechnology industry, governments and health planners, seek to obtain insight in the potential market for biofortification. Especially in the developing world, where commercialized GM food crops with agronomic traits are largely accepted and adopted, and where biofortification is needed the most, understanding consumers' reactions to $2^{nd}$ generation GM products is crucial to reinforce and justify the delivery of this health strategy, especially when the reduction of the respective deficiency is given high priority. As Gonzalez et al. (2009, p. 606) have pointed out: *"In developing countries, hardly any related research [to explore consumer acceptance and purchase intentions towards $2^{nd}$ generation products] has been carried out so far. This is considered a knowledge gap, especially with respect to GM biofortified crops which offer solutions to widespread nutritional problems among the poor"*. While it is particularily relevant to focus on GM rice in China in order to close this gap (Liu, 2009; see section 1.2), conducting biofortification research in a high-risk research location is considered both innovative and recommended.

This thesis will demonstrate if consumers would accept and be willing to pay for FBR, and how much. By exploring the determinants of their reactions, target groups can be defined. I further seek out how (GM) information can affect consumers' valuations for FBR. The consumer research focuses on a particular high-risk region, which can be justified from a health planning point of view (e.g. birth defects programs), in a country known to be supportive of GM food and biofortification research (see section 2.5).

## 1.6. *Research design and structure of the thesis*

### 1.6.1. Research design

The results of this PhD research stem from several published research studies, where different research methods are applied to analyze specific parts of the general conceptual framework (Figure 2). In order to adequately answer the research questions and achieve the main objective of this PhD dissertation, data is gathered through secondary and primary data sources, and analyzed by using exploratory and conclusive statistical techniques. The research design of this thesis summarizes the different studies that are conducted in each of the research chapters (chapter 3-5), as shown in Figure 4. As the methodology sections in these chapters provide a more detailed discussion of the data sources and the procedures to gather, measure and analyze the data, this section will be limited to a brief overview of the studies that are conducted between 2008 and 2011:

- Acceptance: Based on a literature review of GM food acceptance, a standardized survey was developed, translated, tested and administered with 944 rice consumers from Shanxi Province in July 2008. Therefore, this dataset has been used to explore acceptance of FBR and potential negative rice attributes, to explain FBR acceptance (multinomial logistic regression) and to conduct a market segmentation study (cluster analysis; multinomial logistic regression).
- Willingness-to-pay: By investigating the literature regarding the use of valuation methods, with a specific focus on novel technologies, among which GM (biofortified) food, an experimental auction design was constructed and, together with an auction survey, tested and used in Shanxi Province in April 2011 with 252 female rice consumers of childbearing age. Besides univariate statistical analyses to test the differences in (zero) bidding behavior, information effects and auction design effects, a double hurdle model is used to identify significant determinants of FBR. A part of the aforementioned consumer acceptance survey is used to determine stated WTP (multiple regression).
- Cost-effectiveness: Data collection is primarily based on secondary data sources, e.g. epidemiological, population based and biotechnological data, cost estimates and intervention assumptions. Regarding the assumptions to introduce folate biofortification, experts in the field of R&D of GM food and biofortification, such as the Chinese Academy of Agricultural Sciences (CAAS), HUMBO (Golden Rice Humanitarian Board), Nanjing Medical University, and colleagues involved in the development of FBR (see Preface), were consulted through e-mail, telephone or face-to-face. As the objective of such 'interviews' was to collect, verify or update data, these contacts were held on a regular, informal and/or non-structured basis[12]. The analysis itself applies the DALY framework by entering primary and secondary data into the DALY formula in order to measure the health impact of FBR and MBR on folate and micronutrient malnutrition in China. By combining the respective health outcomes and costs, the cost-effectiveness of these health strategies are assessed.

[12] Throughout this PhD dissertation, reference will be made to several meetings that were held with several stakeholders in China, among which: HarvestPlus China; CDC Food Fortification Office Beijing; a key biotechnology company in China; Biotechnology Research Institute, Center for Chinese Academy of Agricultural Sciences and the Chinese Biosafety Committee. When the outcome of an interview refers to data collection or verification, reference is made in the footnotes of the respective tables.

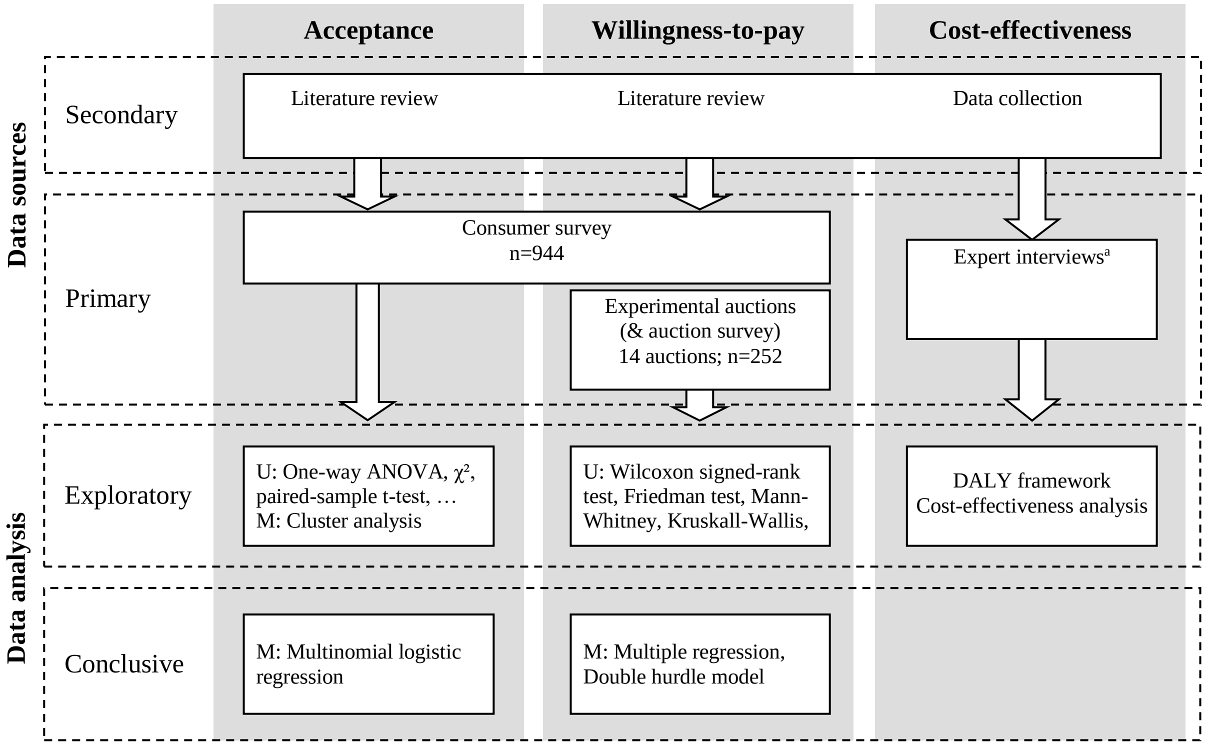


Figure 4 Research design, data sources and statistical techniques, per investigated topic

M: multivariate statistical analysis; U: univariate statistical analysis
[a] Refer not only to face-to-face interviews, but also to short correspondences in order to retrieve primary or secondary data.

### 1.6.2. Thesis outline

This thesis distinguishes six dissertation chapters as outlined in Figure 5. Chapter 3 to 5 provide an answer to the aforementioned research questions and represent one or more research papers.
The introductory chapter presents the rationale of the conceptual framework, research questions, research contribution and the research design. This chapter builds upon a book chapter, which describes the main conceptual framework and the key results of this PhD dissertation. Chapter 2 is mainly adapted from the supplementary discussion of a paper studying the potential health impact of FBR in China. The overall aim of this chapter is to provide the reader a broader understanding of the rationale of this PhD dissertation and a foundation for subsequent chapters. As a consequence, the research objectives, the methodologies, the discussion and the conclusions of the respective studies in the forthcoming chapters refer to this underlying overview. Chapter 3 is dedicated to the consumer survey on FBR acceptance in Shanxi Province and investigates research questions 1 to 3. This study builds upon a published paper that deals with the consumer survey in 2008. The research questions 4 to 6 are addressed in chapter 4. Here, WTP with regard to FBR are determined through stated preferences and experimental auctions with (female) Shanxi rice consumers. In chapter 5, the burden of folate deficiency and micronutrient malnutrition (RQ7) and the potential impacts and costs to implement FBR and MBR (RQ8) are measured. Finally, chapter 6 summarizes the main results and answers the research questions. Also the limitations, policy implications and directions for future

research are highlighted. The last section addresses several important issues to advance towards a successful implementation of FBR in China.

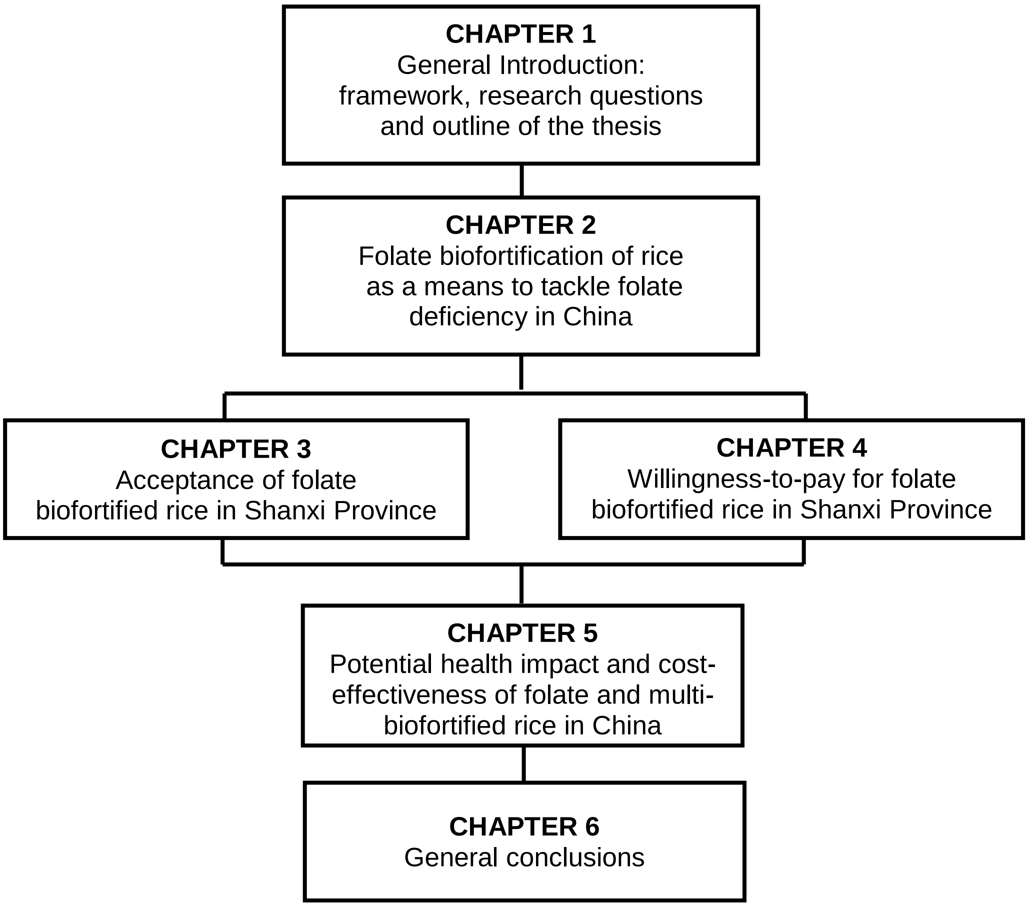


Figure 5 Outline of the thesis

# 2 Folate biofortification of rice as a means to tackle folate deficiency in China

Adapted from:

De Steur, H., Gellynck, X., Storozhenko, S., Liqun, G., Lambert, W., Van Der Straeten D. & Viaene, J. 2010. The health benefits of folate biofortified rice in China. Nat. Biotechnol. 28, 554-556. Supplementary discussion: S1-42.

## 2.1. Introduction

This chapter describes the context of FBR in relation to folate deficiency as a specific type of micronutrient malnutrition on the one hand, and as a novel folate intervention to combat this deficiency on the other hand. In each section, the global situation, as well as the position of China will be discussed with specific attention to the policy context. Furthermore, FBR is positioned in the framework of biofortification, genetic modification and, together, with 2nd generation GM biofortified crops. As a consequence, this chapter provides definitions, data and assumptions that will be used in the forthcoming chapters, e.g. the definitions of folate deficiency and NTDs, the attribution levels of folate deficiency to NTDs, the Chinese status of folate deficiency, micronutrient malnutrition and the number of NTDs, and the technological assumptions and data regarding the development of FBR.

## 2.2. Micronutrient malnutrition

Micronutrient malnutrition[13] is defined by a chronic lack of micronutrients, i.e. essential vitamins and minerals that are needed in small quantities, and has a large impact on global health and (indirectly) hinders social and economic prosperity, e.g. through productivity losses, cognitive impairment and soaring health care costs (FAO, 2004b; Micronutrient Initiative, 2009). Malnutrition is considered one of the principal causes of morbidity and mortality among the poor (Gwatkin and Guillot, 2000).
Most people are not aware of their lack of micronutrients, due to the subclinical character of such deficiencies, and because the underlying causes and health functions of different micronutrients are neglected, poorly addressed, or still undiscovered. Therefore, this form of malnutrition is often referred to as the ‘hidden hunger’. Insufficient intake of micronutrients reflects a lack of dietary quality and especially strikes poor, low educated people living in rural, less developed areas, because they largely depend on staple crops (e.g. rice, maize and wheat), which are known to contain little micronutrients (Gwatkin and Guillot, 2000; FAO, 2004b; UNICEF, 2004b; Micronutrient Initiative, 2009). As a consequence, multiple micronutrient deficiency is the rule rather than the exception. Half of malnourished children, for instance, are deficient on several vital micronutrients (UNICEF, 2004b).

Despite a growing number of global and regional initiatives to control micronutrient malnutrition, especially the main micronutrient deficiencies (Vitamin A, zinc and iron)(Mason et al., 2001), it remains a serious threat to the health of populations worldwide, in particular for pregnant woman and children. Micronutrient malnutrition affects about two billion people worldwide, mainly in low-income countries (Micronutrient Initiative, 2009). Its magnitude differs when looking at specific micronutrient deficiencies and different data sources. The number of people with insufficient vitamin A intake, for example, varies between 140 (West, 2002), 190 (WHO, 2009b) and 254 million (West, 2002; Rice et al., 2004). Iodine and zinc deficiency figures show that a total estimate of nearly 2 billion people is at risk (FAO, 2004b; Hotz and Brown, 2004; UN, 2004). Iron deficiency is another widespread type of micronutrient

[13] There is a clear difference between under- and malnutrition in that the former is a specific type of the latter. Whereas undernutrition refers to an inadequate intake of specific nutrients, malnutrition covers both under and over-nutrition, such as obesity but also micronutrient deficiency (Shettya, 2003). In this dissertation, we will use the term “malnutrition”.

malnutrition, with 1.7 billion people below the recommended intake levels (FAO, 2004b; UN, 2004). However, the public health significance of a micronutrient deficiency must be evaluated by looking beyond its prevalence, i.e. by estimating its health impact. According to Horton et al. (2010), an annual number of 10.3 billion US$ is still required to successfully fight the global burden of malnutrition, of which at least 1.5 billion US$ is needed to adequately combat micronutrient deficiency.

Table 5 lists some key figures regarding the devastating health and socio-economic impact of global micronutrient malnutrition. Its large importance is underpinned by its share in the global burden of disease. Together, vitamin A, iron, zinc and iodine deficiencies account for 4 % of the global burden of disease in 2004. Regarding regional malnutrition, Southeast Asia is found to be the most problematic region, followed by Africa (Ezzati et al., 2004). However, not all micronutrient deficiencies are included in the current burden analyses, among which folate deficiency. Therefore, the contribution of micronutrient malnutrition to the global health impact is underestimated. According to the Micronutrient Initiative (2011a), the total share in the global burden of disease is expected to be around 10 %.

The lack of data on the global burden of specific micronutrient deficiencies, such as folate deficiency, confirms that cost-effectiveness analyses and public health programs are mainly targeting on the three most important micronutrient deficiencies (zinc, vitamin A and iron)(Mason et al., 1999; Fiedler et al., 2008; Horton et al., 2010). As children below 5 years are mainly suffering from these deficiencies, it is not surprising that the nutritional targets of the Millennium Development Goals (MDG)(UN, 2011) and the nutritional challenge of the 2008 Copenhagen Consensus (CC, 2011) focus on this age group. In the framework of MDG 1 (eradicate extreme poverty and hunger), for instance, the United Nations strives to halve the prevalence of underweight children, i.e. one of the proxy indicators of poor nutrition, between 1990 and 2015 (UNICEF, 2006; UN, 2010). Furthermore, malnutrition should also be addressed to reduce child mortality (MDG 4), maternal health (MDG 5) and, indirectly, other major diseases (MDG 6), and to help to achieve the goals on education (MDG 2) and gender equality (MDG 3)(UN, 2004).

The rough estimations of the global burden of folate deficiency based on NTDs caused by folate deficiency, i.e. 4.8 million DALYs lost per year (see Annex 2), show that the importance of this deficiency might be underestimated. It further underpins the need for folate burden studies, which is tackled in this dissertation.

Table 5 Key figures of the estimated global impact of micronutrient malnutrition, estimated burden of disease in million DALYs lost and as a percentage of the Global Burden of Disease, per main micronutrient deficiency

| **Type of micronutrient deficiency** | **Estimated burden of disease**[f] | | | |
|---|---|---|---|---|
| | **2000**[g] | | **2004** | |
| | mi. DALYs lost | % of GBD | mi. DALYs lost | % of GBD |
| **Micronutrient malnutrition (MM)** | **93.2** | **6.3** | **60.9** | **4.0** |
| 2 million children may die each year due to MM[a] | | | | |
| MM is the world's leading cause of mental impairment[b] | | | | |
| MM is responsible for productivity losses of up to 2% of GDP[b] | | | | |
| **Vitamin A deficiency (VAD)** | **26.6**[h] | **1.8**[h] | **22.1**[l] | **1.5**[l] |
| VAD-related night-blindness and blindness are affecting 5 million and 350.000 children, respectively[c] | | | | |
| VAD is responsible for 0.5 to 1 million child deaths each year.[b,c] | | | | |
| **Iron deficiency (ID)** | **35.1**[d] | **2.4**[d] | **19.7**[l] | **1.3**[l] |
| ID affects the health and energy of 40% (women)[a] and the mental development of 40-60 % (children)[b,d] in developing countries. | | | | |
| ID is estimated to result in the annual death of 841.000 persons[g], of which 50.000 young women in pregnancy and childbirth[b]. | | | | |
| **Zinc deficiency (ZD)** | **28.0**[e] | **1.9**[e] | **15.6**[l] | **1.0**[l] |
| About 800 000 child deaths per year are related to ZD[e] | | | | |
| ZD is associated with approximately 176.000 diarrhoea deaths, 406.000 pneumonia deaths and 207. 000 malaria deaths each year[e] | | | | |
| **Iodine deficiency (IOD)** | **3.5**[i] | **0.2**[i] | **3.5**[l] | **0.2**[l] |
| Each year, IOD leads to an estimated number of 18-20 million mentally impaired babies are born.[a,b] | | | | |
| IOD is estimated to lower the intellectual capacity of developing countries by 10 to 15 percentage points.[b] | | | | |
| **Folate deficiency (FD)** | **ND**[j] | **ND**[j] | **ND**[j] | **ND**[j] |
| FD is estimated to result in approximately 200.000 severe birth defects every year.[b] | | | | |
| About 1 in 10 adult deaths from heart diseases are attributed to FD[b]. | | | | |

DALY, Disability-Adjusted Life Year; FD, folate deficiency; GBD, Global Burden of Disease; ID, iron deficiency; IOD, iodine deficiency; MM, micronutrient malnutrition; ND, no data available; VAD, vitamin A deficiency; ZD, zinc deficiency

*Note:* Figures on the global burden of malnutrition are not presented. According to the FAO report on the state of food insecurity in the world (2004b), malnutrition in the developing world leads to a total loss of 220 million (childhood and maternal undernutrition) to 430 million (including nutrition-related risk factors) DALYs.

[a]Micronutrient Initiative (2011a); [b]UNICEF (2004a, b); [c] Micronutrient Initiative report (2009); [d]Stoltzfus et al. (2004); [e]Caulfield and Black (2004); [f]More information on DALYs and the DALY-approach, see Section 5.2; [g]The burden of different micronutrient deficiencies in 2000 are based on the Comparative Risk Factor Assessment (CRA) of the WHO (Ezzati et al., 2004). The data are available at the WHO website (2011b); [h]Rice et al. (2004); [i]WHO World Health Report (2002); [j]The global folate deficiency prevalence is not established, as Kennedy et al. (2003) demonstrate, but is expected not to be a marginal phenomenon (see, for instance, section 2.3.2). Based on the most important outcome of FD, i.e. NTDs, own calculations reveal a global burden of FD of at least 4.8 million DALYs (see Annex 2), which is significantly more than the rough 2.3 mi. estimation of Blencowe et al. (2010). However, this is still an underestimation, as other functional outcomes are not included; [l]WHO report on Global Health Risks (2009a). The statistics from the report are available at the WHO website (2011c).

## 2.3. *Folate deficiency*

### 2.3.1. Defining folate deficiency

Nutritional deficiency of folate or folate deficiency is generally characterized by an inadequate intake of folate (Vitamin $B_9$), i.e. below 400 µg per person, per day. This is the daily recommended dose, as advised by the World Health Organization (WHO, 2006a) and the US Public Health Service (USFDA, 1996). Besides a low dietary folate intake, folate deficiency could also be triggered by specific medications or diseases, such as kidney dialysis, which increase folate losses or needs (Carmel, 2006).

Figure 6 depicts the main (underlying) causes and health outcomes of folate deficiency. The generally low folate content of staple crops is one of the determinants of inadequate folate intake, as it is for the intake of other micronutrients. Folate is water-soluble vitamin, found in a wide variety of foods with green and/or leafy vegetables (e.g. beans, peas and spinach), eggs, liver and certain fruits (e.g. citrus fruits) as the most important dietary folate sources (USDA, 2008). Insufficient folate consumption is thus caused by low access and limited consumption of such folate-rich foods. It is then not difficult to understand why poor people, whose diet is predominantly based on low quality foods, are at high risk of folate deficiency. Other deeper underlying causes of inadequate intake and other micronutrients are the poor (maternal) caring practices and the limited access to health services or a disease stimulating environment, such as the lack of proper sanitation, which are associated with low socio-economic levels.

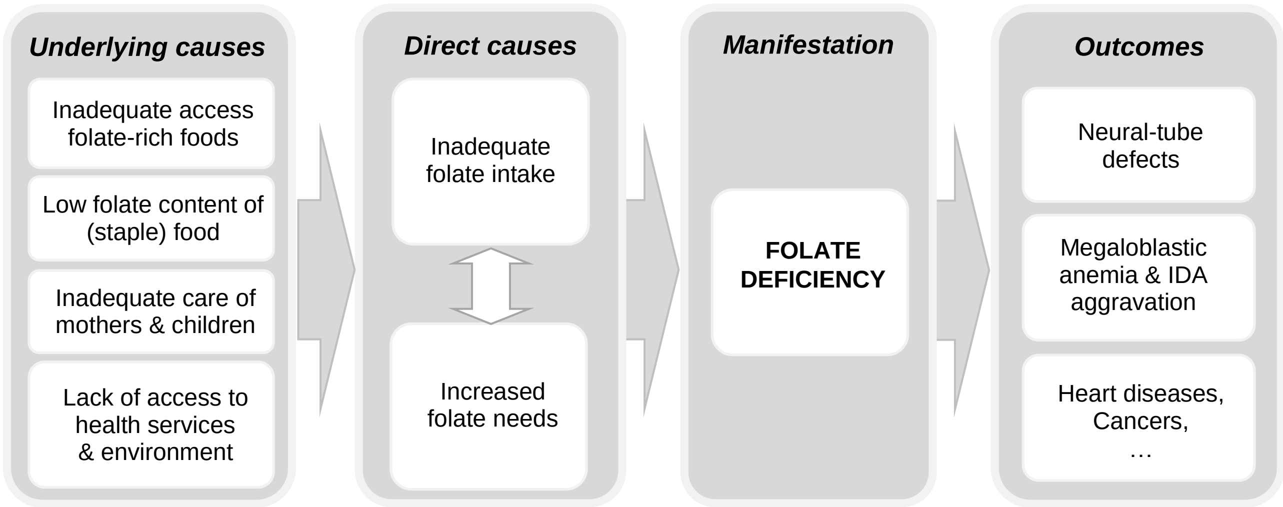


Figure 6 Causes and consequences of folate deficiency

*Source*: Adapted from the UN 5th report on the world nutrition situation (2004) and the global report on vitamin and mineral deficiencies of the Micronutrient Initiative (2009), and applied on folate deficiency.

Suboptimal folate intake plays a pivotal role in the onset of diseases and disorders, such as the occurrence and recurrence of NTDs (see 2.3.3), strokes, megaloblastic anemia and aggravation of iron deficiency anemia (Geisel, 2003; Blancquaert et al., 2010) and can be prevented by an adequate folate intake (Lumley et al., 2001; Rader and Schneeman, 2006). In addition, albeit that a causal link still needs to be proven, folate deficiency has been correlated with certain types of cancer, such as leukemia, colorectal, breast, cervical, pancreatic and bronchial cancer, but also Alzheimer's disease, coronary and cardiovascular diseases (Molloy and Scott, 2001; Bailey et al., 2003; National Library of Medicine, 2011). According to UNICEF (2004a), this deficiency is responsible for 1 out of 10 adult deaths from heart diseases. The role of a low folate status on male reproduction, fetal growth and the syndrome of Down needs to be further explored (Tamura and Picciano, 2006). Potential side effects of consuming high amounts of folate include cognitive impairment (only in combination with Vitamin $B_{12}$ deficiency), facilitated progression and growth of preneoplastic lesions and subclinical cancers, and impaired immune function of postmenopausal women (Tamura and Picciano, 2006; Smith et al., 2008; Tam et al., 2009).

Folic acid is a synthetic form of folate, which does not occur naturally, but is commercially produced into pills (supplementation) or added to foods (fortification). Contrary to folate, humans may be much poorer at handling folic acid than what had been previously thought and there is now more concern that circulating unmetabolized folic acid may have some downsides (Wright et al., 2007). Very high intakes of folic acid (>1 000 µg/day) lead to cognitive decline in the elderly, reduce the response to antifolate drugs used against rheumatoid arthritis, psoriasis, and cancer (Smith et al., 2008), and can mask Vitamin $B_{12}$ deficiency (Mills et al., 2003), which in turn further increases the risk of an NTD (Ray and Blom, 2003). Furthermore, dual effects are observed for colorectal cancer (Lewis et al., 2006; Smith et al., 2008; Ebbing et al., 2009; 2010), breast cancer (Lewis et al., 2006) and prostate cancer (Smith et al., 2008). Ulrich and Potter (2007) found that the time of intake plays a pivotal role in the positive effect on the reduced risk of cancer.
As the research findings on these interactions are often mixed, the potential negative health outcomes of raising the folic acid status resulted in a political reluctance to proceed to mandatory folic acid fortification in Europe (EUROCAT, 2005; Finglas et al., 2006) (see section 2.4). The debate of introducing folic acid interventions in a large population scale is still going on, both at the policy level and in the research world. Building upon their review of the dual effects of folic acid intake, Smith et al. (2008, p. 517) summarize their concerns about mandatory folic acid fortification in the United Kingdom (UK) as follows: *"… a high folic acid intake may be harmful for some people. Nations considering fortification should be cautious and stimulate further research to identify the effects, good and bad, caused by a high intake of folic acid from fortified food or dietary supplements. Only then can authorities develop the right strategies for the population as a whole".* However, exceedingly high levels of folic acid seem to be more attributable to folic acid supplementation rather than to fortification (Yang et al., 2010).

### 2.3.2. Folate deficiency in China and the world

As the most important staple foods, such as potatoes and grains, are poor sources of folate (USDA, 2008), folate deficiency is a global problem for public health. Figure 7 and Figure 8 summarize the scientific evidence of the magnitude of folate deficiencies, based on the plasma folate concentrations and the folate deficiency rate, respectively. These findings are based on a review of adult folate deficiency (Mclean et al., 2008), which compared the results of the most representative survey of each reviewed country. The threshold of folate deficiency is defined by a plasma folate status below 10 Nmol/L (Selhub et al., 2008), as suggested at the WHO Technical Consultation on folate and vitamin $B_{12}$ deficiencies in 2005 (De Benoist, 2008; Selhub et al., 2008). Unlike other micronutrient deficiencies, global estimates of its prevalence or burden are still non-existing. Nevertheless, as the figures confirm, folate deficiency deserves more attention than has received in the past and present by researchers (Oakley, 2003). In line with other micronutrient deficiencies, folate deficiency is more prevalent in less developed, non-western countries, especially where rice is the staple crop (Dexter, 1998; ADB, 2004a). Most of the Western countries are well above this threshold; especially after the implementation of folic acid programs (see section 2.4). However, a high average folate status does not imply that folate deficiency is absent, as Figure 8 shows.

With respect to China, a regional comparison is made. If only the figures of China as a whole would be presented, the differences between Northern and Southern China would be masked. The average plasma folate concentration in Northern China is below the threshold of folate deficiency, by which the number of folate deficient adults is significantly higher than in Southern China (see section 2.3.2.1).

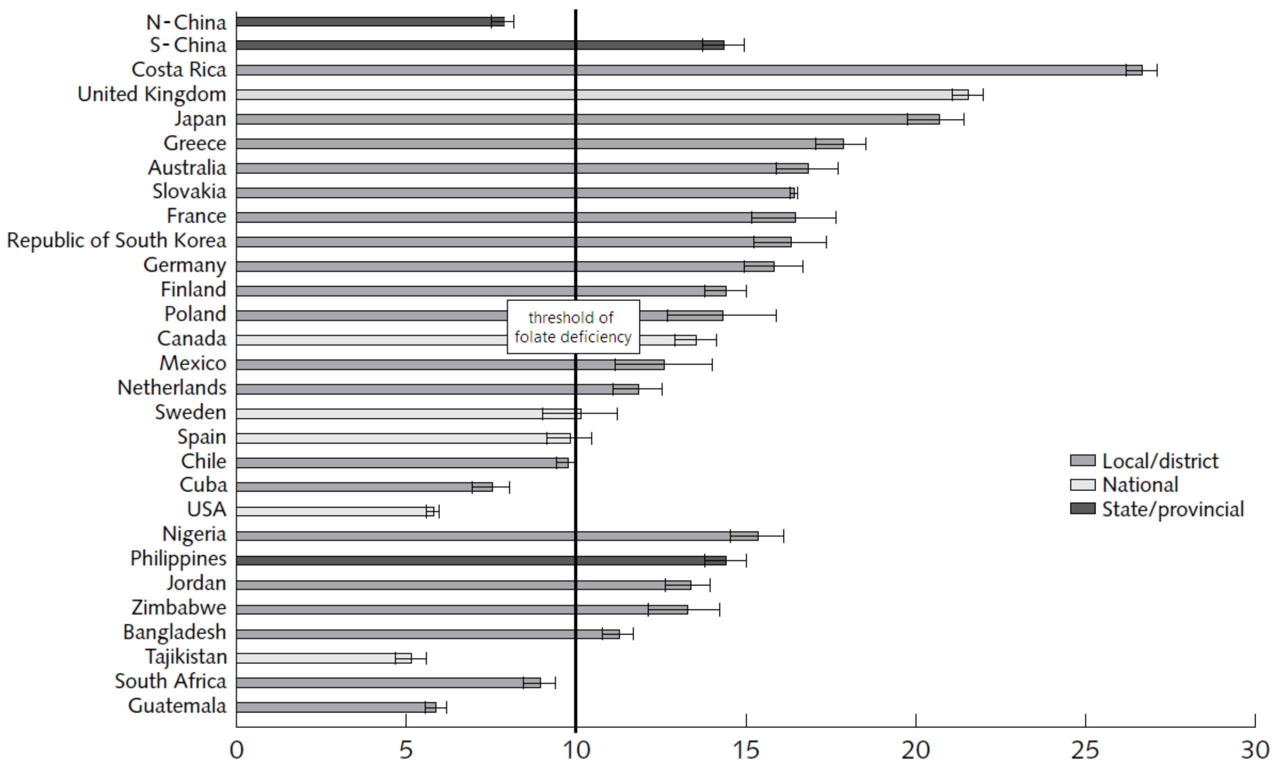


Figure 7 Folate deficiency in the world. Average plasma folate concentrations (in Nmol/L), per country

*Source*: Adapted from Mclean et al. (2008), and Hao et al. (2003) for China.
*Note*: Pre-fortification values are presented in countries with mandatory fortification programs (Canada, Chile, Costa Rica, and the United States). The solid line represents the threshold of folate deficiency, defined by a plasma folate concentration below 10 Nmol/L (De Benoist, 2008; Selhub et al., 2008). A low value indicates a high prevalence of folate deficiency.

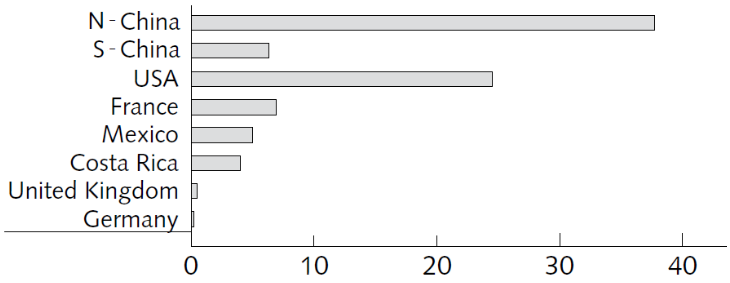


Figure 8 Folate deficiency in the world. Percentage of adults with folate deficiency, per country

*Source*: Mclean et al. (2008), and Hao et al. (2003) for China
*Note:* In countries with mandatory fortification programs, such as Costa Rica and the United States, pre-fortification values are presented.

*2.3.2.1. Folate deficiency in China*

Given the low folate content of China's main staple crop, rice, folate deficiency in China is expected to be high. However, evidence on the total number of folate deficient people in China is scarce (WHO, 2009a; Micronutrient Initiative, 2011b). Only two studies reported the folate deficiency rate in Chinese regions, spread across the country (Hao et al., 2003; Zhao et al., 2009). Other folate status and intake assessment studies in China focused on specific regions, characterized by a low NTD prevalence rate, such as in Shanghai (Shrubsole et al., 2001), Jiangsu (Li et al., 1996; Ren et al., 2007) and Anqing (Ronnenberg et al., 2000), or a high prevalence of NTDs, for instance in Shanxi (Li et al., 1996; Zhang et al., 2006; Ren et al., 2007; Zhang et al., 2008) and Beijng (Gao et al., 2003). The target group in most of these studies was limited to Chinese women of childbearing age, premarital women or pregnant women, due to their potential risk of having a baby with an NTD caused by folate deficiency.

The results of the two countrywide studies in China, i.e. a study on folate deficiency of men and women (Hao et al., 2003) versus the regional folate status of women of childbearing age (Zhao et al., 2009), are summarized in Table 6. The regional distribution of the number of folate deficient people, regardless of gender, indicates substantial disparities between Northern and Southern China. In total, about 19.6 % or 258.8 million people in China are considered to be folate deficient, of which 81.7 % is living in Northern China. Chinese men tend to be more folate deficient than women, with male folate deficiency rates 2 to 5 times higher in Northern and Southern China, respectively. Although these estimates are derived from only two Chinese studies, it cannot be neglected that folate deficiency in (Northern) China is largely prevalent.

The higher number of folate deficient people in Northern China is partly attributable to the lower availability and the limited variety of fresh vegetables, and the lower consumption of folate-rich food products (Hao et al., 2003). The dietary folate intake of people from Northern China mainly depends on their consumption of grains, while folate-rich food products, such as (green) vegetables, are the main folate sources in Southern China (Zhao et al., 2009). With respect to Han populations, the most common ethnicity in China, regional differences could be also due to the higher frequency of mutation in the MTHFR (5-methyl-tetrahydrofolate reductase) gene of Han people from Northern China, which is associated with lower folate blood levels (Ren et al., 2007).

Folate deficiency is of particular importance in one of the northern provinces in China, namely Shanxi Province. Together with the Balrampur District in India (Cherian et al., 2005)[14], this poor coal mining region has one of the highest NTD prevalence rates in the world with rates ranging between 60 and 150 NTDs per 10 000 births (Xiao, 1989; Moore et al., 1997; Dai et al., 2002; Li et al., 2006), up to an NTD rate of 199 (Gu et al., 2007). This high incidence is correlated with the high folate deficiency rates of pregnant women (43.8 %)(Ren et al., 2007) and the limited use of folic acid pills in this region (Ren et al., 2006; Li et al., 2007; Ren et al., 2007; Zhang et al., 2008) (see section 5.1.1.).

Table 6 Folate deficiency in China. Percentage of folate deficient men and women (of childbearing age), and the estimated population affected by folate deficiency in China, per region

| **Region** | **Folate deficiency rate (%)** | | | | **Population[c] (million)** |
|---|---|---|---|---|---|
| | Men[a] | Women[a] | Women of cba[b] | Total[a] | Total |
| NORTH | 51.5 | 24.1 | 20.0 | 38.0 | 211.4 |
| Northeast | / | / | 22.8 | / | / |
| Northwest | / | / | 14.5 | / | / |
| SOUTH | 11.0 | 1.9 | 1.5 | 6.2 | 47.4 |
| Southeast | / | / | 1.0 | / | / |
| Southwest | / | / | 2.0 | / | / |
| **CHINA[d]** | **28.1** | **13.3** | **9.3** | **19.6** | **258.8** |

cba, childbearing age
[a]Own calculations, based on Hao et al. (2003); [b]Zhao et al.(2009); [c]Own calculations, based on the total folate deficiency rate (column 5) and the total population size (Table 40); [d]Own calculations, means are weighted by population size

#### *2.3.2.2. Folate deficiency compared with other micronutritional deficiencies in China*

Controlling micronutrient deficiency is a major public health priority in China (Micronutrient Initiative, 2011b). China has made noteworthy progress to reduce malnutrition and is on its way to achieve the MDG target on malnutrition (see section 2.2), as compared to most of the East-Asian and Pacific region (UN, 2004; UNICEF, 2006). For instance, the underweight prevalence rate of children (<5 years) in 1990 (~19 %) was more than halved in 2002 (UNICEF, 2006). Nevertheless, it remains a serious problem for children and women of childbearing age in rural areas (MoH China; WHO; UNFPA; UNICEF, 2006). According to the FAO and UN, about 140 million Chinese people (~11 %) were undernourished at the beginning of the century (FAO, 2004b; UN, 2004). One third of diabetes and one out of ten strokes and coronary heart diseases are attributed to malnutrition of Chinese children (Popkin et al., 2001). Also micronutrient deficiencies are still largely present and account for an annual GDP loss of 2.5 to 5 billion US$ (World Bank, 2006), mainly due to iron deficiency (Haas and Brownlie, 2001; Ross et al., 2003).

[14] The NTD prevalence of this region varies between 65.7 and 82.1 NTDs per 10 000 births. Besides other regions of the Uttar Pradesh State (Sharma et al., 1994), most Indian NTD risk regions are located in the northwest, such as Rajasthan or Pondicherry (Mahadevan and Vishnu Bhat, 2005; Blencowe et al., 2010) or the southwest, like Chandigarh and Davangere (Krishnaswamy and Madhavan Nair, 2001)(see also section 5.4.4.3).

Table 7 summarizes the key indicators of folate deficiency and other micronutrient deficiencies (iron, vitamin A, iodine and zinc) in China. Although these indicators differ according to the type of micronutrient deficiency, this table benchmarks the importance of different micronutrient deficiencies in China.

Vitamin A deficiency, for instance, remains a serious health problem for Chinese preschool children and mothers, especially those living in rural areas (Shi-an et al., 2004). The average share of Vitamin A deficient preschool children varies between 12.2 % (Jingxiong et al., 2006) and 16.0 %, of which 30 500 children die from increased susceptibility to infection (UNICEF, 2004a).

With respect to zinc deficiency, estimates of people with an inadequate intake of zinc vary between 86 (Ma et al., 2007) and 183 million (Micronutrient Initiative, 2009).

Another important type of micronutrient deficiency is iron deficiency. The number of people affected by iron deficiency anemia (IDA), i.e. 208.6 million, is a reliable indicator of the importance of iron deficiency in China (Ma et al., 2007). The high IDA prevalence rate of women of childbearing age (21 %) demonstrates that China's fight against iron deficiency is still going on (Brabin et al., 2001; Shi-an et al., 2004; UNICEF, 2004a).

In comparison with important iodine deficient countries, the goiter (thyroid swelling) rate in China - the main cause of iodine deficiency - is rather low. Nevertheless, more than 425 million people in China live in areas of endemic iodine deficiency (Shi-an et al., 2004), including 24.0 million affected children (6-12 years). Iodine deficiency in pregnancy, for instance, is responsible for the annual birth of nearly 2 million Chinese babies with intellectual impairment (UNICEF, 2004a). Although recent figures reveal that most of the Chinese household consume iodized salt (93 %), several provinces still have not achieved universal salt iodization (UNICEF, 2006; Dary et al., 2009).

The only available indicator of folate deficiency is the NTD prevalence rate (see section 2.3.3), i.e. 12.2 NTDs per 10 000 births in China (Dai et al., 2002). However, the number of NTDs only covers a part of the total estimated folate deficient population, i.e. 258 million people in China.

Data on other micronutrient deficiencies in China, like thiamin (vitamin $B_1$), riboflavin (vitamin $B_2$), niacin ($B_3$), cobalamin (vitamin $B_{12}$), pyridoxine (vitamin $B_6$) and Vitamin D are not available.

Table 7 Estimations of the main micronutritional deficiencies in China

| | **Vitamin A deficiency** | **Zinc deficiency** | **Iron deficiency** | **Iodine deficiency** | **Folate deficiency** |
|---|---|---|---|---|---|
| Estimated affected population (million) | 11.4[a] (< 6 yrs) 0.4[a] (maternal) | 86.0[d] | 208.6[d] | 425[f] (living in ID areas) 24[a] (children 5-12 yrs) | 258.8[h] |
| Prevalence rate of micronutrient deficiency (indicators) | VAD 12.2 %[b] 16.0 %[c] (< 6 yrs) | Stunting 5.95 %[e] | IDA 8 % (< 5 years)[c] 21 % (women of cba)[b] | Goiter rate 5[g] to 10[c] | NTD 12.2 NTDs per 10 000 births[i] |

cba, childbearing age; VAD, Vitamin A deficiency; IDA, iron deficiency anemia; ID, Iodine deficiency; NTD, neural-tube defects
[a]Based on the 5th UN Report on the World Nutrition Situation (2004); [b]Based on a Chinese study of Jingxiong et al. (2006); [c]Based on a report of UNICEF and The Micronutrient Initiative (2004a); [d]Based on a Chinese study of Ma et al. (2007); [e]Stunting or a reduced growth rate is one of the most important indicators of zinc deficiency (Gibson et al., 2008). Stunting incidence is based on the 10-year report on nutrition status in China (Chen et al., 2004); [f]Based on a Chinese review of Shi-an et al. (2004); [g]Based on the micronutrient status in China, from MI (Micronutrient Initiative, 2011b); [h]Own calculations, see Table 6; [i]Based on Dai et al. (2002), see Table 6 and Table 40.

### 2.3.3. Neural-tube Defects

This section focuses on the most important adverse health outcome of folate deficiency, i.e. NTDs, which will be the starting point to measure the health impact of folate biofortification in China (see chapter 5).

An NTD is defined as a birth defect that occurs after a failed closure of the neural tube. NTDs are characterized by malformations of the spine (such as spina bifida), skull or brain (e.g. anencephaly; encephalocele or cranium bifidum), and are considered to be the most common congenital malformations in the world (Pinar et al., 1998). These malformations occur when the open neural tube, formed in the early stages in the development of the human embryo, fails to close around the 28th day after fertilization. As a consequence, the development of skull and/or spine is hampered (Figure 9).

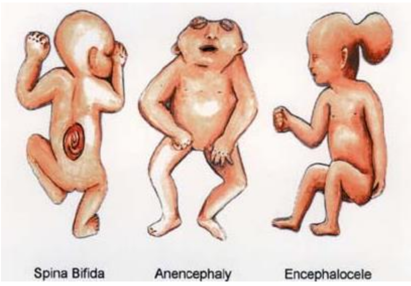


Figure 9 Main types of neural-tube defects

*Source*: The Gale Encyclopedia of Nursing and Allied Health (Krapp, 2001)
*Note:* This picture has been used during the experimental auctions when participants learned about the benefits of FBR (see section 4.3.4).

Each year, between 200 000 and 300 000 NTDs occur (UNICEF, 2004b; Christianson et al., 2006; Kondo et al., 2009). Like all birth defects, NTDs are considered a global health problem, but almost all severe or fatal defects occur in developing, low-income countries (Christianson et al., 2006). Nevertheless, NTDs are still present in the Western world (EUROCAT, 2005). Every year more than 4 500 births in the European Union are affected by a neural tube defect (Busby, 2005). In the United States the prevalence rates for the two most common NTDs, spina bifida and anencephaly, were 1.8 per 10 000 live births and 1.1 per 10 000 live births, respectively (Mathews, 2007). The lower prevalence of NTDs in the United States, about 3 000 per year, is partly based on the successful implementation of policy interventions to increase folate intake (see section 2.4).

Figure 10 gives an overview of the top 20 countries according to the estimated annual number of NTDs, which is considered as the most important indicator of the magnitude of folate deficiency. There is a significant difference in the estimated number of NTDs between the two highest ranked countries, India and China, and the other countries. When controlled for population size, African and Middle-Eastern countries are considered the most problematic.

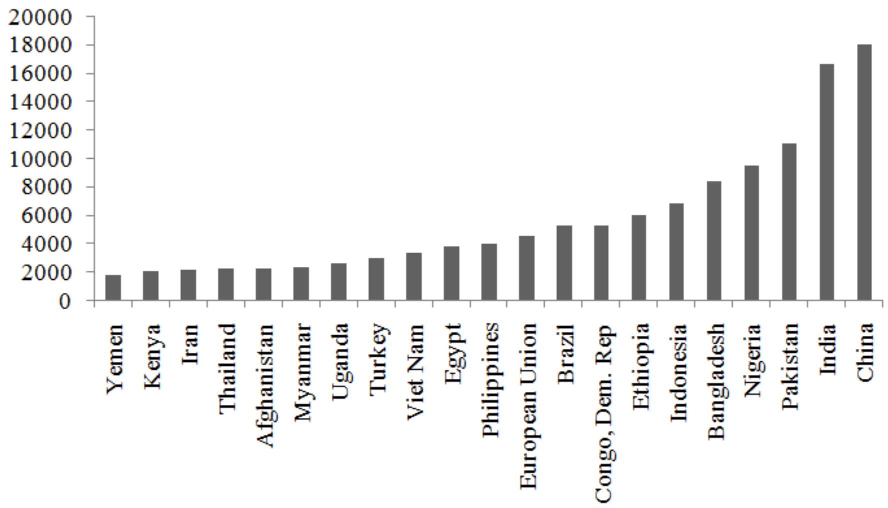


Figure 10 The estimated annual number of neural-tube defects, Top 20 countries.

*Source*: Own calculations based on UNICEF (2004b), Busby et al. (2005) for EU, Cherian et al. (2005) for India and own calculations for China (see section 5.2.1.1).
*Note:* NTD estimates of 80 (mainly developing) countries are available in the UNICEF Global Damage Assessment Report (2004b). For a global report on all birth defects, see Christianson et al. (2006). The Indian NTD figure is based on an average NTD prevalence rate of 8.8.

Approximately 18 000 NTDs are born in China each year, about 9 % of the lower global estimate. These NTDs account for one-third of stillbirths and a quarter to a third of neonatal deaths, mainly due to the high prevalence of NTDs in Northern China (Dai et al., 2002; Li et al., 2006)(see section 3.2.). With respect to Shanxi Province as a high-risk region in Northern China, the situation is even worse. Each day, an estimated number of 6.5 births is affected with an NTD[15].

The relationship between maternal folate deficiency and the risk of having a baby with an NTD is widely established in scientific literature (for a review, see Lumley et al. 2010). Worldwide, studies investigated the impact of periconceptional folate intake on the prevalence of NTDs (MRC Vitamin Study Research Group, 1991; Daly et al., 1997; Moore et al., 2003; Tamura and Picciano, 2006; De Wals et al., 2007). Given that folate deficiency refers to a daily folate intake below 400 µg, between 50 % and 70 % of all NTDs in the world are considered to be attributable to folate deficiency[16]. These global protective rates define the percentage of NTDs that can be prevented by consuming the daily recommended folate level of 400 µg. Given the increased risk of recurrence of NTD babies (MRC Vitamin Study Research Group, 1991), periconceptional folate intake recommendations for mothers at high risk are often elevated to 4 or 5 mg per day (Lumley et al., 2001; EUROCAT, 2005)[17].
In China, the North-South disparities in terms of folate deficiency (see section 2.3.2.1) determine the number of NTDs and, thus, the attribution level. Based on a folic acid supplementation study among pregnant women, Berry et al. (1999) estimated that women in Northern and Southern China are able to reduce the risk of having a baby with an NTD by 85 % and 40 %, respectively, if they achieve the daily folate recommendation. In other words, respectively 85 % and 40 % of all NTDs are attributable to folate deficiency in northern and southern regions. Although this study only investigated some of the

[15] Based on the most conservative NTD prevalence rate in Shanxi Province (see Table 54) and the demographic profile of the region (see Table 40).
[16] Other potential NTD risk factors are related to the mother, e.g. an 'NTD affected' mother, a spontaneous abortion, hyperthermia, use of anti-epileptic drugs and other medication, or the newborn, e.g. female newborns (Todoroff and Shaw, 2000; Kondo et al., 2009).
[17] 1 mg = 1 000 µg

provinces in Northern and Southern China, similar rates are found in a Chinese study of Chen et al. (2008). Therefore, the attribution levels of Berry et al. will be used to measure the current burden of folate deficiency in the health impact study (see chapter 5). Due to the Chinese one-child policy and folate biofortification as a population based strategy, the focus in this dissertation will be on the prevention of NTDs in first-births and its recommended dose of 0.4 mg.

## *2.4. Micronutrient interventions to tackle folate deficiency*

Like other micronutrient deficiencies, folate deficiency can be mainly addressed by three currently existing interventions, i.e. distributing folic acid supplements (pharmaceutical supplementation)[18], fortifying foods with folic acid (industrial fortification) and diversifying people's diets to increase the consumption of folate-rich foods (dietary diversification). Or by folate biofortification as a novel and alternative agricultural technology based approach, e.g. by which people consume folate through FBR. The common objective of these interventions is primary prevention, i.e. tackling folate deficiency as a risk factor of various diseases. While the two folic acid based interventions aim to limit folate deficiency through the increased intake of synthetic folic acid, the objective of dietary diversification and biofortification is to enhance the natural folate intake level. The former are often criticized because of the relationship between excessive folic acid intake and masking anemia caused by vitamin $B_{12}$ deficiency (Czernichow et al., 2005)(see section 2.3.1). Although the folic acid fortification policy in the United States did not cause a major increase in the number of vitamin $B_{12}$ deficient people (Mills et al., 2003), a multi-micronutrient fortification or supplementation policy to increase both folic acid and vitamin $B_{12}$ could be a partial solution (Czernichow et al., 2005; Finglas et al., 2006). Nevertheless, the debate about the adverse health effects of high folic acid intake still hampers the introduction of (mandatory) folic acid fortification in many (European) countries (Cornel et al., 2005).

Key differences between the three existing folate interventions and folate biofortification are listed in Table 8. The characteristics of each of the different policy interventions and, if applicable, its relation to the (Chinese) policy context will be discussed in the next sections. As not all interventions have been implemented in China, the experiences of folate or other nutritional programs in other countries are also drawn.

[18] Although evidence is limited, some authors also advocate to add folic acid to oral contraceptives, which increases the folate levels in blood, up to 12 weeks after it is discontinued (Cornel and De Smit, 2010).

Table 8 Current policy interventions to reduce folate deficiency and biofortification as a novel and alternative health strategy

| | Folic acid based interventions | | Folate based interventions | |
|---|---|---|---|---|
| | **Supplementation** | **Food fortification** | **Dietary diversification** | **Biofortification** |
| **Micronutrient dose** | RNI dose *(High)* | Folic acid enriched staple crops *(Low)* | Folate-rich foods *(Low)* | Folate enriched staple crops *(Low)* |
| **Potential coverage** | People taking folic acid supplements *(Narrow)* | Consumers of processed staple crops *(Wide)* | Consumers taking part in promotion/ education program *(Narrow)* | Consumers of GM[a] staple crops *(Wide)* |
| **Target group** | (Rural) risk regions *(Specific)* | (Urban) populations *(General)* | Rural risk regions *(Specific)* | Urban and rural, poor populations *(General)* |
| **Behavioral changes** | Taking pills (correctly) | None | Changing dietary habits | None, unless a product attribute is changed |
| **Examples of selected countries** | e.g. Philippines, Cambodia, & Vietnam (Cordero et al., 2008) | e.g. Australia, Ireland, UK and US (Lawrence et al., 2009) | None specifically oriented towards folate-rich foods | None[b] |

GM, genetically modified; RNI, recommended nutrient intake
*Source*: Main characteristics adapted from Stein et al. (2005a) and applied on folate or folic acid.
[a]Although biofortified staple crops could also be developed by conventional breeding techniques, folate biofortified crops are based on transgenic biofortification (see also 2.4.4.2). Therefore, the coverage rate may not be as wide as for 'conventional' biofortified crops; [b]As with other transgenic biofortified crops, folate biofortification is not commercialized. Regarding other micronutrients, only conventionally bred biofortification is implemented, see also 2.4.4.

### 2.4.1. Folic acid supplementation

Folic acid supplementation is an 'external' nutritional intervention to tackle folate deficiency in specific target groups by promoting the use of folic acid or multivitamin supplements, in addition to their diet. This intervention is categorized as either a 'pharmaceutical' or a 'dietary' supplementation intervention, depending on the circumstances to which it is consumed: respectively, prescribed and taken home or voluntarily taken. Folic acid supplementation programs mainly target vulnerable subgroups, such as women of childbearing age living in poor, rural areas. By encouraging them to consume folic acid pills daily, from the periconceptional period until approximately three months of pregnancy, the number of NTDs can be reduced. The ability to focus on specific population groups is considered both an advantage and disadvantage of this intervention. On the one hand, targeting women of childbearing age tackles folate deficiency where it is most needed. On the other hand, a population-based approach is needed, as folate deficiency is present in all sections of the population (Mclean et al., 2008).

Folic acid pills generally contain 400 µg of folic acid, which is in line with the folate recommendations (i.e. RNI). Therefore, a daily consumption of such pills is currently considered as the most effective strategy for women of childbearing age in order to prevent them against a pregnancy affected by an NTD caused by folate deficiency (Lumley et al., 2001). Besides these daily supplements, folic acid can also be given less frequently, e.g. 5 mg on a weekly basis. Although weekly supplementation could be a practical answer to the low compliance to consume folic acid supplements, evidence is needed to demonstrate that it is as effective as daily folic acid supplements (Cordero et al., 2008). Folic acid supplements can also be delivered with other micronutrients. By implementing such a multivitamin program, by which folic acid is incorporated in another vitamin supplement, e.g. iron and folic acid capsules, duplication of costs and efforts can be avoided (Klemm et al., 2009).

#### *2.4.1.1. Folic acid supplementation programs*

Effective programs were introduced in the Philippines, Cambodia, and Vietnam, where pregnant women received free daily iron and folic acid supplements and non-pregnant women were encouraged to take weekly supplements (Cavalli-Sforza et al., 2005). Due to its importance for women of childbearing age, folic acid supplementation is often promoted in countries with low rates of unplanned pregnancies, such as with countries in Europe (Cornel and De Smit, 2010). Although folic acid supplementation policies are well established in Western and Northern Europe, their effectiveness to reduce NTDs is rather limited (Busby et al., 2005; Czernichow et al., 2005; EUROCAT, 2005), partly due to incorrect use (Busby, 2005). The success of supplementation programs depends on the duration and the intensity of supplementation efforts, the accessibility and adequate supply of supplements, the effectiveness of the health system, the involvement of health personnel and/or the community, and the inclusion of a targeted educational and information component in the social marketing efforts of the program (World Bank, 1994; Hotz and Brown, 2004; Campos-Bowers and Wittenmyer, 2007; Cordero et al., 2008). However, pharmaceutical supplementation is not considered as a long-term solution to tackle folate deficiency. Previous campaigns to promote folic acid supplementation in the United States (CDC, 2005) and The Netherlands (Van Der Pal-De Bruin et al., 2003) for instance, increased knowledge about folic acid, but were less effective in stimulating the use of folic acid supplements. And if a program is effective, the increased folic acid intake is often not sustainable and decreases again once the program ceased (Underwood and Smitasiri, 1999; Lawrence et al., 2003), partly due to poor obedience and compliance of taking folic acid pills (correctly)(Ren et al., 2006).

Supplementation programs are therefore considered to be a potential (cost-)effective, but short-term strategy to improve the nutritional intake of high-risk populations, especially when these subgroups have no access to fortified products or if changing dietary patterns is not an option (WHO, 2002; Hotz and Brown, 2004), or if the rate of unplanned pregnancies is low to moderate (CDC, 2010). Furthermore, while supplementation programs can improve the intake of folic acid, they often fail to address socio-economic disparities (De Walle and De Jong-Van Den Berg, 2008).

#### *2.4.1.2. China and folic acid supplementation*

Because of the one child per family policy and the high prevalence of birth defects[19], the prevention and control of birth defects is a high priority for the Chinese government. In their “2002-2010 National

[19] In China, 6 % of the newborns are affected with a birth defect. resulting in 2 birth defects per minute (Yinan, 2007).

Action Plan for Reducing Birth Defects and Disabilities in China", the Ministry of Health (MoH) and the Chinese Disabled Person Federation (CDPF) recommend that all women of child-bearing age should obtain folic acid and health information on folic acid supplementation, in order to bring birth defects under effective control by 2010 (Chinese Ministry of Health, 2001). By the end of 2010, at least 60% of all married women who plan to be pregnant will need to achieve the daily recommendation for folate. Therefore, a national public health education campaign and a national preconception care program was launched. In 2009, for instance, the Ministry of Health and its provincial divisions set up initiatives to improve the folic acid intake of Chinese women of child-bearing age, mainly from rural areas (90 %)(Juan, 2009). The aim was to distribute free folic acid pills for 6 months to 12 million women through (biweekly) medical consultations, coordinated by regional health workers. Hereby, women with a history of NTDs received 4 µg instead of the regular 0.4 µg daily dose. Prolongation of the free folic acid supplementation support was only allowed when a woman is pregnant within the period of 6 months. In that way, this program aims to anticipate the unplanned pregnancies, which is considered an important bottleneck of folic acid supplementation interventions (Durkin et al., 2006).

Although folic acid or multivitamin supplementation programs are expected to reduce the number of NTDs, the costs of such programs are generally high (see section 5.4.4.2), while the reduction is likely to be a short term effect in China. Between 1993 and 1995 for instance, a successful folic acid supplementation intervention was conducted as a part of the public health campaign (Berry et al., 1999). This intervention reduced the number of NTDs by delivering folic acid supplements to women during their mandatory premarital health examination. However, once the program ceased, the NTD prevalence rate increased to its pre-supplementation value (Li and Hao, 2008).

Despite the previous supplementation efforts, the current intake of folic acid supplements is very low in rural areas and high-risk regions. In Shanxi Province, for example, only 10 % of women of childbearing age once used folic acid pills, regardless of their knowledge about the correct time of use (Ren et al., 2006; Li et al., 2007)[20]. The low intake of folic acid supplements in such poor, rural areas might be determined by the price of folic acid (30 pills of 400 µg folic acid is about ¥ 10 or US$ 1.5) and the limited access (Li and Hao, 2008). Low compliance of taking folic acid pills is also a consequence of the large number of unintended pregnancies in China (Singh et al., 2009). Most Chinese women in high-risk regions are not aware of the need to take folic acid supplements during the periconceptual period (Ren et al., 2006; Zeng et al., 2011). Furthermore, implementing a targeted folic acid supplementation program will be more difficult when all women of childbearing age need to be reached and continuation of the program is crucial to keep them motivated (Cordero et al., 2008). Instead of providing solely folic acid supplements, encouraging the use of multi-micronutrient supplementation or at least a combination of iron and folic acid might be a better strategy to reach high-risk groups, as previous intervention studies in rural China showed (Zeng et al., 2001; Ma et al., 2008).

[20] The low knowledge/use of folic acid supplements is also found in the Shanxi experimental auctions, of which the results are reported in chapter 4 (see, for instance, Table 34): about 17.5 % of the female participants stated to have used folic acid once. However, only four persons indicated to use it before and during pregnancy. Moreover, only 1 out 5 women of the auctions indicated that they know the national birth defect program.

## 2.4.2. Folic acid food fortification

While folic acid supplementation targets a specific population group, (industrial) folic acid fortification, i.e. adding folic acid directly to staple crops during the first stage of milling, is currently considered the most (cost-)effective population-based strategy to fight folate deficiency without altering dietary habits (Wallich et al., 2001; Hardjanti, 2005; Finglas et al., 2006). In line with multivitamin supplementation, folic acid can also be added to existing fortified foods, which has been successfully demonstrated in Costa Rica (Chen and Rivera, 2004). Nevertheless, this long-term strategy can only increase vitamin intake of consumers who purchase and consume centrally processed foods. As these are often not the ones that need it the most, i.e. the poor, deficient people from rural regions, who regularly cultivate crops themselves, effectiveness of this intervention may be hampered and limited to middle- and upper-income class consumers, which urges the need for public education (Hotz and Brown, 2004). Furthermore, as successful folic acid fortification requires specialized infrastructure (i.e. few large mills with fortification equipment), strict quality control and capital, strong partnerships between public and private sectors, it is less feasible in developing countries and regions that are characterized by large micronutrient deficiencies and a segmented milling sector (Mason et al., 1999; Underwood, 2000; Mannar, 2001; Durkin et al., 2006; Campos-Bowers and Wittenmyer, 2007; Cordero et al., 2008). Also the public concern that mainly stems from the largely unknown effects and potential risk of excessive nutritional intake levels might be a constraint (Allen, 2006). In any case, the selection of an appropriate food vehicle will be crucial to the success of food fortification (Baltussen et al., 2004).

### *2.4.2.1. Folic acid food fortification programs*

Historically, food fortification interventions have been used for three reasons: restoring (micro)nutritional levels of foods that are affected by food processing, replacing nutrients in substitute foods and improving (micro)nutrients in staple foods to counter malnutrition (Allen, 2006). In 2005, about 38 mainly industrialized countries had opted for a mandatory folic acid fortification policy (Czernichow et al., 2005). In the United States (Choumenkovitch et al., 2002; Quinlivan and Gregory, 2003; Rader and Schneeman, 2006) and Canada (De Wals et al., 2007; Shakur et al., 2010), for example, cereal grain products were fortified with folic acid to a level of 140 and 150 µg per 100 g, respectively, and proved to successfully enhance folate status. Other countries focused their mandatory folic acid fortification policy on one, e.g. wheat flour in Chile (Hertrampf et al., 2003) and Australia (Oakley et al., 2004), or more food vehicles, e.g. wheat flour, maize flour, milk and rice in Costa Rica (Chen and Rivera, 2004). As expected, these mandatory fortification programs led to folic acid consumption levels above the recommended nutrient intake (RNI)(Cordero et al., 2008; Dary et al., 2009; CDC, 2010), especially in developed countries (FAO/ILSI, 1997; Hotz and Brown, 2004). In the United States, for instance, the folate intake requirements for most adults were met or exceeded, by which the number of NTDs decreased from 4 000 to 3 000 NTD affected pregnancies in a few years (CDC, 2004). In (Eastern) Europe, most countries have started to embrace voluntarily folic acid fortified foods (Abramsky et al., 2007; FFI, 2011). In some cases, such as in Ireland and in the UK, the introduction of mandatory folic acid fortification of bread has been advocated (SACN, 2005) and, despite the rising concerns about potential adverse health effects of high folic acid intake levels (Smith et al., 2008; BBC News, 2009, October 20)(see section 2.3.1), implemented. These concerns were also heard in the United States (CDC, 2010) when a recently published study concluded that 2.7% of the adults exceeded the tolerable upper level (UL) of 1 000 µg folic acid per day (Yang et al., 2010).

#### *2.4.2.2. China and folic acid fortification*

In 2003, the flour fortification pilot program “Flour Fortification in the Western Region of China” was initiated by the State Grain Bureau and the Chinese Ministry of Health (FFI, 2009; Lawrence et al., 2009). With the support of the Global Alliance for Improved Nutrition (GAIN), a market-based, voluntary fortification program was introduced, with a folic acid fortification level of 200 µg per 100 g. This resulted in the production of fortified flour, often known as “7+1 flour”, in a few companies. However, due to delays in implementation, this project came to an end in 2008.

Between 2006 and 2007, folic acid fortified flour was introduced to more than 60 000 consumers in Shanxi Province, as a part of the “Strong Newborn” project (FFI, 2009). The objective of this program was to evaluate the effect of flour fortification in the prevention of NTDs. Although the findings indicate a positive effect, there were significant problems to guarantee the quality of fortified flour and to obtain funding in order to start a province-wide implementation.

In 2008, the Chinese Public Nutrition and Development Center (PNDC) developed a voluntary flour fortification standard, which was released by the State Grain Authority (SGA)(FFI, 2009; WHO et al., 2009). However, at present, very little flour is voluntary fortified in China (about 1 %; FFI, 2009). Given the limited access to voluntary folic acid fortified foods in China, the main challenge will be to guarantee that the fortified food vehicle will actually (continue to) reach the Chinese consumer, especially in the rural regions of China. As policy makers have still concerns on the feasibility of folic acid fortification in China, the Chinese Ministry of Health (MoH) intends to undertake additional flour and rice fortification trials in the future (Li and Hao, 2008; FFI, 2009; PNDC, 2011). Nevertheless, the actual implementation of provincial flour fortification in the market will depend largely on provincial authorities’ interest and commitment.

While folic acid fortification is still a marginal phenomenon in China, other fortification programs are more advanced. While the introduction of iodized salt proved to protect 133 million Chinese infants from iodine related brain damage (UNICEF, 2006), large scale programs on iron fortified wheat flour and soy sauce hold the promise to be effective (Chunming, 2001; ADB, 2004a; Dary et al., 2009; GAIN, 2011)(see also section 5.4.4.2). For example, the Ministry of Health’s Centers for Disease Control and the China Soy Sauce Manufacturers Association have agreed to promote fortified soy sauce through a 5-year collaborative plan to engage 200 major producers (ADB, 2004a). Regarding folic acid fortification of rice in China, the different bottlenecks are discussed in section 5.4.4.2.

### 2.4.3. Dietary diversification

Dietary diversification aims to modify the dietary patterns of consumers through interventions that promote the consumption or production of micronutrient-rich foods, e.g. home gardening, as well as nutrition education, e.g. teaching consumers to retain micronutrients during processing. Previous food-based strategies focused mainly on the reduction of Vitamin A or iron deficiencies (Soleri et al., 1991; Ruel, 2001). Although this strategy is considered to be the most sustainable solution, especially when targeting several micronutrients simultaneously (FAO/ILSI, 1997; Hotz and Brown, 2004), they are less successful in practice due to the need of making the micronutrient rich products accessible, affordable, and more attractive to consumers (CDC, 2010).

There are currently no scientific reports of population-based interventions which promoted a folate-rich diet, e.g. green leafy vegetables and orange-fleshed fruits (Cordero et al., 2008). While a vegetarian eating pattern, characterized by long-term high consumption of vegetables, positively affects the folate intake (Koebnick et al., 2001), dietary folate interventions would not necessarily be effective to address folate deficiency as such food-based strategies rely on food varieties that are already available in the market (Cuskelly et al., 1996). Due to the limited availability and consumption of folate-rich products in Northern China, it will be difficult to alter the eating behaviors in this high NTD risk region (Hao et al., 2003; Zhao et al., 2009). But also in the poor rural areas throughout China, where folate-poor staple crops are the mainstay of the diet, increasing the production or consumption of folate-rich food products is practically, economically and culturally less feasible than other pro-poor interventions, such as folate biofortification (see section 2.4.4.).

If folate interventions primarily aim to improve the situation for the poor, rural populations, one could also argue that initiatives to reduce poverty and strengthening health care systems could be as effective as dietary interventions. However, this is not necessarily the case, as improving income levels in developing regions did not necessarily lead to an increased demand for micronutrient-rich foods (ADB, 2004b).

### 2.4.4. Folate biofortification of rice as a new, potential strategy

#### *2.4.4.1. Biofortification*

Biofortification is considered a novel strategy to combat the 'hidden hunger', by which the nutritional content of staple crops is enhanced. By sharing the advantages of fortification (e.g. wide coverage) and addressing the limitations of supplementation (e.g. short term strategy, limited coverage, compliance of taking pills), it is intended to be a pro-rural and pro-poor health intervention (see Table 8). According to Welch (2004), agricultural approaches are a prerequisite to sustainably control micronutrient malnutrition. Biofortification is considered an agriculture-based approach as it uses the regular food chain and goes beyond fortification, because the crops are fortifying themselves (Stein, 2006; Johns and Eyzaguirre, 2007) [21]. Contrary to dietary diversification and supplementation, biofortification uses staple food crops as its food vehicle, by which behavioral changes are unlikely to be required. As a consequence, biofortification is self-targeting: besides the whole population, it especially addresses the groups at risk that need to benefit the most from the biofortified crops (Bouis, 2002). In that way, biofortification can be a complementary policy intervention by fighting micronutrient malnutrition where other interventions fail to do so.

Due to the relatively low costs of biofortified crops, e.g. a one-time investment in R&D and the ability of farmers to reproduce their biofortified crop seeds, the cost-effectiveness of biofortified crops is often argued as one of the main arguments in favor of this strategy (Bouis, 2002; Stein, 2006; Meenakshi et al., 2007)(further elaborated in chapter 5). Whereas supplementation and fortification were the two key strategies to control micronutrient malnutrition in the past, biofortification receives more and more attention (Micronutrient Initiative, 2009). During the 2008 Copenhagen Consensus, where a panel of economists evaluated the top priorities to counter the world biggest challenges, biofortification was placed fifth (Horton et al., 2008).

Before biofortification, efforts to improve crop content were mainly focusing on agronomic traits, such as increasing yield potential and productivity, drought resistance and pest resistance, which primarily benefit the farmer. As these developments were based on two different techniques, conventional versus transgenic technology (i.e. using biotechnology in agriculture), they marked the Green and Gene Revolution, respectively (Underwood, 2000; Pingali and Raney, 2005; Stein, 2006; Mayer et al., 2008)[22]. Conventional or transgenic biofortification has to be seen as the next phase of these two

[21] Not to confuse with the research initiatives to improve the crop efficiency in the uptake of trace minerals (zinc, iron) from deficient soils, which resulted in higher yields, but not necessarily improved the mineral concentrations in the grain (Brooks, 2010). Nevertheless, as about 50 % of the arable land for crop production in China is micronutritional deficient, this type of biofortification might be another interesting pathway for future research (Campos-Bowers and Wittenmyer, 2007).

[22] The Green Revolution refers to a broad public sector led transformation of agricultural sectors in developing countries, mainly between the 1960s and 1980s, which focused on developing high yielding staple crop varieties (wheat, rice), promoting the utilization of hybridized seeds, pesticides (insecticides) and fertilizers, and providing agricultural extension in order to reduce food shortages and hunger and stimulate overall development (Brooks, 2010). Nobel Peace Prize winner Norman Borlaug is seen as the founding father of this breakthrough in crop development. In the last decennium of the 20th century, a novel private led agricultural revolution took place, the Gene (biotech) Revolution, which built upon the previous revolution by implementing GM technology in agriculture to improve productivity and, thereby, reduce hunger.

The history of biofortification followed a similar approach, starting with the introduction of conventionally bred nutritionally enriched products in the 2000s, and now making progress to commercialize the 'gene revolution' in biofortification through private-public partnerships. In other words, what the two revolutions meant for agricultural productivity and hunger, biofortification hopes to achieve in the field of malnutrition or hidden hunger. Next to this tendency, some people argue the need for an 'evergreen' revolution, which combines the economic viability of the Green revolution with a need for ecological sustainability, while improving awareness and knowledge (Seshia and Scoones, 2003).

revolutions, where improving the micronutrient content of the crop is the targeted 'trait'. In this respect, FBR is based on transgenic technology and is therefore considered as a GM food product (see section 2.4.4.2). Such transgenic biofortified crops belong to the 2nd generation of GM crops, which are primarily designed to benefit the consumer by improving quality traits, such as nutritional and sensory properties. This generation followed the 1st generation of GM products (Gene Revolution, started in 1990s), which dealt with improvements of agronomic traits, such as insect resistance and herbicide tolerance. In other words, the shift from first to second generation involves a shift from producer-friendly to consumer-friendly genetic modification (Engel et al., 2002)[23]. An overview of the consumer and farmer benefits of first and second generation GM food products is described in Toenniessen et al. (2003) and Lönnerdal (2003), respectively.

Biofortification research was accelerated when the international, multidisciplinary HarvestPlus (Biofortification Challenge) program was launched in 2004 by the Consultative Group on International Agricultural Research (CGIAR) and the International Food Policy Research Institute (IFPRI) (HarvestPlus, 2009; Brooks, 2010). It became the key project in development and dissemination of biofortified crops, with an emphasis on iron, zinc and vitamin A deficiencies in Africa and Asia. Initially, only conventional biofortified crops were explored, until the development of Golden rice as the first biofortified staple crop genetically engineered to tackle Vitamin A deficiency in 1999 (Beyer et al., 2002; Potrykus, 2008). This was the starting point of the humanitarian HarvestPlus supported 'Golden Rice project' (HUMBO, 2011b).
While Africa and Asia fall within the scope of HarvestPlus, AgroSalud coordinates the biofortification efforts in Latin America and the Caribbean (LAC), and aims to increase the iron and zinc content of beans, rice, maize, and sweet potatoes, and develops yellow maize and orange-fleshed sweet potato with higher beta-carotene contents (CIAT, 2004; Agrosalud, 2011a). Between 2007 and 2010, AgroSalud introduced 42 biofortified cultivars in 13 LAC countries (Agrosalud, 2011b). Depending on each country's policy, the seeds are sold at full or subsidized price, or given for free to farmers.

The global status of biofortified staple crops, developed and/or released by HarvestPlus or AgroSalud, is shown in Table 9. To date, only conventionally bred biofortified staple crops, such as vitamin A enriched sweet potatoes, iron biofortified beans and rice, and maize with higher vitamin B3 content, are released. Also the future releases will be mainly dominated by conventional breeding techniques, such as vitamin A biofortified cassava and maize, and wheat, rice and beans with higher zinc and iron levels. However, the progress of Golden Rice or vitamin A biofortified rice shows that transgenic biofortified staple crops are in the pipeline of approval. Also other crops, like banana, barley, cowpeas, groundnuts, lentils, pigeon peas, potatoes and sorghum, are expected to become the subject of biofortification (Stein, 2006). A more exhaustive overview of biofortified products, including strawberries (vitamin C), maize and canola (vitamin E), potatoes and mustard (beta-carotene), carrots (calcium), lettuce (iron) is available in Hirschi (2009) and Johns and Eyzaguirre (2007). In China, only

[23] Others refer to a shift from input to output traits (GMO EFSA, 2008). There is also a third generation of GM crops, where products are developed to be used as industrial or pharmaceutical products. Among the examples are vaccines or biodegradable plastics. In this case, regulatory issues are even more stringent then for crops from the preceding generations (Naranjo, 2008).

the conventional biofortified zinc enriched wheat (“Jingdong 8”) is commercialized, but at a very small-scale. Vitamin A fortified sweet potatoes will be disseminated in the near future (Sun Hui, HarvestPlus China, personal communication, 20-04-2011). Nevertheless, 16 crop varieties/lines are developed, of which 4 have been approved for advanced testing.

Table 9 A brief overview of the currently biofortified products in the world, developed by HarvestPlus or Agrosalud, according to the improved micronutrient, applied technology, target area of first release and (expected) release year.

| **Micronutrient** | **Product** | **Applied technology** | **Target Area[c]** | **Release year (# cultivars released)** | **Expected release year** |
|---|---|---|---|---|---|
| Vitamin A (Beta-carotene)[a] | Cassava | CB | DR Congo and Nigeria | | 2011-2012 |
| | Maize | CB | Zambia | | 2012 |
| | Sweet Potato | CB | Uganda and Mozambique | 2007 | |
| | | | Brazil, Cuba, Dominican Republic, Haiti and Peru | 2009-2010 (8) | |
| | Rice | TB | Philippines, Bangladesh, India | | 2012, 2013, 2014[e] |
| Iron | Pearl Millet | CB | India | | 2012 |
| | Rice | CB | Bolivia, Cuba and Panama | 2009-2010 (8) | |
| | | | Brazil, Colombia, Nicaragua and Dominican Republic | | 2011 |
| | Bean | CB | Bolivia, Brazil, Cuba and Guatemala | 2008-2010 (5) | |
| | | | Colombia, Costa Rica, El Salvador, Honduras and Nicaragua | | 2011 |
| Iron, Zinc | Wheat | CB | India and Pakistan | | 2013 |
| | Bean | CB | DR Congo and Rwanda | | 2011-2012 |
| | Rice | CB | India, Bangladesh | | 2013 |
| Vitamin B3 (Niancin)[b] | Maize | CB | Bolivia, Colombia, El Salvador, Guatemala, Haiti, Honduras, Mexico, Nicaragua and Panama | 2008-2010 (21) | |
| *Folate* | *Rice* | *TB* | *China[d]* | | *ND[d]* |

ND, No data

*Source*: Own compilation, based on Agrosalud (2011b) for Latin America and the Carribean, and HarvestPlus (2009) for Asia and Africa, except for Vitamin A enriched rice (HUMBO, 2011b) and FBR (Storozhenko et al., 2007).

[a]The human body converts beta-carotene or provitamin A into vitamin A; [b]Niancin or Vitamin $B_3$ is an essential nutrient which is mainly lacking in maize consuming populations (IOM, 1998a). Niancin is available in different foods, but can also be made in the human body through tryptophan, i.e. an amino acid that is improved by biofortification; [c]These are the selected countries where the biofortified crops are released or expected to be tested and released. However, after the first release, these crops are intended to benefit also other countries characterized by similar micronutrient deficiencies; [d]Because these crops are still in a development phase, it is too early to select a target country and a release date. Nevertheless, the remainder of this PhD will focus on the market potential of FBR in China; [e]Although the transgenic Golden Rice was expected to be released in 2011 (ISAAA, 2007), field tests and biosafety regulations are still ongoing in the Philippines (Tony Alfonso, PhilRice, personal communication, 05-02-2011). The GR trait was also bred into rice varieties in, for example, India, Vietnam, Bangladesh and Indonesia.

*2.4.4.2. Folate biofortified rice as a 2nd generation genetically modified crop*

Folate biofortification, the enhancement of folate in staple food crops, can improve the folate intake of malnourished rural populations that are unlikely to benefit from folic acid supplementation or fortification. Currently, rice with high folate content, developed by metabolic engineering, is the most advanced folate biofortified staple crop (Bekaert et al., 2008; Blancquaert et al., 2010)[24]. Storozhenko et al. (2007) obtained different transgenic lines with a natural folate content ranging from 350 to 1 700 µg per 100 g of raw polished rice grains. These figures are 20 to 100 times higher than normal folate levels in rice (USDA, 2008). Folate in food is subject to additional losses due to the processing methods, such as cooking (Scott et al., 2000), and its bioavailability degree (50 %) is significantly lower than in folic acid fortified foods (85 %) or supplements (100 %) (Bailey, 2004; FSAI, 2006). The selection of rice as the food vehicle for biofortification is in line with the technical considerations of fortification, i.e. using an inexpensive, country-wide staple crops, as postulated by the Asian Development Bank (Mason et al., 1999; Mannar, 2001).

Even though there is a clear potential to use conventional plant breeding techniques to increase the folate content of rice, similar to conventional biofortification developments in maize, wheat, beans, cassava and rice (Bouis, 2002), it may be hard to reach the same level of enhancement as in transgenic techniques, because of the low intrinsic folate concentrations in natural rice varieties (Rébeillé et al., 2006; Bekaert et al., 2008). Therefore, folate enriched rice in this study is seen as a transgenic biofortified staple crop or a GM rice variant of the 2nd generation.

As such, folate biofortification of China's and the world's main staple crop is considered as an alternative and complementary approach to the above mentioned strategies, especially in poor, rural regions where other interventions are less successful or feasible. First of all, unlike folic acid fortification or supplementation, folate biofortification does not rely on industrial food processing, specialized distribution channels or accessible health systems. Although fortification is often promoted as the primary option to reduce micronutrient deficiencies (Micronutrient Initiative, 2004), the key target group of this intervention rarely consumes processed foods suitable for fortification (ADB, 2004b). In addition, folic acid supplementation programs were less successful in risk-regions of China (see section 2.4.1.2). Second, given the technical and practical difficulties it will be hard to successfully implement folic acid fortified rice (see section 5.4.4.2). Third, biofortification uses staple crops as its food vehicle and, therefore, can easily target the folate deficient subgroups, without the need to administer pills or to promote the consumption of, generally more expensive, folate-rich foods. Furthermore, industrial fortified foods and supplements are often only available in cities and hence cannot reach the poor rural populations. Fourth, possible negative side effects of folic acid fortification, such as masking Vitamin $B_{12}$ deficiency and the increased risk of colorectal cancer, are less likely to occur with folate biofortification (see section 2.3.1).

[24] An overview of the typical steps in the development process of transgenic biofortified crops, e.g. efficacy testing, elite event selection and trait integration, is available in Dubock (2008). For a detailed discussion on the technological issues regarding folate biofortification of food plants (DellaPenna, 2007; Bekaert et al., 2008), rice (Storozhenko et al., 2007), wheat (McIntosh et al., 2008) and tomatoes (Diaz de la Garza et al., 2007).

*2.4.4.3. From folate biofortified rice towards multi-biofortified rice*

Despite the large potential of FBR, one could argue that the large prevalence of multiple micronutrient deficiencies (see section 2.2) and the generally low micronutritional content of rice require a combined biofortification strategy. In other words, there is a need to increase the intake of different micronutrients simultaneously through nutritionally complete crops. This is where multi-biofortification enters the public health debate. By enhancing different vitamins and minerals, through conventional or transgenic technology, multi-biofortification could address micronutrient malnutrition more adequately and efficiently. Despite several ongoing initiatives that attempt to develop multi-biofortified crops, especially those that were or are supported by the Bill & Melinda Gates Foundation under the Grand Challenges in Global Health Initiative, such as rice, sorghum, cassava and banana (Qaim et al., 2007; B&M Gates Foundation, 2009), evidence of a developed staple crop which stacks different nutrient traits is scarce. Recently, Naqvi et al. (2009) published the development of the first transgenic multi-biofortified crop, i.e. maize enriched with vitamin A, vitamin C and folate. However, these technologies are still in the research pipeline, and little is known about their potential from a public health and economics perspective.

Targeting different micronutrient deficiencies at once is a strategy which is also found in other policy interventions, such as pharmaceutical multi-vitamin supplementation, e.g. iron-folic acid multivitamin pills in India (Micronutrient Initiative, 2006) and other Asian countries (Sanghvi et al., 2010), multi-micronutrient food fortification, e.g. fortifying grain with folic acid, Vitamin $B_{12}$ and several minerals (Alavi et al., 2008), and dietary diversification.

In chapter 5, I explore the potential health benefits and cost-effectiveness of multi-biofortification of rice (MBR). This crop is enriched with beta-carotene (pro-vitamin A), zinc and iron, in addition to folate, in order to address the main micronutrient deficiencies in China (see Table 7).

The development of multi-biofortified crops may occur in two ways. The different micronutrient traits could be combined in one gene construct ('single insertion') and be transferred such that a new stacked event is generated.[25] Such gene stacking was successfully done for transgenic crops with modified agronomic characteristics, combining insect-resistance and herbicide-tolerance traits (James, 2009b). Alternatively, each micronutrient trait could be developed and deregulated independently, and then the four traits could be combined later on through backcrossing. The 'single insertion' approach may have advantages from a cost perspective (Storozhenko et al., 2007; Blancquaert et al., 2010). Due to high regulatory hurdles, the time and money required for the testing and approval of each new transformation event are extremely high (Miller, 2010), so that significant resources could potentially be saved when dealing with one stacked rather than multiple single trait events. In practice, however, the four traits were currently being developed independently by different research institutes, so that the single trait approach with later backcrossing seems to be the more realistic avenue in the short run.

[25] One could stack the transgenic provitamin A and folate traits and add the conventional iron and zinc traits through backcrossing. On the other hand, iron and zinc contents may also be further increased though transgenic approaches (Vasconcelos et al., 2003), so that eventually all four traits could be stacked in one gene construct. However, increasing zinc and iron levels through genetic modification was not always successful (Ghandilyan et al., 2006; Cakmak, 2008).

## *2.5. The status of genetic modification & biofortification in China*

The global commercialization of GM crops is an asynchronous process, where a few developed countries are leading the way, apart from the marginal involvement of Europe, and where the large GM food producers are more and more outnumbered by the poor farmers that introduce biotechnology in their small-scale farms (Stein and Rodríguez-Cerezo, 2009). Albeit the dominance of North and South America, the developing world, among which Africa and South-East Asia, is increasingly involved (Karembu et al., 2009).

Worldwide, the global area of biotech crops amount to 148 million ha., of which maize, cotton, canola (rapeseed) and soybeans were the most important crops (Figure 11). These GM crops are characterized by an improved agronomic trait, such as herbicide tolerance, virus and insect resistance, an extended shelf life or a delayed ripening process, or a combination of these characteristics, the so-called stacked traits. It is important to note that these traits only refer to the 1$^{st}$ generation of GM crops. Biofortified, 2$^{nd}$ generation GM varieties are not commercialized yet (see section 2.4.4.1).
The global agricultural sector of GM crops is traditionally dominated by the US (45.1 %), followed by Brazil (17.2 %), Argentina (15.5 %), India (6.4 %) and Canada (6.0%). Together with China, which produced 3.5 million ha. of GM biotech crops in 2010, these countries were the protagonists of the global commercialization of biotech crops, which started in 1996 (James, 2010).

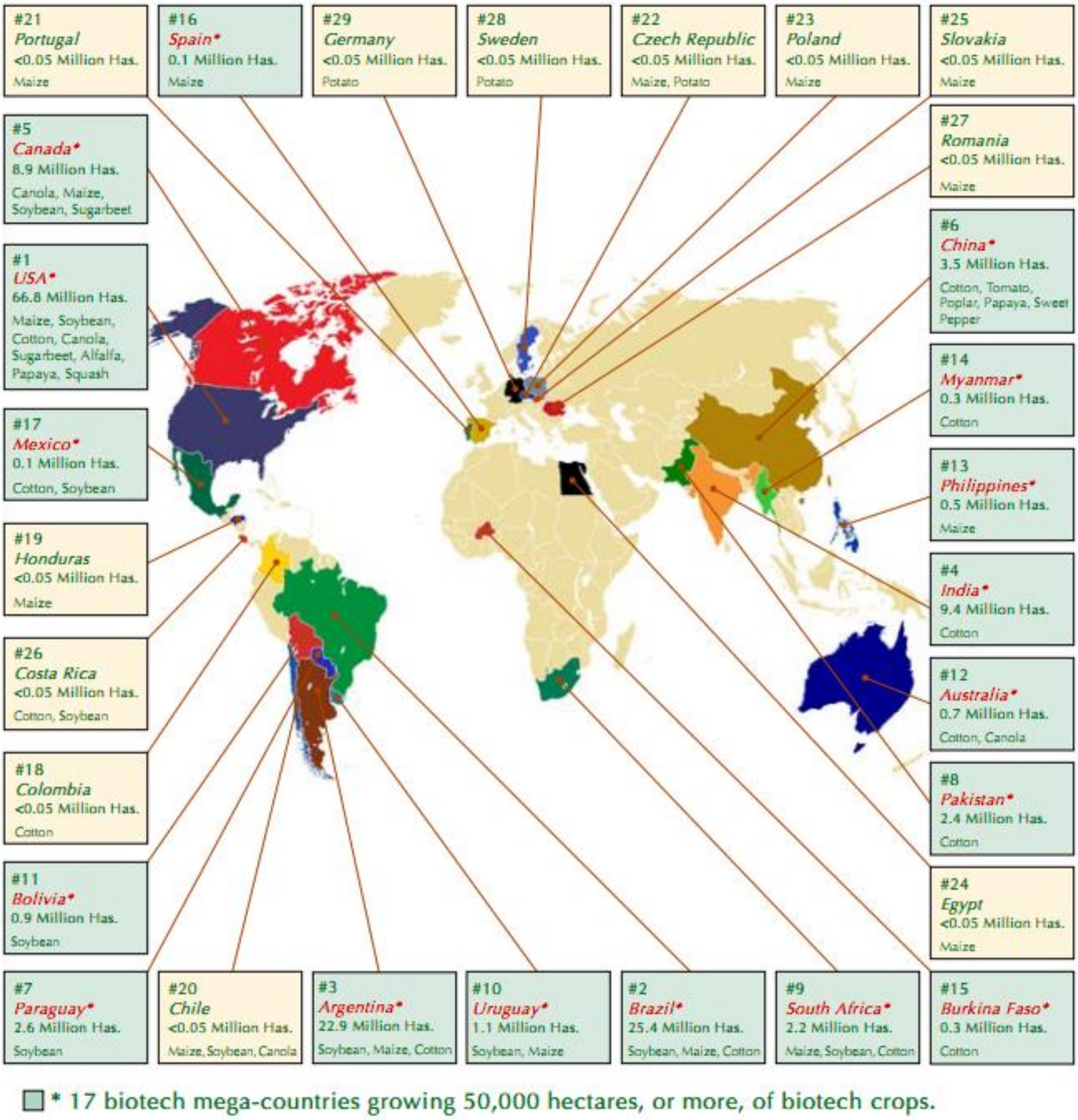


Figure 11 Overview of commercialized genetically modified crops in China and the world

*Source:* Figure based on the ISAAA 2010 global status report (James, 2010)
*Note: A country in a green box, marked with an asterisk (*), is considered to be one of the 17 biotech mega-countries, which grow 50 000 hectares, or more, of biotech crops.*

After the approval of Bt Cotton in 1997, China became the biggest producer of this insect-resistant crop. At least seven million small, subsistence Chinese farmers grew one of the 64 Bt cotton varieties in 2009, which successfully led to higher yields, lower production costs and diminished use of insecticides in China (Huang et al., 2002; Rozelle et al., 2006). Two types of cotton are commercially produced, one from the Chinese Academy of Sciences, the other from Monsanto. Since then, eight different GM crop varieties were approved and/or cultivated in China, such as sweet peppers, papayas and tomatoes that have been modified to be insect- or virus-resistant, herbicide-tolerant, to increase shelf life or to improve the appearance (Table 10). Three GM crops are currently imported to China: rapeseed, maize and soybeans. Their modified product characteristics aim to make either the plant resistant against insects (pests) or tolerant of herbicides. Despite the limited approval rate of commercialized GM crops in China, 1044 GM applications were submitted in 2005, of which more than 100 varieties were approved for advanced testing (Pray et al., 2006; Wang and Johnston, 2007a).

Table 10 Status of key GM crops in China, per biotech crop, by year of approval and improved trait.

| Status | Biotech crop | Approval year | Trait |
|---|---|---|---|
| Approved | Rice | 2009[a] | Insect-resistant (Bt) |
| | Maize | | Phytase-rich[c] |
| Produced | Cotton | 1997 | Insect-resistant (Bt) and herbicide-tolerant |
| | Petunia | 1997 | Modified flower color |
| | Tomato | 1997; 1998 | Virus resistant; Delayed ripening |
| | Sweet pepper | 1998 | Virus resistant |
| | Poplar trees | 2003 | Insect-resistant (Bt) |
| | Papaya | 2006 | Virus-resistant |
| Imported | Rapeseed[b] | 2004 | Herbicide-tolerant |
| | Maize | 2004; 2005 | Insect-resistant (Bt) and/or herbicide-tolerant |
| | Soybean | 2004; 2008 | Herbicide-tolerant |

*Source*: Own compilation, based on James (2009b), Huang (2004), Biosafety clearing house of China (2004) and Elisa Zhang (ISAAA ChinaBIC, personal communication, 30-05-2011)
*Note:* Approval does not necessarily imply commercialization (e.g. Bt rice in China, see section 6.5.2)
[a]The own production of GM rice and GM maize is now under the procedure of variety registration; [b]Argentine canola; [c]Phytase maize is generally used as feed for poultry and chickens. It influences the digestion and growth of the animals, by which the meat production can be optimized.

China's world leading position in terms of R&D and commercialization of GM crops is further reflected in its large and increasing investments. Between 2001-2005, for instance, almost 120 million US dollars were made available for public-sector R&D regarding transgenic rice (Jia et al., 2004), making China the biggest investor in rice biotechnology (Wang and Johnston, 2007a). The positive government position on GM rice (research) are closely related to its large domestic consumer market, which allows testing of GM food products on a substantial scale, without jeopardizing the smaller rice exports (Glover, 2003). In 2008, nearly ¥ 30 billion (US$ 4.6 billion) is allocated to a key GM crop research project over 15 years (Jiao, 2011). One of the main reasons for these funding decisions is China's traditional strategy of self-sufficiency, where the government seeks ways to avoid or at least minimize the dependence on other countries (Huang et al., 2003; Wang and Johnston, 2007b; James, 2009b). According to Stone (2008), this will lead to a "transgenic green revolution" by which China's food supply is secured and the competition to identify and patent plant genes is strengthened. As a consequence, Chinese research institutions are more and more setting up collaborations with foreign biotech oriented companies, such as Monsanto (2009) and Bayer Crop Science (2008, 2009), who seek to grasp the opportunities this country offers as one of the rising governmental supported biotech areas[26].

Although genetic modification remains a subject of discussion, both in political and research forums, the widespread adoption of (transgenic) biofortified food crops in China is likely to happen. Given the traditional support of the Chinese government, research on biofortification of staple crops became increasingly important for China's food security policy, especially after China's entry into the World

[26] Other initiatives include the Green super rice Project, funded by The Bill and Melinda Gates Foundation, which builds upon the Green revolution to develop, refine and promote a rice variant which combines more than 250 rice (hybrid) varieties (CAAS, 2011).

Trade Organization (WTO) in 2001 (Campos-Bowers and Wittenmyer, 2007; Pray and Huang, 2007). In 2004, for instance, the HarvestPlus China Program (HarvestPlus China, 2009, 2011), initiated eight research projects related to the development of biofortified maize, wheat, sweet potato and rice in China, in order to address specific deficiencies of micronutrients, such as iron or vitamin A (Bouis and McClafferty, 2008).

Nevertheless, no transgenic staple feed or feed crop was approved in China, until recently, when China's Ministry of Agriculture (MoA) granted two biosafety certificates and approved phytase maize, i.e. a feed crop, and pest-resistant Bt rice, i.e. a food crop (Shuping and Miles, 2009; Waltz, 2010)(See also Table 10). This is considered the final regulatory check and is expected to lead to full commercialization of these major transgenic crops in the near future. As a consequence, China will be the first to introduce a troika of key transgenic crops into the market place, i.e. Bt cotton (fiber), phytase maize (feed) and Bt rice (food) (James, 2009a, b)[27]. The approval and deployment of the latter might lead to the approval of many other transgenic food crops, including biofortified staple crops. Dr Clive James, founder of the International Service of the Acquisition of Agri-biotech Applications (ISAAA) formulates it as follows: *"The approval by China of the first major biotech food crop, Bt rice, can be the unique global catalyst for both the public and private sectors from developing and industrial countries to work together in a global initiative towards the noble goal of food for all and self sufficiency"* (James, 2009a, p. 2). As China is one of the key players in terms of producing and consuming rice, as well as GM rice research (Huang et al., 2004; Jia et al., 2004; Xiong, 2004; Wang and Johnston, 2007b), this decision is expected to facilitate and speed up the approval of transgenic biofortified crops and clear the path for other GM (rice) varieties in China. Even though this might be promising for biofortified staple crops, the process and outcomes of the standard food safety and environmental field trials makes it impossible to predict if and when these biotech crops will be approved in China. Furthermore, if transgenic biofortified crops will be introduced, GM labeling will be required, alongside other policy issues (for an overview of implementation issues, see section 6.5.2).

[27] China is traditionally considered the largest user of pesticides, which underpins China's governmental support for pest-resistant (Bt) GM crops, especially Bt rice, as rice production accounts for about 40 % of the pest-resistant use (Chunyi Zhang, CAAS, personal communication, 18-04-2011).

# 3 Acceptance of folate biofortified rice in Shanxi Province

Adapted from:

De Steur, H., Gellynck, X., Storozhenko, S., Liqun, G., Lambert, W., Van Der Straeten D. & Viaene, J. (2010). Willingness-to-accept and purchase genetically modified rice with high folate content in Shanxi Province, China. *Appetite*, Volume 54, Issue 1, Pages 118-125.

De Steur, H., Gellynck, X., Storozhenko, S., Liqun, G., Lambert, W., Van Der Straeten, D. and J. Viaene (2011). The potential market for GM rice with health benefits in a Chinese high-risk region. Submitted for publication in *British Food Journal.*

De Steur, H., Gellynck, X., Storozhenko, S., Liqun, G., Lambert, W., Van Der Straeten, D. and J. Viaene (2011). How negative product attributes alter the acceptance of folate biofortified rice in a high-risk region of China. Submitted for publication in *International Journal of Biotechnology.*

## 3.1. Introduction

Since the 1990's, the success of the Gene Revolution in agriculture, whether it focused on producer (1st generation) or consumer oriented (2nd generation) GM crops (see section 2.4.1.1), was closely related to political support. Thereby, public acceptance was often considered an important precursor. Due to the controversial nature surrounding the use of biotechnology in food, GM food products remain a subject of discussion. While environmental organizations and a number of scientists and politicians question the technology, biotechnology proponents and several governmental organizations point out the potential benefits to producers and consumers. The United States is one of few developed countries to feel positively about the technology, however, the positive orientation toward GM food is more common among developing countries (Gaskel et al., 1999; Macer et al., 2000; Bredahl, 2001; Magnusson and Koivisto Hursti, 2002; Paarlberg, 2002; Anand et al., 2007). China, for example, is also characterized by consumers who are typically in favor of 1st generation GM food products (Li et al., 2002; Ho et al., 2006; Huang et al., 2006b; Lin et al., 2006; Xi and Harris, 2006) and a government with a supportive position towards biotechnology (Huang et al., 2004; Xi and Harris, 2006). According to Gonzalez et al. (2009) the positive reactions in developing regions might be related to the (increasing) food insecurity they are facing, by which new technologies, among which biotechnology, are viewed as one of the potential strategies to help ensure food security. This is true for China, where one of the top priorities of the Chinese government is universal food security (Huang et al., 2004; Fang, 2010), especially after China's entry into the WTO (Campos-Bowers and Wittenmyer, 2007).

In line with the asynchronous approval and commercialization of GM food (see section 2.5), consumers' attitudes towards GM food differ across and within countries (Costa-Font et al., 2008). In turn, these trends led to substantial differences in consumer acceptance between GM products (Kuznesof and Ritson, 1996; Magnusson and Koivisto Hursti, 2002; Frewer et al., 2003), and between the type of applications (Grunert et al., 2001). For example, consumers are more favorable to GM plants than to applications involving human genetic material or animals (Frewer et al., 1997b; Verdurme et al., 2003a), but GM food is significantly less positively embraced than medical biotechnology (Frewer and Shepherd, 1995). Regarding biofortified staple crops, such as FBR, one could expect that its intrinsic nutritional health benefits would increase public approval compared to GM crops with improved agronomic traits (Lusk et al., 2005; Anand et al., 2007). However, future development and refinement of FBR could imply undesired changes in rice attributes, which might influence the initial acceptance rate of this nutritionally enhanced crop. This chapter addresses the need to explore consumer acceptance of GM food with consumer benefits, as formulated by Lusk (2003), by focusing on a high-risk region.

In scientific literature, the concept of GM food acceptance and its underlying determinants is largely analyzed (see section 1.3.1). In order to identify and explain the market potential of FBR, 944 random interviews have been administered in the Chinese Shanxi Province. Therefore, a questionnaire was mainly built upon three complementary approaches of GM food consumer acceptance (Bredahl et al., 1998; Verdurme and Viaene, 2001; Costa-Font et al., 2008). It consists of important consumer

characteristics that might influence consumer acceptance of FBR: socio-demographic attributes, GM knowledge and consumer perceptions of GM food (see also Figure 2, section 1.3).
Besides analyzing the determinants of FBR acceptance (see section 3.3.2), this chapter further investigates GM food knowledge acquisition and trust in information channels and sources (see section 3.3.3) and the role of negative rice attributes in FBR acceptance (see section 3.3.4), based on specific parts of the sample, namely respondents with subjective knowledge and consumers favorable to this GM rice variant, respectively. So far, relatively few segmentation studies on 2nd generation GM food products, such as biofortified crops, exist (see section 1.3.1.2).

## *3.2. Methodology*

### 3.2.1. Study design

A standardized questionnaire was developed based on the different concepts of Figure 2. The content and the structure of this questionnaire were evaluated during expert meetings with the developers of FBR. The survey was conducted in July 2008 and comprises 944 random face-to-face interviews with rice consumers from the Chinese Shanxi Province, in particular in its capital city of Taiyuan, three counties (Mingxing, Houcheng, and Beiwang) and ten villages. For ease of understanding, the interviews were conducted by trained Chinese students of Shanxi Agricultural University and researchers of Liaoning Rural Economy Research Institute. To ensure a random sample encompassing a cross-section of the urban and rural population in Shanxi Province, the survey was performed in supermarkets, outdoor markets or shopping areas. Respondents were randomly selected with the criterion that the interviewer was to solicit every fifth consumer that came into the survey area (street-intercept method). Consumers who did not purchase rice were not considered to take part in the study.

### 3.2.2. Survey design

The standardized questionnaire consisted of six main sections.

The first section focused on consumers' behavior at rice purchase. Respondents were required to evaluate the importance of seven attributes when buying rice: health benefits, taste, external appearance, price, market availability, the cultivation potential or the possibility to cultivate the rice on their own, and the environmental impact. These variables were measured on a 7-point Likert scale, ranging from 'not important' to 'very important'.

The second section dealt with information on the consumer's knowledge of GM food and GM rice, the acquisition of GM food information and trust in information channels and sources. Subjective or perceived knowledge of GM food and GM rice was measured on a 5-point Likert (and recoded into a dummy variable) and dichotomous scale, respectively. Given that GM food knowledge was determined by multiple information sources and channels (Costa-Font and Mossialos, 2007), consumers were also asked where (channels) and by whom (sources) they learned about GM food. In general, the majority of GM related information in China is disseminated by the mass media, while Chinese consumers have restricted access to different information sources (Ho et al., 2006; Lin et al., 2006). As the respondents are living in a rural province, different categories of information channels were included: ‘Radio/television’, ‘Internet’, ‘Newspaper/magazine/book’, ‘Market’ and ‘Oral conversation’. Analogues, the categories of information sources are ‘Personal’ (friends, neighbors, relatives), ‘Medical experts’ (doctors, scientists), ‘Industry’ (biotechnology, food) and ‘Consumer or environmental associations’. This classification takes into account the importance of both personal and public information channels and sources (Costa-Font and Mossialos, 2007; Kornelis et al., 2007). In addition, data about trust in several information channels and sources was collected. Based on a 5-point Likert scale, ranging from 1 (=‘strongly distrust’) to 5 (= ‘strongly trust’), participants were asked to specify how much they trust information from the different channels or sources. This part ended with the measurement of the respondents’ objective knowledge, based on six different true-or-false statements related to genetic modification (Verdurme et al., 2003a; Christophe et al., 2008). This variable only refers to consumers who believe to know what GM food is (subjective GM food knowledge).

The third part consisted of questions with respect to consumer perceptions of GM food and FBR acceptance as a 2$^{nd}$ generation GM food product. Consumers with subjective knowledge were presented a series of statements about beliefs on benefits (7 statements), risks (4), safety (4) and price impact (2), derived from different GM food acceptance studies (Verdurme and Viaene, 2003; Pope et al., 2004). Each of the statements was measured by five-point scale statements (1 = “strongly disagree”, 5 = “strongly agree”, with 3 = “neutral” as the midpoint). To introduce the concept of FBR, information about the specific benefits of this GM product was provided (adapted from section 2.3). Consumers were also informed about the application of the GM technology, through a GM food definition that was provided alongside the second part of the survey (i.e. after the subjective knowledge item): “*GM food is food of which the genetic material has been modified by technology in order to make the plant more resistant against diseases or to grow plant varieties with a better nutritional value or positive health effects”*. As such, they evaluated this GM rice crop by its main product and process characteristics. The importance of mentioning both attributes has been pointed out by Frewer et al. (1997a) and Bredahl et al. (1998). FBR acceptance was then measured as an agreement to consume (no, indifferent, yes)(House et al., 2001; Chern et al., 2002; Ganiere et al., 2004; Onyango and Nayga, 2004; Wachenheim et al., 2008). Although some theorists propose to measure the evaluation of objects on a bipolar scale (Fishbein and Ajzen, 1975), i.e. acceptance versus rejection, GM food acceptance also included an ‘indifferent’ option to distinguish indifferent from favorable consumers. Due to the low socio-economic status of Shanxi Province, the specific source of the transferred genes was not mentioned, i.e. Arabidopsis thaliana (Storozhenko et al., 2007). This could have influenced the results, as plant-to-plant gene transfer technology is generally causing more reluctance when the transferred genes are derived from unrelated species (Aerni and

Rieder, 2000; Schnettler et al., 2008a; Schnettler et al., 2008b; Colson and Huffman, 2009), but not as much as when animal genes are transferred to plants (Onyango and Nayga, 2004). Although it is reasonable to expect that the source of the GM technology could alter acceptance, the perceived consumer benefits may still dominate consumer decisions (Frewer et al., 1997a).

Fourth, only the respondents who were favorable to folate enriched rice, were asked to re-evaluate this GM rice product when the quality of an attribute would be negative. The selection of the attributes was based on the previously mentioned literature review (see section 1.3.1.3): taste, external appearance, availability, price impact; cultivation potential and environmental impact. Each of these variables consisted of three categories: unlikely, no difference, likely. Due to the fact that this product is still in a laboratory phase, these questions are hypothetical in nature.

Fifth, information was gathered about WTP for FBR, which is further elaborated in chapter 4, when dealing with stated willingness-to-pay for FBR (see section 4.2 and 4.4.1.).

The questionnaire ended with the socio-demographic profile of the respondent, based on nine indicators. Education, income and residence, for instance, were incorporated to take into account the socio-economic profile of Shanxi Province as a poor, rural province (Shanxi Province Statistical Bureau, 2007). Due to the close link between FBR and maternal folate deficiency, family-related variables were included. Because biofortified food will be produced by farmers, the farmer status (yes/no) was questioned. Residence was also included because rural consumers in Shanxi Province are more at risk and rely more on home cultivation and farming (Shanxi Province Statistical Bureau, 2007).

### 3.2.3. Statistical analyses

Data of 944 completed questionnaires were entered and analyzed using the statistical package SPSS (version 15). A 5 % threshold was used as the critical significance level in all statistical analyses. In order to make all variables operational, recoding old and constructing new, reliable variables was necessary. For example, all consumer perception statements were recoded so that high scores indicate a positive perception. Cronbach’s alpha was used to measure the internal consistency in order to justify the use of an overall objective knowledge score, the statement categories of consumer perceptions and the overall trust scores of information channels/sources (Aaker et al., 2007). Furthermore, categorical variables, such as income and subjective GM food knowledge, are recoded into variables with less categories when more than 20 % of the cells in a crosstab had less than 5 answers.

Regarding univariate tests, the paired sample t-test was used to compare the statements (categories) of consumer perceptions, the level of trust in different GM food information sources/channels and the perceived importance of each rice attribute at purchase. With respect to the acceptance of rice attributes, significant differences between the acceptance of negative attribute changes (dichotomous) were assessed by using the McMenar Test, which is designed for use of nominal or ordinal test variables (Janssens et al., 2008).

On a multivariate level, a conclusive and descriptive statistical technique were selected, respectively multinomial logistic regression and cluster analysis. Multinomial logistic regression was employed to analyze the influence of a set of predictor variables by comparing the categories of a depend variable through a combination of binary logistic regressions (Malhotra, 2004). The entered variables fulfill the requirements, e.g. a categorical dependent variable and a sufficient number of cases per predictor variable (i.e. at least 10)(Hosmer and Lemeshow, 2000).
By using this technique, the determinants of FBR acceptance in Shanxi Province (section 3.3.2) and the socio-demographic determinants of the cluster membership were explored (section 3.3.3). To include objective knowledge and consumer perceptions of GM food as potential factors, this regression only applied to consumers that have subjective knowledge of GM food (451 respondents), as these persons answered these questions. Due to the non-randomness of this subjective knowledge variable, the estimation of other investigated relationships might be disturbed or biased. By using the Heckman two-step procedure, this potential selection basis can be explored. Based on a probit analysis, the inverse mill's ratio (lambda) was entered in the multinomial regression to control for the effect of subjective knowledge related factors. As the coefficient of lambda indicated that there is no such selection bias, the multinomial regression analysis which includes respondents with perceived subjective knowledge of GM food was presented.

Cluster analysis was applied to identify consumer segments regarding GM food related knowledge, consumer perceptions and trust levels (section 3.3.3) or FBR acceptance of negative attributes (section 3.3.4). Hierarchical cluster analysis (Ward's variance method, Squared Euclidean Distance measure of similarity) was carried out to distinguish relatively homogenous groups of respondents. Based on the different cluster centers, subsequent k-means clustering was applied to obtain the final consumer segments. Thus, by using the hierarchical clustering as input for the non-hierarchical subsequent K-means clustering, the differences between respondents within each segment were minimized, while the differences between the segments are maximized (Malhotra, 2004). This two-stage clustering approach has been applied to other GM food segmentation studies (Arvanitoyannis and Krystallis, 2005; Onyango et al., 2006; Kaye-Blake et al., 2007; Zhang et al., 2010).
Differences in cluster membership were analyzed by two statistical tests. First, the $\chi^2$-test and the Kruskal-Wallis test were carried out to assess the statistical significance of, respectively, nominal and ordinal categorical variables, such as the socio-demographic indicators and cluster membership. Second, cluster differences in metric variables, such as consumer perceptions, objective knowledge and trust scores, were tested by means of one-way ANOVA. Post Hoc Sheffe tests were performed to define which segments were responsible for the significant cluster differences.

## 3.3. Results

### 3.3.1. Sample profile

The summary statistics of the *socio-demographic* variables are presented in Table 11. The total sample of 944 respondents is considered indicative for Shanxi Province. For instance, the high poverty rate of this region is reflected in the asymmetric frequencies of education and income. Because the target group consists of those responsible for the purchase of rice, there is no respondent aged below 20 years. Residence is controlled in order to have an equal representation of respondents living in rural or urban areas.

Table 11 Socio-demographic characteristics of the sample (% of respondents, n=944)

| Variable | % | | % |
|---|---|---|---|
| *Gender* | | *Family Size* | |
| Male | 47.5 | ≤2 persons | 7.0 |
| Female | 52.5 | 3 persons | 40.8 |
| *Age* | | 4 persons | 29.8 |
| 20-29 years | 16.5 | >4 persons | 22.5 |
| 30-39 years | 29.3 | *Number of Children* | |
| 40-49 years | 30.4 | none | 11.1 |
| 50-59 years | 16.7 | 1 child | 41.7 |
| >59 years | 7.0 | 2 children | 31.4 |
| *Education*[a] | | >2 children | 15.8 |
| Low | 71.9 | *Age Youngest Child* | |
| High | 28.1 | none | 11.1 |
| *Income*[b] | | < 3years | 7.0 |
| Low | 92.8 | 3-10 years | 22.0 |
| High | 7.2 | >10 years | 59.9 |
| *Farmer status* | | *Residence* | |
| Farmer | 20.7 | Rural | 50.2 |
| Non-farmer | 79.3 | Urban | 49.8 |

[a]low: primary or secondary school; high: college or university; [b]low: yearly income ≤ ¥ 40 000; high: yearly income > ¥ 40 000.

Perceived or *subjective knowledge* of GM food (yes/no) is more or less equally divided among the sample: 47.8 % of the consumers are aware of GM food (Table 12). This is about 20 % lower than what Huang et al. (2006b) found in urban China. This might be explained by the higher public attention about GM food in urban areas. Furthermore, only 3.1 % assumes to have knowledge of, at least, the benefits or risks of GM food. The specific variables regarding the acquisition of GM food knowledge are further elaborated in section 3.3.3. With respect to GM rice, subjective knowledge is significantly lower (26.4 %) than for GM food. As the first GM rice product still needs to be commercialized in China, knowledge related to GM rice rather refers to information regarding the progress of commercialization (see section 2.5).

*Objective GM knowledge* is even lower, with a mean score of 39.2 %. The lack of GM knowledge in China has been pointed out in other studies on GM food acceptance (Ho et al., 2006; Huang et al., 2006b; Lin et al., 2006; Xi and Harris, 2006). This low score reveals significant misjudgment of subjective GM food knowledge, which is in accordance to the Chinese study of Li et al. (2002). Table

12 shows the percentage of correct answers for each objective knowledge statement. Fifty-three percent of the respondents answered two or less items correctly. The percentage of persons that answered the sixth statement correctly, which is closely related to the health benefits of our GM rice, is relatively high in comparison to other statements.

Table 12 Subjective GM food/rice knowledge (n=944) and objective GM knowledge (n=451), evaluation of the objective knowledge statements, the number of correct statements and objective knowledge score (%)

| **Subjective knowledge** | | **GM food (%)** | **GM rice (%)** |
|---|---|---|---|
| No | I don't know what GM food/rice is | 52.2 | 73.6 |
| Yes | Yes, | 47.8 | 26.4 |
| | I heard of GM food, but don't know what it is | 31.5 | / |
| | I know GM food, without details | 13.1 | / |
| | I know GM food and its main dis/advantages | 2.4 | / |
| | I have a profound understanding of GM food | 0.7 | / |
| **Objective knowledge statements** | | **% Correct** | **% incorrect** |
| 1. Genetic modification can help to make agricultural crops resistant to certain diseases (True) | | 53.2 | 46.8 |
| 2. Genetically modified bacteria are capable of cleaning oil-polluted beaches (True) | | 13.0 | 72.7 |
| 3. The gender of a boy is decided by his father's genetic material (True) | | 37.3 | 62.7 |
| 4. Animal genes can in no way be transferred to plants (False) | | 27.5 | 72.5 |
| 5. GM food contains genes but conventional food does not (False) | | 41.5 | 58.5 |
| 6. Genetic modification can help to improve the vitamin content of food (True) | | 48.6 | 51.4 |
| **Number of objective knowledge statements** | | **% correct** | |
| 0-2 statements | | 53.7 | |
| 3-4 statements | | 40.1 | |
| 5-6 statements | | 6.2 | |
| **Objective knowledge[a]** | | **% correct** | |
| Average objective knowledge score | | 39.2 | |

[a]Objective knowledge scores vary from 0 (= no true/false question correct) to 1 (= all true/false scores correct)

*Consumer perceptions* of GM food are split into four categories (benefits, risks, safety and price impact). After reliability analysis (α>0.6), means are analyzed for each statement (Table 13) and each category of statements (Table 14). In general, consumers evaluate the four groups of GM food statements as slightly positive, but perceptions of GM food safety are significantly more positive.

Table 13 Comparison of the evaluation of consumer perception categories, by paired sample t-tests (n = 451)

| **Paired consumer perception categories** | **Comparison of means** | **t** | **df** | **p** |
|---|---|---|---|---|
| Safety - Benefits | 3.47 - 3.17 | **9.26** | 450 | 0.00 |
| Safety - Risks | 3.47 - 3.18 | **11.29** | 450 | 0.00 |
| Safety - Price impact | 3.47 - 3.20 | **6.15** | 450 | 0.00 |
| Benefits - Risks | 3.17 - 3.18 | - 0.17 | 450 | 0.87 |
| Benefits - Price impact | 3.17 - 3.20 | - 0.64 | 450 | 0.49 |
| Risks - Price impact | 3.18 - 3.20 | - 0.57 | 450 | 0.57 |

*Note:* Consumer perceptions scores vary from 1 (= strongly disagree) to 5 (= strongly agree): high scores refer to positive perceptions. Bold indicates statistical significance at 0.1 %.

Specific statements such as health improvement (benefits), worthiness of trying (risks), labeling (safety) and cost reduction (price impact) are considered most positive within their statement category. However, GM food is often considered as a threat to biodiversity with dangerous side-effects. Related to FBR, consumers evaluate the health benefits of GM food as positive, while the potential of being a medical substitute is more considered as neutral. Their expectations of the price impact of GM food are slightly positive.

Table 14 Consumer perception statements per consumer perception category, means and standard deviation (n=451)

| Consumer perception statements | Mean | St. dev. |
|---|---|---|
| *Benefits* | | |
| B1. GM food can improve the health of consumers | 3.45 | 0.78 |
| B2. GM food can reduce poverty | 3.29 | 0.86 |
| B3. GM food can be a good substitute for some medicines | 3.07 | 0.92 |
| B4. The development of GM food should be encouraged | 3.27 | 0.86 |
| B5. GM food will lower environmental pollution | 3.18 | 0.80 |
| B6. GM food can prevent diseases | 3.22 | 0.80 |
| B7. The quality of GM food is better than of conventional food | 3.10 | 0.89 |
| *Risks* | | |
| R1. GM food is worth trying | 3.53 | 0.81 |
| R2. GM food does not pose a serious threat to biodiversity | 2.29 | 0.84 |
| R3. GM food will lower the use of pesticides | 3.31 | 0.77 |
| R4. GM food does not have dangerous side-effects | 2.96 | 0.83 |
| *Safety* | | |
| S1. The safety of GM food is carefully controlled | 3.43 | 0.96 |
| S2. GM technology is an acceptable technology to use | 3.44 | 0.78 |
| S3. Producing GM food is not messing around with nature | 3.07 | 0.76 |
| S4. GM food should be labeled | 3.96 | 0.83 |
| *Price impact* | | |
| P1. GM can lower the food prices on the market | 3.17 | 0.82 |
| P2. GM food can lower the costs for growing crop | 3.24 | 0.87 |

*Note:* Scores vary from 1 (= strongly disagree) to 5 (= strongly agree): high scores refer to positive perceptions. Therefore, some of the statements were recoded and rephrased (R2, R4 and S3).

With regard to FBR *acceptance*, 62.2 % of the Shanxi respondents indicate that they would accept it, 26.6 % react indifferently, while 11.2 % are reluctant. Similar results are obtained in other Chinese GM food studies, which underlines the general positive findings for other GM foods in China (Ho et al., 2006; Huang et al., 2006b; Lin et al., 2006; Anand et al., 2007).

### 3.3.2. Explaining the acceptance of folate biofortified rice

The multinomial logistic regression compares the three categories of the dependent variable (FBR acceptance), i.e. reluctance, indifference and acceptance, through a combination of three binary logistic regressions. Because this statistical technique analyzes relationships between a non-metric dependent variable, namely consumer acceptance of FBR, and metric or dichotomous independent variables, some categorical socio-demographic indicators such as age (with 40 years as threshold) and family size (≤ or > 2 persons) are dichotomized. The age thresholds are selected so that they divide the sample into two more or less equally sized groups, while family size dummy takes into account the presence of children (as nearly all 2 person households have no children).

The multinomial logistic regression model to predict FBR acceptance shows a model that fits significantly better than the null model. The Likelihood Ratio tests in Table 15 reveal significant relationships between acceptance of FBR and gender, age, education level, farmer status, objective GM knowledge, and consumer perceptions of GM benefits and risks. Details about significant differences between the FBR acceptance groups are presented subsequently.

Table 15 Determinants of FBR acceptance, by Multinomial Logistic Regression

| | **Likelihood ratio tests** | |
|---|---|---|
| | **$\chi^2$** | **p** |
| *Socio-demographic indicators* | | |
| Gender | **6.90** | 0.03 |
| Age | **10.61** | 0.01 |
| Family size | 9.56 | 0.15 |
| Education | **9.78** | 0.04 |
| Income | 0.01 | 0.99 |
| Farmer/non Farmer | **7.84** | 0.02 |
| Residence | 1.43 | 0.49 |
| *Knowledge* | | |
| Objective GM | **11.74** | 0.00 |
| Subjective GM rice | 3.07 | 0.22 |
| *Consumer perceptions* | | |
| Benefits | **5.93** | 0.05 |
| Risks | **6.31** | 0.04 |
| Safety | 1.53 | 0.45 |
| Price impact | 0.60 | 0.74 |
| *Model* | **102.03** | **0.00** |
| *Pseudo $R^2$ (Nagelkerke)* | **0.25** | |

*Note:* Bold indicates a significant effect. To avoid multicollinearity, only one of the family related variables is included.

The parameter estimates in Table 16 show the prediction of the probability that a respondent belongs to a category of the FBR acceptance variable, in comparison to another category of this variable, i.e. the reference category. The acceptance variable consist of three categories, by which three binary logistic comparisons are analyzed:

(1) “acceptance” versus “reluctance” (reference category),

(2) “acceptance” versus “indifference” (reference category), and

(3) “indifference” versus “reluctance” (reference category).

Because the socio-demographic variables are dichotomous, the parameter estimates of the binary comparisons refer to a specific category, expressed in parentheses in Table 16. The results support the scientific evidence that acceptance of GM food is mainly determined by knowledge and consumer perceptions (Bredahl et al., 1998; Verdurme et al., 2003b; Ganiere et al., 2006), but also by the socio-demographic profile of a consumer (Hoban, 1998; Chen and Li, 2007).

Table 16 Significant determinants of FBR acceptance, by Multinomial Logistic Regression, interpretation of the effects, per binary logistic comparison

| | **Acceptance *versus* reluctance**[a] | | **Acceptance *versus* indifference**[a] | | **Indifference *versus* reluctance**[a] | |
|---|---|---|---|---|---|---|
| | **B** | **p** | **B** | **p** | **B** | **p** |
| *Socio-demographic* | | | | | | |
| Gender (male) | | | 1.21 | 0.01 | | |
| Age (< 40 years) | 1.75 | 0.00 | | | | |
| Education (low) | | | -0.71 | 0.03 | | |
| Farmer/non-farmer (farmer) | 1.71 | 0.02 | | | 1.83 | 0.02 |
| *Knowledge* | | | | | | |
| Objective GM | | | 2.25 | 0.00 | -2.19 | 0.03 |
| *Consumer perceptions* | | | | | | |
| Benefits | 0.83 | 0.03 | | | 1.01 | 0.02 |
| Risks | | | 0.80 | 0.01 | | |

[a]Reference category

Men and people younger than 40 years old feel more favorable towards folate enriched rice than, respectively, indifferent or reluctant (reference categories). While consumers with a low education level have a higher probability to be indifferent to FBR (than being favorable). Farmers are more likely to accept FBR (indifferent/yes), rather than being reluctant.

Also the objective knowledge score is considered an important determinant of FBR acceptance. Consumers with substantial objective knowledge are either more accepting or rejecting FBR. In other words, consumers that know less about GM food are more indifferent to FBR.

Two statement categories of consumer perceptions influence FBR acceptance, namely the perceptions towards the benefits and the risks of using genetic modification in food products, which confirms the results of different reviews on determinants of GM food acceptance (Bredahl et al., 1998; Verdurme and Viaene, 2001). If the consumer perceptions of GM food benefits are positive, respondents are significantly more likely to accept or to be indifferent to FBR. When looking at risk perceptions, the more positive a consumer evaluates the risks of GM food, the more likely he/she will accept this GM rice crop instead of being indifferent. In other words, acceptability is higher when Shanxi consumers have a more positive perception of the benefits of GM food and a less negative perception of its risks.

Information aspects are not included in this model because of multicollinearity effect problems. However, from a communication point of view, these aspects deserve attention. The next section will focus on information aspects when determining different market segments in Shanxi Province.

### 3.3.3. Segmenting the market for folate biofortified rice

Based on the GM food related variables, i.e. objective knowledge, consumer perceptions and information trust scores, cluster analysis identified three consumer segments in Shanxi Province: “enthusiasts” (14.2 %), “cautious” consumers (41.2 %) and “opponents” (44.6 %). This is in line with findings from other segmentation studies (Kuznesof and Ritson, 1996; Kontoleon and Yabe, 2006)(see Table 1, section 1.3.1.2.). The cluster names are derived from main characteristics of the three Shanxi consumer segments, as discussed below and illustrated in Figure 12. Based on the standardized cluster means of objective GM knowledge and consumer perceptions, trust in channels and sources providing GM food information, enthusiasts generally obtain the highest score. Only their view on the price impact of GM is slightly lower than the other segments. At the other extreme are the opponents, who have the lowest objective knowledge and the least positive perceptions. Nevertheless, their perception of the benefits and price impact, and their trust in information channels is more positive than for cautious people, while their concerns regarding safety and risks are higher. Below the differences are presented for each of the clustered variables, FBR acceptance, information acquisition (sources/channels) and socio-demographic indicators.

Linking FBR acceptance with the identified consumer segments, shows that more enthusiasts are accepting this GM rice product, while the group of cautious consumers is more indifferent. In general, enthusiasts have the highest acceptance rate (81.3 %), followed by cautious consumers (68.3 %) and opponents (60.2 %).

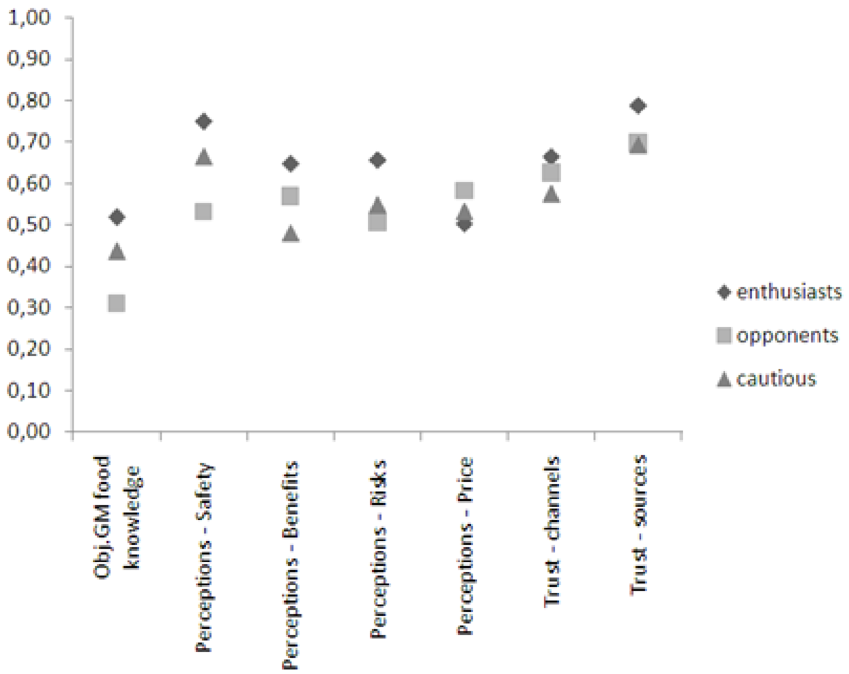


Figure 12 Overview of cluster variables. Objective knowledge and consumer perceptions of GM food and the levels of trust in information channels and sources

*Note:* Standardization (0 to 1) of the mean values of all variables.

The mean objective knowledge scores vary between 31 % for the opponents and 52 % for the enthusiasts, with the cautious' score (44%) in between (Table 17). But no matter what the cluster membership is, the average respondent has limited knowledge of what GM food actually is (39 %). A closer look at the significant difference in the number of correct answers reveals that 67.7 % of the opponents had less than two GM food knowledge statements correct, while the enthusiasts mainly answered 3 to 4 items correctly and the cautious are more or less equally divided into the groups below 5 answers. Only 1.5 % of the opponents had (almost) all statements correct, confirming the groups' limited knowledge of GM food.

Table 17 Objective GM knowledge, number of correct statements (% respondents) and average score (%) per cluster, and significant differences, by Chi²-test and One-way ANOVA

| **Correct answers** | **Enthusiasts** n = 64 (14.2%) | **Opponents** n = 201 (41.2 %) | **Cautious** n = 186 (44.6%) | **Sample** n = 451 | **Chi²-test** $\chi^2$ (df) | **One-way ANOVA** F (df) |
|---|---|---|---|---|---|---|
| 0-2 correct | 21.9 | 67.7 | 49.5 | 53.7 | | |
| 3-4 correct | 67.2 | 30.8 | 40.9 | 40.1 | 49.13 (4)*** | |
| 5-6 correct | 10.9 | 1.5 | 9.7 | 6.2 | | |
| *Obj. knowledge score* [a] | *52 %* | *31 %* | *44 %* | *39 %* | | 31.84 (450)*** |

*Note:* *** denotes statistical significance at 0.1 %. The six objective knowledge statements are described in Table 12 .
[a]Objective knowledge scores vary from 0 (= no true/false question correct) to 1 (= all true/false questions correct).

GM food knowledge is gathered through several information channels and sources. Audio-visual media, such as radio and television (39.3 %), are the information channels that are most used, followed by newspapers and magazines (23,7 %), the internet (23.5 %) and, to a lesser extent, oral tradition (8.0 %) and markets (5.5 %). A similar hierarchy is found in Chinese (Lin et al., 2006) and other GM food studies (Bredahl et al., 1998). However, while trust in the internet and radio are neither positive nor negative, consumers put less trust in advertisements and brochures (Table 20). When respondents receive GM food related information, they mainly depend on two sources: friends or relatives on the one hand, and scientists or doctors on the other. The industry or consumer/environmental associations are less preferred (Table 18). In other words, scientific and personal information dominate consumer oriented GM food information. Information sources are considered significantly more trustworthy than information channels, which are more or less perceived as neutral (paired sample t-test, p<0.001). The main sources of GM food information, informal and scientific sources, are also considered the most trustworthy (paired sample t-test, p<0.001). Consumers put also trust in their government and, although less used, in consumer oriented organizations. The industry, however, obtains the lowest trust score. These trust scores correspond with similar GM food studies (Dean and Shepherd, 2007; Costa-Font et al., 2008).

Differences between the three consumer segments related to how they obtain information about GM food is depicted in Table 18. Due to the high number of null cells, the use of information channels is recoded into a dummy variable, distinguishing audio-visual information channels from the other channels. The results show that significantly more opponents are using informal information channels to gather GM food knowledge, such as markets or oral conversations (17.4 %), while almost all enthusiasts (93.8 %) rely on audio-visual information channels. The level of trust in information channels is significantly higher in the group of enthusiasts, while the cautions take an intermediate position. Second, enthusiasts depend significantly less on information from consumer oriented organizations, while experts and personal sources are perceived as more important sources of opponents and cautious consumers, respectively. Regarding trust in information sources, opponents and cautious people have a significantly lower score than enthusiastic consumers.

With respect to the trust in information channels and sources, the means for each cluster are presented in Table 19. Education is considered most trustworthy in the enthusiastic cluster, i.e. the segment with the highest objective knowledge. The lower trust levels of the cautious consumers are mainly due to their skepticism about advertisements and brochures. The information sources that mainly account for the high trust levels of the enthusiasts are the medical sector, the government and the scientific world. This is not surprising given the well established relationship between GM food approval and trust in GM food proponents (Siegrist et al., 2000; Frewer et al., 2003; Yee et al., 2008). The reluctant consumers typically have a similar trust level as the cautious consumers, but they differ in the way they trust the food/biotech industry (more) or the government and scientists (less).

Table 18 Use of information channels/sources (% respondents), per cluster, and significant differences by Chi²-test

| **Variable** | **Enthusiasts** n = 64 (14.2%) | **Opponents** n = 201 (41.2 %) | **Cautious** n = 186 (44.6%) | **Sample** n = 451 | **Value** $\chi^2$ (df) |
|---|---|---|---|---|---|
| *Information channels* | | | | | 5.95(2)* |
| Audio-visual (Radio, television, internet, newspapers, magazines, books) | **93.8** | 82.6 | 88.2 | 86.5 | |
| Markets, shops, oral conversations | 6.2 | **17.4** | 11.8 | 13.5 | |
| *Information sources* | | | | | 14.29(6)* |
| Personal (friends, relatives, neighbors) | 35.9 | 29.9 | **46.8** | 37.7 | |
| Medical experts (doctors, scientists) | 35.9 | **39.3** | 31.2 | 35.5 | |
| Industry (food, biotechnology) | 20.3 | 20.4 | **11.8** | 16.9 | |
| Consumer organizations, environmental associations | **7.8** | 10.4 | 10.2 | 10.0 | |

*Note:* * denotes statistical significance at 5 % . Bold indicates relevant findings, as referred to in the text.

Table 19 Consumer perceptions of trust in information channels/sources, mean and standard deviation per cluster, and significant differences, by one-way ANOVA

| Variable | Enthusiasts n = 64 (14.2%) | | Opponents n = 201 (41.2 %) | | Cautious n = 186 (44.6%) | | Sample n = 451 | | Value[a] |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | St.dev | Mean | St.dev | Mean | St.dev | Mean | St.dev | F |
| Trust in information channels | 3.32 | 0.5 | 3.13 | 0.6 | 2.88 | 0.5 | 3.05 | 0.5 | 22.55*** |
| Newspaper | 3.83 | 0.7 | 2.97 | 0.9 | 3.11 | 1.0 | 3.15 | 1.0 | |
| Magazine | 3.42 | 0.9 | 3.01 | 0.8 | 3.02 | 0.9 | 3.07 | 0.9 | |
| TV | 3.86 | 0.8 | 3.33 | 0.9 | 3.42 | 0.9 | 3.44 | 0.9 | |
| Radio | 3.17 | 1.1 | 3.16 | 0.8 | 2.83 | 0.9 | 3.03 | 0.9 | |
| Internet | 3.33 | 0.9 | 3.30 | 0.9 | 2.79 | 0.8 | 3.09 | 0.9 | |
| Education | **4.00** | 0.8 | 3.28 | 0.9 | 3.34 | 0.9 | 3.41 | 0.9 | |
| Advertisement | 2.55 | 0.9 | 3.03 | 0.9 | **2.18** | 0.7 | 2.61 | 0.9 | |
| Brochure | 2.41 | 1.1 | 3.00 | 0.8 | **2.31** | 0.8 | 2.63 | 0.9 | |
| Shops | 3.63 | 0.8 | 3.30 | 0.7 | 3.33 | 0.7 | 3.36 | 0.8 | |
| Trust in information sources | 3.94 | 0.4 | 3.49 | 0.4 | 3.47 | 0.4 | 3.55 | 0.4 | 37.95*** |
| Family | 3.81 | 1.1 | 3.47 | 0.8 | 4.05 | 0.6 | 3.76 | 0.8 | |
| Medical | **4.25** | 0.6 | 3.66 | 0.8 | 3.73 | 0.8 | 3.77 | 0.8 | |
| Consumer organizations | 3.95 | 0.7 | 3.47 | 0.7 | 3.43 | 0.7 | 3.52 | 0.7 | |
| Environmental organizations | 3.98 | 0.7 | 3.52 | 0.7 | 3.34 | 0.7 | 3.51 | 0.7 | |
| Biotech industry | 3.53 | 0.7 | 3.44 | 0.8 | **3.05** | 0.8 | 3.29 | 0.8 | |
| Food industry | 3.33 | 0.8 | 3.51 | 0.8 | **2.73** | 0.8 | 3.16 | 0.9 | |
| Government | **4.44** | 0.6 | 3.49 | 0.8 | 3.80 | 0.7 | 3.75 | 0.8 | |
| Scientists | **4.56** | 0.7 | 3.58 | 0.8 | 3.81 | 0.7 | 3.81 | 0.8 | |

*Note:* *** denotes statistical significance at 0.1 %. Trust scores vary from 1 (=distrust a lot) to 5 (= trust a lot). Bold indicates relevant findings, as referred to in the text.
[a]The number of degrees of freedom is 450.

The cluster statements of the four perception categories differ significantly, as Table 20 illustrates. The enthusiasts, for instance, are more positively oriented towards the safety, the benefits and the risks of GM food than the other two clusters. This is consistent with the fact that those who are likely to identify the high benefits, are those who minimize the risks (Costa-Font and Mossialos, 2007). As a result, the perceptions of safety and risks of the opponents are the least positive, while cautious consumers are characterized by a more negative view on the benefits and the price impact. Hence, reactions of cautious consumers refer to the secondary conditions of GM food, while the opponents' doubts are related to its primary conditions. In general, safety issues of GM food are evaluated significantly more positively than its price impact, benefits and risks (paired sample t-test, p<0.001).

A detailed look at the various consumer perception statements, provides more insight on how these segments think about GM food (Table 20). Although all segments generally agree that the health of consumers can be improved with GM food, it is the enthusiastic segment that is optimistic towards the statements that are closely linked to folate biofortification, e.g. the ability of GM food to improve health (B1), be a substitute for medicines (B3), or prevent diseases (B6). Cautious people are more concerned about the potential of GM food, e.g. to reduce poverty and to be a valuable alternative to medicines. Regarding GM food risks, enthusiasts strongly believe that GM food will lower pesticide use (R3) and is worth trying (R1). Opponents have concerns about its side-effects (R4), including its impact on biodiversity (R2). A similar trend is found for food safety perceptions. Compared to the opponents, the enthusiasts and cautious people are positively evaluating the safety control of GM food (S1) and (strongly) agree that GM food is an acceptable technology (S2). Nevertheless, all market segments confirm the need for labeling, which corresponds to China's mandatory labeling policy (Huang et al., 2005a). Finally, the different price impact statements are evaluated more or less neutrally.

Table 20 Consumer perceptions of GM food, mean and standard deviation per cluster, and significant differences, by One-way ANOVA

| **Variable** | **Enthusiasts** n = 64 (14.2%) | | **Opponents** n = 201 (41.2 %) | | **Cautious** n = 186 (44.6%) | | **Sample** n = 451 (100.0 %) | | **One-way ANOVA**[a] |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | St.dev | Mean | St.dev | Mean | St.dev | Mean | St.dev | F |
| Benefits | 3.59 | 0.5 | 3.28 | 0.4 | 2.92 | 0.4 | 3.18 | 0.5 | 67.64*** |
| B1. Health improvement | 4.16 | 0.6 | 3.31 | 0.7 | 3.37 | 0.7 | 3.45 | 0.8 | |
| B2. Poverty reduction | 2.94 | 1.0 | 3.19 | 0.8 | 2.68 | 0.7 | 2.94 | 0.9 | |
| B3. Potential substitute for medicines | 3.48 | 1.0 | 3.37 | 0.8 | 2.61 | 0.8 | 3.07 | 0.9 | |
| B4. Encourage development | 3.81 | 0.8 | 3.37 | 0.8 | 2.99 | 0.8 | 3.27 | 0.9 | |
| B5. Lower environmental pollution | 3.55 | 1.1 | 3.24 | 0.8 | 2.98 | 0.7 | 3.18 | 0.8 | |
| B6. Disease Prevention | 3.98 | 0.7 | 3.21 | 0.8 | 2.96 | 0.6 | 3.22 | 0.8 | |
| B7. Better quality than regular food | 3.20 | 0.9 | 3.28 | 0.8 | 2.87 | 0.9 | 3.10 | 0.9 | |
| Risk | 3.63 | 0.4 | 3.02 | 0.4 | 3.20 | 0.4 | 3.18 | 0.4 | 55.64*** |
| R1. Worth trying | 4.27 | 0.7 | 3.31 | 0.7 | 3.52 | 0.7 | 3.53 | 0.8 | |
| R2. No threat to biodiversity (RC) | 3.02 | 1.0 | 2.77 | 0.9 | 3.05 | 0.7 | 2.92 | 0.8 | |
| R3. Lower the use of pesticides | 3.77 | 0.8 | 3.27 | 0.7 | 3.20 | 0.7 | 3.31 | 0.7 | |
| R4. No dangerous side-effects (RC) | 3.45 | 1.0 | 2.76 | 0.8 | 3.01 | 0.6 | 2.96 | 0.8 | |
| Safety | 4.00 | 0.4 | 3.13 | 0.4 | 3.67 | 0.4 | 3.47 | 0.5 | 135.60*** |
| S1. Carefully controlled safety | 4.23 | 0.7 | 2.95 | 0.9 | 3.68 | 0.8 | 3.43 | 0.9 | |
| S2. Acceptable technology | 4.13 | 0.7 | 3.16 | 0.8 | 3.50 | 0.6 | 3.44 | 0.8 | |
| S3. Not messing with nature (RC) | 3.36 | 0.8 | 2.88 | 0.7 | 3.17 | 0.7 | 3.07 | 0.8 | |
| S4. Should be labeled | 4.28 | 0.9 | 3.53 | 0.8 | 4.32 | 0.6 | 3.96 | 0.8 | |
| Price impact | 3.01 | 1.0 | 3.33 | 0.6 | 3.13 | 0.7 | 3.20 | 0.7 | 7.07** |
| P1. Lower food prices | 3.08 | 1.1 | 3.30 | 0.7 | 3.06 | 0.8 | 3.17 | 0.8 | |
| P2. Lower the costs to grow | 2.94 | 1.2 | 3.36 | 0.8 | 3.20 | 0.8 | 3.24 | 0.9 | |

B, benefits; P, Price impact; R, risks; RC, recoded; S, safety
*Note:* ***, ** denote statistical significance at 1 % and 0.1 %. Consumer perceptions scores vary from 1 (= strongly disagree) to 5 (= strongly agree): high scores refer to positive perceptions.
[a]The number of degrees of freedom is 450.

Multinomial logistic regression is used to compare the impact of socio-demographic indicators on cluster membership, a non-metric dependent variable, at multivariate level. All included socio-demographic indicators are dummy-variables and were not entered as variables in the cluster analysis, unlike the other variables, which justifies the use of this technique. The multinomial logistic regression model which predicts cluster membership shows a model that fits significantly better than the null model (p<0.001), while the non-significant Goodness-of-Fit test shows that the model adequately fits the data (p>0.278).

Based on the Likelihood Ratio tests, the significant socio-demographic determinants are identified, namely gender, income, farmer status and residence (see Table 21). The effect of these variables can be interpreted by the parameter estimates of the multinomial logistic regression. First, men are likely to be enthusiastic consumers, while women are more likely to be in the group of cautious consumers (and opponents). Second, a low income level increases the odds of being in the group of opponents instead of belonging to one of the other two segments. Farmer status reduces the likelihood of being a reluctant consumer, as compared to a cautious consumer. Finally, residence is significant in distinguishing the cautious segment from the other two segments. Consumers that live in urban areas of Shanxi Province are more likely to be a member of the cautious segment. In turn, rural consumers have a higher probability to belong to the reluctant or enthusiastic segment.

Table 21 Significant socio-demographic determinants of the consumer segments, by Multinomial Logistic Regression, likelihood ratio tests and parameter estimates per binary logistic comparison

| **Socio-demographic variable (dummy)**[a] | **Likelihood Ratio tests** | | **Enthusiasts *versus* opponents**[b] | | **Enthusiasts *versus* cautious**[b] | | **Cautious *versus* opponents**[b] | |
|---|---|---|---|---|---|---|---|---|
| | $\chi^2$ | p | B | p | B | p | B | p |
| Gender (male) | **7.46** | 0.02 | | | 2.25 | 0.02 | | |
| Age | 3.65 | 0.16 | | | | | | |
| Education | 1.99 | 0.37 | | | | | | |
| Income (low) | **6.09** | 0.05 | -1.03 | 0.05 | | | -0.91 | 0.03 |
| Farmer/non Farmer (non-farmer) | **5.67** | 0.05 | | | | | -0.84 | 0.02 |
| Residence (urban) | **11.15** | 0.01 | | | -2.25 | 0.02 | 2.08 | 0.01 |
| *Model* | **110.84** | 0.00 | | | | | | |
| *Pseudo $R^2$ (Nagelkerke)* | **0.25** | | | | | | | |

*Note:* Bold indicates a significant effect. The dependent variable, cluster membership, consists of three categories or segments: enthusiasts, cautious and opponents. To compare all groups of the dependent variable, cluster membership, three binary logistic regressions are presented.
[a]The parameter estimates of the binary comparisons refer to a specific category, expressed in parentheses; [b]Reference category.

## 3.3.4. Acceptance of negative attributes of folate biofortified rice

### *3.3.4.1. Influence of negative rice attributes on folate biofortified rice acceptance*

In this section, the Shanxi consumers' trade-off between the positive health attribute of FBR and potential negative rice attributes is analyzed. Therefore, the analysis only takes into account the respondents who accept FBR.

By linking different rice attributes to the current rice purchase behavior, Table 22 gives an indication of the perceived importance of rice attributes when buying rice. Except for taste and health, which are perceived as the most important product attributes of rice purchase in Shanxi Province, the importance of all rice attributes differs significantly from each other (paired sample t-test, p<0.001, not shown). While the importance of the availability is evaluated as neutral, the cultivation potential of rice varieties is considered the least important. These results support a study of Kim (2009) who stated that Chinese consumers attach large importance to the price level of GM food products when making their purchase decisions[28].

Table 22 Perceived importance of rice attributes (n=588)

| **Perceived importance of rice attributes at purchase[a]** | **Rank of importance** | **Mean** | **St. dev.** |
|---|---|---|---|
| Taste | 1 | 5.85 | 1.44 |
| Health | | 5.76 | 1.41 |
| Price | 3 | 5.13 | 1.46 |
| External Appearance | 4 | 4.48 | 1.61 |
| Availability | 5 | 4.06 | 1.57 |
| Environmental impact | 6 | 3.86 | 1.85 |
| Cultivation potential | 7 | 2.56 | 1.65 |

[a]Measured on a 7-point Likert scale, ranging from 1 (= not important) to 7 (= very important)

Table 23 presents consumers' evaluation of potential negative attributes of FBR. The figures in the fourth column define the potential impact of each negative rice attribute on the introduction of this GM rice product, i.e. the potential coverage rate of this folate intervention in Shanxi Province.

Although 62.2 % of the Shanxi consumers stated to accept FBR, negative changes of rice attributes could deter this acceptance rate. If the taste of this rice product is not as good as the conventional rice, or its impact on the environment is negative, the acceptance or the coverage rate will be substantially lower. The coverage rate of its introduction will be more than halved, reducing the acceptance rate to 28.1 % and 28.9 %, respectively, which underlines the importance of the taste and the environmental impact when developing (2nd generation) GM food products. Also a negative price impact would increase reluctance of FBR. On the contrary, changes in the cultivation potential, the least important rice attribute (see Table 22), or the external appearance does not make a difference for most of the consumers. The reduction of the initial acceptance rate of rice enriched with folate is less dramatic, when the cultivation potential (-12.2 %), the external appearance (-16.2 %) or the availability (-21.6 %) would be negatively affected.

[28] WTP for FBR will be analyzed in chapter 4.

Table 23 Acceptance of folate biofortified rice with negative rice attributes, % of respondents, and impact on the initial acceptance rate, in % reduction (n = 588)

| **Negative rice attributes[a]** | **Acceptance of negative rice attributes** | | | **Reduction of the initial acceptance rate (62.2 %)** | **Remaining acceptance rate[b]** |
|---|---|---|---|---|---|
| | **Unlikely to accept** | **Does not make a difference** | **Likely to accept** | | |
| Taste | 54.8 | 19.7 | 25.5 | -34.1 | 28.1 |
| External appearance | 26.0 | 46.3 | 27.7 | -16.2 | 46.0 |
| Price impact | 44.4 | 24.3 | 31.3 | -27.7 | 34.5 |
| Availability | 34.7 | 40.1 | 25.2 | -21.6 | 40.6 |
| Cultivation potential | 19.7 | 53.4 | 26.9 | -12.2 | 50.0 |
| Environmental impact | 53.6 | 33.3 | 13.1 | -33.3 | 28.9 |

[a]Reduction of the initial acceptance rate, i.e. without negative attribute changes, is calculated as: ('unlikely to accept')*0.622; [b]The remaining acceptance rate is calculated as: ('does not make a difference' + 'likely to accept')*0.622

To test the differences in consumer's acceptance of negative rice attributes, the six variables of Table 23 are dichotomized. The McMenar test reveals that there is a significant difference in nearly all negative FBR attributes (Table 24): a lower cultivation potential of folate enhanced rice will less likely influence the coverage rate of FBR, followed by external appearance, availability, price impact, and taste and environmental impact. Only the negative changes in taste and environmental impact, i.e. the attributes that causes the largest reduction of the GM rice acceptance rate, are more or less equal.

Table 24 Comparison of the acceptance of different negative folate biofortified rice attributes, by McMenar test (n=588)

| **Paired acceptance of negative rice attributes[a]** | **Comparison of means[b]** | **$\chi^2$** | **df** | **p** |
|---|---|---|---|---|
| Taste - External appearance | 0.45 - 0.74 | **117.12** | 587 | 0.00 |
| Taste - Availability/accessibility | 0.45 - 0.65 | **63.38** | 587 | 0.00 |
| Taste - Cultivation potential | 0.45 - 0.80 | **139.16** | 587 | 0.00 |
| Taste – Price impact | 0.45 - 0.56 | **14.82** | 587 | 0.00 |
| Taste - Environmental impact | 0.45 - 0.46 | 0.14 | 587 | 0.71 |
| External appearance - Availability | 0.74 - 0.65 | **11.21** | 587 | 0.00 |
| External appearance - Cultivation potential | 0.74 - 0.80 | **6.58** | 587 | 0.01 |
| External appearance - Price impact | 0.74 - 0.56 | **43.69** | 587 | 0.00 |
| External appearance - Environmental impact | 0.74 - 0.46 | **95.29** | 587 | 0.00 |
| Availability - Cultivation potential | 0.65 - 0.80 | **34.72** | 587 | 0.00 |
| Availability - Price impact | 0.65 - 0.56 | **15.15** | 587 | 0.00 |
| Availability - Environmental impact | 0.65 - 0.46 | **44.98** | 587 | 0.00 |
| Cultivation potential - Price impact | 0.80 - 0.56 | **81.32** | 587 | 0.00 |
| Cultivation potential - Environmental impact | 0.80 - 0.46 | **135.65** | 587 | 0.00 |
| Price impact - Environmental impact | 0.56 - 0.46 | **11.51** | 587 | 0.01 |

[a]Each variable of the acceptance of negative folate enriched rice attributes are dichotomized as follows: 0 = reject; 1 = accept; [b]Although the McMenar method tests the differences in binary responses of two variables, the comparison of means is presented, instead of the cross-tabulation for each pair.

### *3.3.4.2. Four clusters of FBR acceptance with negative rice attributes*

To obtain a better understanding of consumer acceptance of negative rice attributes in the high-risk region Shanxi Province, different segments of potential FBR consumers are identified. Through binary cluster analysis, reluctance (= 0) and acceptance (= 1) are compared for each negative attribute change. Given the consumers' trade-off between the higher folate content and a potential negative product attribute, cluster analysis detected four FBR consumer segments in Shanxi Province: 'Traditional attribute buyers' (17.9 %), 'Market consciousness' (20.2 %), 'Intrinsic attribute buyers' (27.4 %) and 'Health seekers' (34.5 %). Table 25 describes for each consumer segment how the acceptance of rice with a higher folate would change when a conventional product characteristic would be altered. Traditional attribute buyers are in general the most reluctant when it comes to negatively altered rice attributes. In other words, these consumers are significantly more favorable to FBR if it resembles the original rice crop. All market conscious consumers revised their opinion when undesirable market consequences would be involved, such as a negative price impact or a reduced availability compared to the conventional product. Taste is also considered as a crucial factor in their acceptance, which is the case in most of the consumer segments. The cluster of the "intrinsic attribute buyers" is significantly more represented by consumers that depend on taste and external appearance in order to accept folate enriched rice. Health seekers are mainly accepting it, even with negative changes in other attributes. Their reaction towards the additional health benefits seems to outweigh their perception of each undesired rice attribute. The average health seeker accepts five rice attribute changes of FBR, of which the negative environmental impact is the most important attribute that increased reluctance.

Table 25 Four cluster segments based on the acceptance of potential negative FBR attributes, % of respondents per cluster, and significant cluster differences, by Chi²-test.

| Acceptance of negative rice attributes | | Traditional attribute buyers[a] | Market consciousness[a] | Intrinsic attribute buyers[a] | Health seekers[a] | Sample | Value[b] |
|---|---|---|---|---|---|---|---|
| | | n = 105 (17.9 %) | n = 119 (20.2 %) | n = 161 (27.4 %) | n = 203 (34.5 %) | n = 588 (100 %) | |
| *Rice attribute* | | | | | | | $\chi^2$ |
| Taste | Reject | **64.8** | **80.7** | **98.1** | 0.0 | **54.8** | 404.49*** |
| | Accept | 35.2 | 19.3 | 1.9 | **100.0** | **45.2** | |
| External appearance | Reject | **34.3** | 17.6 | **46.6** | 10.3 | **26.0** | 69.34*** |
| | Accept | 65.7 | **82.4** | 53.4 | **89.7** | **74.0** | |
| Price impact | Reject | **58.1** | **100.0** | 14.9 | 28.1 | **44.4** | 235.64*** |
| | Accept | 41.9 | 0.0 | **85.1** | **71.9** | **55.6** | |
| Availability | Reject | **48.6** | **72.3** | 31.7 | 7.9 | **34.7** | 148.14*** |
| | Accept | 51.4 | 27.7 | **68.3** | **92.1** | **65.3** | |
| Cultivation potential | Reject | **100.0** | 0.0 | 0.0 | 5.4 | **19.7** | 522.30*** |
| | Accept | 0.0 | **100.0** | **100.0** | **94.6** | **80.3** | |
| Environmental impact | Reject | **67.6** | **55.5** | **55.3** | 43.8 | **53.6** | 16.42*** |
| | Accept | 32.4 | 44.5 | 44.7 | **56.2** | **46.4** | |
| *Number of accepted attributes* | Mean (st.dev) | 2.27 (1.46) | 2.74 (0.98) | 3.53 (1.03) | 5.04 (0.83) | **3.67 (1.51)** | F 211.07***[c] |

*Note:* ***denotes statistical significance at 0.1 %. Bold indicates relevant findings, as referred to in the text.
[a]For each cluster, the figures of the category where the number of respondents is significantly higher than the sample percentage, is presented; [b]The degree of freedom of the Chi²-tests is 3; [c]The degrees of freedom of the One-way ANOVA test of the number of accepted attributes is 3; 587.

Below, the main cluster differences are presented, based on socio-demographic indicators, objective GM knowledge and consumer perceptions of GM food (Table 26).

Only three socio-demographic indicators (gender, famers status and residence) are significantly different between the four consumer segments. The market conscious group and the traditional buyers, i.e. the cluster segments where the number of accepted negative attributes is the lowest, are significantly more represented by men and rural consumers. On the contrary, slightly more women and urban consumers seek health or intrinsic attributes. The group of health seekers is mainly represented by non-farmers, while most farmers are concerned about the price impact.

When buying rice, taste is considered a crucial factor of acceptance in the group of intrinsic attribute and market conscious consumers. The latter cluster, together with the traditional attribute buyers, attach significantly more importance to the price impact. As expected, health seekers take health aspects more into account when they are purchasing rice.

With respect to consumer perceptions, there is a significant difference between the way clusters evaluate the benefits, the risks and the price impact of GM food. First, health seekers acknowledge the benefits of bringing genetic modification into food more than other groups. Second, a market conscious consumer is more positively oriented towards the risks of GM food. But they are more concerned about the price impact of GM crops, which is in line with their high perceived importance of the price at rice purchase and their lower acceptance rate when FBR would imply a negative impact on the production costs and product price.

Table 26 Significant differences of the four segments regarding the acceptance of negative FBR attributes, by Chi² or One-way ANOVA

| | | Traditional attribute buyers<br>n = 105<br>(17.9 %) | Market consciousness<br>n = 119<br>(20.2 %) | Intrinsic attribute buyers<br>n = 161<br>(27.4 %) | Health seekers<br>n = 203<br>(34.5 %) | Sample<br>**n = 588**<br>**(100 %)** | Value |
|---|---|---|---|---|---|---|---|
| *Socio-demographic indicators (% respondents)* | | | | | | | $\chi^2$ |
| Gender | Female | 41.9 | 35.3 | **50.9** | **52.7** | **46.8** | 11.29** |
| | Male | **58.1** | **64.7** | 49.1 | 47.3 | **53.2** | |
| Farmer status | Yes | 25.7 | **29.4** | 23.0 | 15.3 | **22.1** | 10.06* |
| | No | 74.3 | 70.6 | 77.0 | **84.7** | **77.9** | |
| Residence | Rural | **58.1** | **63.9** | 51.6 | 48.8 | **54.3** | 7.99* |
| | Urban | 41.9 | 36.1 | **48.4** | **51.2** | **45.7** | |
| *Perceived importance of rice attributes at purchase (mean, st.dev)* | | | | | | | F |
| Taste | | 5.50 (1.74) | **6.25** (1.00) | **6.19** (1.35) | 5.71 (1.35) | **5.85 (1.44)** | 9.31*** |
| Price impact | | **5.45** (1.40) | **5.35** (1.53) | 4.78 (1.43) | 5.11 (1.43) | **5.13 (1.46)** | 5.86*** |
| Health | | 5.63 (1.57) | 5.77 (1.32) | 5.58 (1.51) | **6.08** (1.22) | **5.76 (1.40)** | 3.17* |
| *Consumer perceptions (mean, st.dev)* | | | | | | | |
| Benefits | | 3.14 (0.45) | 3.11 (0.53) | 3.12 (0.49) | **3.34** (0.46) | **3.20 (0.49)** | 4.78** |
| Risks | | 3.17 (0.39) | **3.41** (0.33) | 3.25 (0.44) | 3.15 (0.50) | **3.23 (0.44)** | 3.95** |
| Price impact | | 3.20 (0.58) | **2.91** (0.55) | 3.42 (0.76) | 3.08 (0.74) | **3.19 (0.72)** | 7.04*** |

*Note:* *, **, *** denote statistical significance at 5 %, 1 % and 0.1 %, respectively. Bold indicates relevant findings, as referred to in the text.
Perceived importance scores vary from 1 (= not important) to 7 (= very important). Consumer perceptions scores vary from 1 (= strongly disagree) to 5 (= strongly agree): high scores refer to positive perceptions.

## 3.4. Discussion and conclusions

This chapter investigated consumer's acceptance of FBR as an intervention to address the high burden of folate deficiency and its adverse health outcomes, such as NTDs, in Shanxi Province in Northern China. The results show that Shanxi consumers generally accept this GM rice variant with higher folate content (62.2 %). This confirms the expectation that GM products with consumer benefits are (more) positively embraced by consumers (Frewer et al., 1997a; Lusk et al., 2005; De Groote and Kimenju, 2008; Stevens and Winter-Nelson, 2008), especially in China (Lin et al., 2004; Anand et al., 2007). According to Li et al. (2002), the high consumer acceptance rate of GM food in China is one of the main factors of the strong support of the Chinese government. The large use of audio-visual sources for GM information acquisition might have created or reinforced the high acceptance rate of GM food, as the Chinese government has traditionally control over these media (Xi and Harris, 2006).

Although the explained variance of our model is rather low, it does appear to be useful to explore the sign and impact of some of the most important determinants of GM acceptance in a high-risk region. As expected, FBR acceptance is determined by GM food knowledge, consumer perceptions, and the socio-demographic factors (Bredahl et al., 1998; Hoban, 1998; Verdurme et al., 2003b; Ganiere et al., 2006; Chen and Li, 2007). Linking these findings with consumers' acquisition of GM food information, makes it possible to formulate recommendations which deserve specific attention.

Four socio-demographic indicators, i.e. gender, age, education and farmer status, play a role in influencing FBR acceptance. In line with the literature, being female (Siegrist et al., 2000; Moerbeek and Casimir, 2005), older (Ganiere et al., 2006; Gonzalez et al., 2009) or a non-farmer decreases the probability of FBR acceptance. Thus, contrary to several studies that questioned the importance of socio-demographic indicators to explain GM food acceptance (Bredahl et al., 1998; Li et al., 2002; Kontoleon and Yabe, 2006; Anand et al., 2007), these results show that it is important to take into account the socio-demographic profile of consumers, especially when the GM food product is targeted towards specific beneficiaries. Unexpectedly, women as one of the main beneficiaries of FBR are less favorable to this GM product than men. The lack of a significant relation between income and acceptance, as Wachenheim et al. (2008) and Yee et al. (2008) observed, could be due to the threshold of a high income level, by which only a marginal part of the sample is not assumed to be poor.

Acceptance is also determined by objective knowledge in the way that people who are indifferent to FBR are more likely to be those without any understanding of GM food. This contradicts the common positive effect of education (Hoban, 1998; Traill et al., 2004) and knowledge (Gaskel et al., 1999; Huang et al., 2006b; Chen and Li, 2007), and might lead one to conclude that keeping the knowledge levels low would lead to more indifferent people and thus, a higher coverage rate. However, FBR acceptance is also positively associated with consumer perceptions of the risks and benefits of GM food, which correspondents with the general findings (Baker and Burnham, 2001; Li et al., 2002).

Hence, if a promotion campaign of this potential intervention aims to influence the general acceptance rate of FBR, there is a need to increase knowledge about its advantages and improving consumers' risk perception at the same time.

As consumers with a high objective knowledge are more likely to either accept or reject the FBR, instead of being indifferent, the way consumers acquire GM food related knowledge is also crucial. Taking together the socio-demographic, consumer perceptions and information trust scores, Shanxi consumers with subjective GM food knowledge could be divided into an enthusiastic (14.2 %), an opposing (41.2 %) and a cautious group (44.6 %). The results show that both audio-visual and, particularly for the latter two, informal information channels, such as markets, could also play a role in informing consumers. Nevertheless, acceptance is likely to be hampered by sources that generally provide negative messages about GM food, such as consumer/environmental organizations, because these sources are significantly more popular with the group of opponents. The importance of experts in the latter might be related to the fact that anti-GM information campaigns in China are openly supported by several scientists and medical experts (Stone, 2011). Regarding future communication campaigns, it can be recommended to improve the low trust levels towards GM proponents, such as the government (opponents), and the industry (cautious).

At first sight, the representation of these clusters gives the impression that the implementation of GM rice in Shanxi Province will not be successful as only a small group of enthusiasts will be the first to adopt this GM rice product. However, it is important to note that enthusiastic consumers obtain high scores on all investigated GM food determinants. Therefore, cautious consumers are not averse to GM rice, but rather less optimistic. Their doubts are mainly related to the secondary conditions of GM food, namely its benefits and its price impact. The opponents on the other hand, have the lowest objective GM knowledge score and the least optimistic perception of the primary conditions of GM food, i.e. safety and risks, which further supports the need for a segmented communication strategy to tackle folate deficiency in China.

Depending on the objective of the FBR intervention, three broad groups could be targeted.

First of all, FBR is primarily intended for women, especially women with a low income levels, in order to reduce the prevalence rates of NTDs as the most important negative cause of folate deficiency. Unfortunately, despite the fact that Shanxi women are better informed about GM food and are less deficient than men (see Table 6), they are less likely to enthusiastically accept GM rice than men. In addition, a large segment of female cautious consumers exist, to whom attention should be paid in order to improve to their perception of the price impact and safety aspects.

Secondly, if raising the folate intake levels of the high-risk population is considered the main objective, this folate policy intervention should target the opponents, which are significantly more represented by people with insufficient folate intake levels, i.e. poor, rural consumers (Gao et al., 2003; Ren et al., 2007). Thus, while women of childbearing age should be the target group of FBR when tackling the prevalence of NTDs, the opponents should be addressed to further ensure a widespread adoption of FBR and to alleviate the global burden of folate deficiency at the population level.

Third, another strategy is to take into account the reaction on the supply side, i.e. farmers' acceptance, who are not only considered as the future producers of FBR, but who will also act as rice consumers. Farmers are generally more in favor of GM rice than regular consumers. Nevertheless, farmers will be more in favor of adopting biofortified crops when production related traits are beneficial (Hotz and Brown, 2004; Low et al., 2007). To attract such farmers, improved agronomic traits, such as a pest-resistance, could be added to this folate enriched rice crop in order to improve its price impact. Another option is to make the biofortified staple crop royalty-free for humanitarian use, so that subsistence farmers can use the rice free of cost (Brewster et al., 2005). This is true for Golden Rice (Kowalski and Kryder, 2002)(see section 6.5.1). Nevertheless, consumer acceptance as such is often strong enough to convince farmers to start to adopt biofortified crops, as was successfully the case in Uganda (Heyd), 2007; Gonzalez et al., 2011).

Because FBR is still under development, this acceptance study must be considered as an ex-ante evaluation of the potential coverage rate of FBR. The current product attributes could be altered due to folate biofortification or by adding the folate trait to a 1st or 2nd generation GM product. If the final FBR would imply a negative taste, environmental or price impact, the initial acceptance rate of this GM product in Shanxi Province would be more or less halved. As a consequence, these differences will negatively influence the coverage rate of this potential folate intervention in Shanxi Province Shanxi Province and have to be carefully considered in the further development of this rice.
Furthermore, cluster analysis distinguished four different consumer segments regarding the acceptance of negative rice attributes in Shanxi Province: "Traditional attribute buyers", "Market consciousness", "Intrinsic attribute buyers", and "Health seekers". Whereas female and urban consumers are likely to be health seekers or intrinsic attribute buyers, male and rural people mainly belong to the other two segments. This shows that even consumers who accept the initial folate biofortified staple crop are a heterogeneous group when their perception of various negative changes of conventional rice attributes is included. On the one extreme, health seekers seem to evaluate FBR only by its health benefits, regardless of other altered attributes, while on the other extreme the traditional attribute buyers demand a GM crop that resembles its regular counterpart. In between, there are market conscious consumers, such as farmers whose acceptance also depends on the price impact or consumers who are concerned about its availability, and intrinsic attribute buyers, who might become reluctant when the color or taste would be different. Although folate biofortification is not expected to change sensory (taste, texture) and visual product attributes (Bekaert et al., 2008), contrary to folic acid fortified rice (Shrestha et al., 2003), this might be a problem when folate trait would be incorporated in MBR varieties. However, as Bouis et al. (2000) stated, color changes could also be an advantage from a marketing point of view. It can help to introduce and promote a product with a clear relation between the distinct visible trait and a higher beta-carotene content.

The most important limitations in this chapter refer to the measurement of variables and data analysis. They can be seen as potential avenues for future research in order to validate or improve the findings of this consumer study. First of all, this chapter aimed to explain consumer acceptance of FBR.

Therefore, the influence of the different potential determinants was measured, rather than measuring the hierarchies of effects, e.g. through path analysis. Second, FBR acceptance was measured and treated as a categorical variable. Although the distinction between an indifferent and favorable category was useful to detect some key differences within the group of consumers that is non-averse, a continuous variable might improve the results. Third, it was assumed that people without any subjective GM food knowledge have no objective GM knowledge. As a consequence, the latter was dependent on the former in the survey, which reduced the sample size in some of the analyses. Fourth, the information acquisition variables refer to the information channels and sources that were used to learn about GM food knowledge. From a communication point of view, it would be interesting to find out which information channels and sources are preferred to obtain (more) knowledge of the investigated product, i.e. GM rice product with health benefits. As their prior knowledge of GM food is likely to be associated with 1$^{st}$ generation GM crops, consumer's communication needs might be different when dealing with a consumer-oriented GM food product with health benefits.

Finally, regarding the impact of negative rice attributes, future research will be needed to validate the findings in this chapter. One option is to include attribute changes as an information treatment in an experimental auction setting or to use conjoint analysis to compare different combinations of negative attributes. Another suggestion for future research relates to the evaluation of sensory attributes once the product is ready for consumption. Although it is less likely that the final FBR product will be characterized by taste or visual differences (Bekaert et al., 2008), these attributes might become a problem when the folate trait would be inserted in another GM rice crop, such as MBR. If this is the case, consumer sensory research, e.g. product evaluation through taste panels, might be considered to define the coverage of this intervention.

# 4 Willingness-to-pay for folate biofortified rice in Shanxi Province

Adapted from:

De Steur, H., Gellynck, X., Feng, S., Rutsaert, P. and W. Verbeke (2011). Determinants of Willingness-to-Pay for GM rice with health benefits in a high-risk region: Evidence from experimental auctions for folate biofortified rice in China. Submitted for publication in *Food Quality and Preference.*

De Steur, H., Gellynck, X., Feng, S. (2011). Experimental auctions to assess the role of information on willingness-to-pay for second generation GM crops. The case of folate biofortified rice in a high-risk region of China. Submitted for publication in *Asian Economic Journal.*

## 4.1. Introduction

Because novel products, like GM foods, are often not for sale at the marketplace, it is important to explore their potential market demand. The so-called non-market valuation aims to elicit the economic value of a new, hypothetical good or product by examining how much consumers are willing to pay for it, in other words, what this product is worth to them.

The burgeoning public concerns about risks and safety issues regarding the implementation of new technologies into food products led to a large body of scientific research on purchase intentions and WTP with regard to 1st generation GM food products (Lusk et al., 2005)[29]. WTP for GM food is closely related to the acceptance of biotechnology and differs across countries and according to the targeted GM food product (Costa-Font et al., 2008). European consumers are generally prepared to pay a premium for non-GM food products (Noussair et al., 2002), as compared to US consumers (Lusk et al., 2004b). Nevertheless, there is also a lot of heterogeneity within a traditional favorable or reluctant country. As Rousu et al. (2004a) demonstrated, many consumers in the US would like to pay a substantial amount to avoid GM in their products. Besides cultural differences and acceptance, WTP for GM food products is also explained by knowledge and consumer perceptions of GM food (Bredahl et al., 1998; Verdurme et al., 2003b; Ajzen, 2005; Lin et al., 2006), which are thoroughly described as determinants of FBR acceptance (see section 1.3.1.1); information provision (Tegene et al., 2003); the governmental GM food (labeling) policy (Costa-Font and Mossialos, 2007); the characteristics of the GM food product (Lusk et al., 2005) and methodological aspects of the economic valuation study (see section 4.3). Socio-demographic determinants could also play an important role (Costa-Font et al., 2008; De Groote and Kimenju, 2008), although some studies contradict this (Lusk et al., 2001a; Umberger and Feuz, 2004).

When examining WTP for new, controversial products, whether it is a GM food (Tegene et al., 2003; Rousu et al., 2005), an irradiated food (Fox et al., 2002), or an imported product (Wang and McCluskey, 2010), information is considered extremely important (Buhr et al., 1993; Shaw et al., 2006). Providing positive information about the GM technology generally leads to higher WTP values for GM food (Tegene et al., 2003; Colson and Huffman, 2009) or a lower compensation to accept GM food (Jaeger et al., 2004; Liu, 2009), and vice versa. Especially if relevant health or environmental benefits of the GM food are mentioned, the product will more likely be accepted (Frewer et al., 1996; Kassardjian et al., 2005) or purchased (Jaeger et al., 2004; Lusk et al., 2004b; Hobbs et al., 2006). In line with these results, nutritional information about conventionally bred biofortified products increases a consumer's WTP (De Groote et al., 2010). However, such favorable preferences might be compensated when people are informed about the involved GM technology, which is partially the case for Golden Rice in the Philippines (Depositario et al., 2009a), but does not hold for India (IIM, 2007). To date, WTP valuations of biofortified crops are scarce (Chowdhury et al., 2009). De Groote et al.

[29] In their meta-analysis, Lusk et al. reviewed 25 peer reviewed GM food research publications with a total of 57 WTP valuations for different GM food products, in order to explore the effect of the value elicitation method, the research location, the product being valued, the WTA or WTP price mechanism, the sample characteristics and the product benefits.

(2011), for example, found a premium of 24 % for the yellowish conventional biofortified maize with higher provitamin A in Kenya, while US and Indian consumers are prepared to pay a surplus of, respectively, 16 % (Lusk, 2003) and 19.5 % for the transgenic Golden Rice (Deodhar et al., 2008). In North-East Brazil, WTP for vitamin A enriched cassava is 60 % to 70 % higher than the price of its regular counterpart (Gonzalez et al., 2009).
In reality, however, positive GM information is often countered by anti-GM sources. In China, for instance, leading activist groups, like Greenpeace China (Greenpeace China, 2011a), or local NGOs, such as Utopia (Wu You Zhi Xiang) were responsible for a delay in the commercialization process of GM rice (Stone, 2011; Utopia, 2011)(see also section 6.5). When positive and negative information are simultaneously presented, two-sided information can be more persuasive as it improves the credibility and mitigates the need for counterarguments (Crowley and Hoyer, 1994). Regarding GM information treatments, previous studies have shown inconsistent findings about the direction of the impact of two-sided information treatments about controversial food products (Fox et al., 2002). While a few researchers argue that positive information might dominate negative statements in specific cases (Rousu et al., 2004b; Colson and Huffman, 2009; Corrigan et al., 2009), the opposite is what is generally found in scientific literature (Fox et al., 2002; Tegene et al., 2003; Parkhurst et al., 2004; Hu et al., 2006). One explanation regarding the latter is that two-side information is treated as negative information, known as the alarmist reaction (Parkhurst et al., 2004). Some authors observed even more negative reactions than when negative statements are provided only (Depositario et al., 2009a). According to Fox et al. (2002) the dominance of negative information over positive information might be attributable to the loss aversion hypothesis (see section 4.3.2.1), which stimulates people to stick to the regular product, or the risk-averse nature of people when dealing with a decision problem. Other potential explanations refer to a bias in favor of ‘status quo’ alternatives (Fox et al., 2002), or a negativity bias (Rozin and Royzman, 2001), by which negative information is more carefully processed and has a bigger attractiveness (Smith and Petty, 1996). Besides the discussion surrounding the outcome of conflicting information, also the sequence in which people receive such information could influence WTP for GM food (Liu, 2009). Here, the ‘primacy’ versus ‘recency’ information order effect comes into play. When measuring immediate behavioral responses, such as reporting an auction-based WTP, the last presented information (recency) is expected to dominate, unless the information is highly relevant to people (Buda and Zhang, 2000).

Given the nature of the product being valued in this dissertation, i.e. a 2$^{nd}$ generation GM food product with tangible consumer benefits, and the positive results regarding its acceptance in China (see chapter 3), it can be expected that consumers would be less averse of buying this biofortified product than GM food of the 1$^{st}$ generation (Rousu et al., 2005; Han and Harrison, 2006). Therefore, the aim is to explore the premium for FBR, rather than its discount. In other words, instead of willingness-to-accept compensation, a consumers’ WTP for this GM rice product with health benefits will be the topic of this chapter (see also section 1.3.2.1).

This chapter reports the results of WTP for FBR, and is dedicated to two value elicitation methods.
The first measures the stated preference of Chinese consumers and is obtained from the standardized survey in Shanxi Province (in 2008; see chapter 3). Stated willingness-to-pay (sWTP) is a self-reported construct based on a contingent valuation method (CVM) where consumers were asked what they are willing to pay for a GM food product (Bateman and Turner, 1993; Hanemann and Kanninen, 1999; Pearce and Özdemiroglu, 2002; Venkatachalam, 2004; Bonti-Ankomah and Yiridoe, 2006; Ganiere et al., 2006; Anand et al., 2007).
The second explores consumers' auction-based willingness-to-pay (WTP)[30] for FBR by means of experimental auctions in Shanxi Province. An experimental auction is a non-hypothetical value elicitation method, which combines the advantages of stated and revealed preference methods, in order to determine WTP for products or goods (see also section 1.3.2).
Since the 1990s, experimental auctions have been extensively applied to value food characteristics (Lusk and Shogren, 2007)[31], with only a few of them conducted in urban China, e.g. in Beijing (Kachelmeier and Shehata, 1992) and Shanghai and Beijing (Wang and McCluskey, 2010). Using experimental methods to elicit valuations for 2nd generation GM food products is relatively new, with Rousu et al. (2005) being the first to explore this area. In China, two studies investigated purchase intentions for GM rice products in large cities: WTP for a 1st generation GM rice cookie by using experimental auctions (Liu, 2009) and WTP for a 2nd generation GM rice product with a higher, undetermined vitamin content, based on contingent valuation (Li et al., 2002). While the participants in the former ask for a price discount of more than 35 % to accept GM rice with undefined farmer benefits, the latter found that 43.9 % of the consumers are prepared to pay an average premium of 38 % for GM rice with consumer benefits. Although the latter confirms that Chinese consumers might be (more) willing to purchase biofortified crops, it remains to be proven if they would be as enthusiastic for GM rice with higher folate content, especially in high-risk regions under challenging conditions of low socio-economic levels. This chapter aims to provide an answer to this question.
Special attention is devoted to the impact of different (GM) information treatments on (zero) bidding behavior. Hence, an experimental auction design with 5 non-repeated information rounds was developed. Furthermore, the determinants of WTP for FBR are analyzed, including the effect of auction design characteristics. Compared to the stated preference method, the auctions were specifically targeted towards two groups in rural Shanxi: poor, low educated women and female students. These two subsamples are expected to be more responsible for the rice purchases and more interested in the benefits of folate, by which they are considered important beneficiaries of FBR. Besides a target group effect, the impact of providing folic acid supplementation as a folate substitute for FBR was examined. Other investigated design characteristics are related to the time and day of the auction, and the number of participants per auction.
Finally, sWTP and WTP are compared with each other and with indirect, depersonalized valuations in order to detect, respectively, potential hypothetical and social desirability bias (see section 1.3.2.1).

[30] When referring to the auction-based valuations, the general term 'WTP' is used as it is expected to be the measurement that most resembles consumer's true value, given the non-hypothetical nature of this method.
[31] This book contains over 50 citations of auction-based valuation studies, mainly focusing on food products.

In the next section, the methodology to measure the stated WTP in a standardized survey is described. Section 4.4.2 contains detailed information about the experimental design, including the rationale behind the auction mechanism, the bidding procedures and assumptions. The results section is split into three parts. Whereas the first part analyzes the hypothetical, stated WTP values, the second determines the (role of information) non-hypothetical, auction-based WTP values for FBR in Shanxi Province. The last results section compares the different valuation methods. The main conclusions, limitations and pathways for future research are described in the last section of this chapter.

## *4.2. Measuring stated WTP*

### 4.2.1. Method

The stated willingness-to-pay (sWTP) of FBR is measured in the fifth part of the 2008 consumer survey in Shanxi Province (see section 3.2.2)[32]. To assess consumer's sWTP for this GM rice product, an open-ended contingent valuation approach is applied. Unlike closed-ended or dichotomous questions, where people have to decide whether or not to pay a specific provided premium, the respondents were asked to specify directly their WTP (Kealy and Turner, 1993; Balistreri et al., 2001).

There are several arguments to underpin the selection of an open-ended format, as compared to the dichotomous choice approaches.

First, this short, straightforward WTP question is a convenient method and especially appropriate when the participants are familiarized with the product (Mitchell and Carson, 1989).

Second, it does not require a large sample to evaluate a range of open-ended values (Venkatachalam, 2004). In choice experiments with Golden Rice, for instance, using dichotomous contingent valuation (DC-CV) complicated the design and increased the required sample size, as 6 different survey versions needed to be applied (Lusk, 2003).

Third, an open-ended elicitation procedure is expected to yield systematically lower hypothetical WTP estimates than a discrete-choice format (Brown et al., 1996; Schulze et al., 1996; Halvorsen and Soelensminde, 1998; Balistreri et al., 2001) and generates values who approximate values from experimental auctions (Balistreri et al., 2001). In other words, the open-ended values are assumed to be less subject to hypothetical bias than other contingent valuation methods (Balistreri et al., 2001). Higher values in the DC-CV approach could be due to the presence of an anchoring bias, because people use the randomly proposed bid as a reference point ('anchor') to adjust their initial valuation (Langford and Bateman, 1993). Furthermore, a starting point bias occurs when the reactions in the second question are determined by the offered price in the starting question (Herriges and Shogren, 1996; Ready et al., 1996).

[32] Although the valuation method to measure indirect WTP (iWTP) is also considered a stated preference method, it is not tackled here because it is included in the experimental auctions. It is also assumed to be less hypothetical because it follows a non-hypothetical WTP bid from the experimental auctions. Therefore, the methodology regarding iWTP is discussed in the auction related section (4.3.2.2), while the respective results are discussed in the comparison of different valuation techniques (4.4.3).

Fourth, there is no risk of creating a 'yea-saying' bias as in DC-CV, where participants agree with the offered bid, no matter what value this bid represents (Brown et al., 1996; Ready et al., 1996). One could then argue that OE-CV determines consumers' stated WTP rather than their acceptance of stated bids (Boyle et al., 1996).

Despite these advantages, open-ended questions are still criticized because they are assumed to be more vulnerable to strategic bias (Mitchell and Carson, 1989; Hanemann et al., 1991; Venkatachalam, 2004); and could be difficult to answer, especially when participants are not familiar with the market, by which people estimate the potential cost instead of their WTP (Hanemann and Kanninen, 1999). An overview of the potential biases of stated preference methods is presented in section 1.3.2.1.

Based on the consumer study in chapter 3, those who are not reluctant to FBR and willing to buy this product were asked the following open-ended question: *"Think of a situation where you can buy this GM rice for consumption, considering that 1 kg (or 2 Jīn)*[33] *of conventional rice costs 3 ¥ (Yuan) on average, at what price would you think this product is expensive, but you would still purchase it?"* Their stated price is then assumed to reflect the highest price they are prepared to pay for FBR. As this measure might be prone to criticism, e.g. consumers' stated valuation might be not necessarily the same as the highest price they would actually pay, this open-ended valuation measure should be interpreted with caution and compared with other preferences, such as auction-based values (see section 4.4.3).

A crucial precondition to elicit WTP values is the provision of unbiased, understandable information about the potential benefits (Hanley et al., 2006). Consumers state their sWTP based on objective GM information (see section 3.2.2), but without receiving any positive and negative information about GM food. The effect of such kind of information on WTP is further investigated in the experimental auctions (see section 4.4.2). If relevant, our survey-based measurement of the stated WTP complies with most of the 22 guidelines of contingent valuation methods, as listed by Bateman and Turner (1993). For example: a clear realistic scenario; consumers with experience of valuing the product; a WTP measure rather than using WTA (willingness-to-accept); provision of information that is not open to interpretation; a large, representative sample and no starting points. However, their recommendation to combine both open-ended and dichotomous choice approaches, to conduct additional validity tests and to include a control-group design to measure information and design biases is not followed because of practical and budgetary constraints.

Compared to the 'endowment' approach in the auctions, where respondents state their highest amount to exchange FBR with regular rice, sWTP was based on a 'full bidding' approach (this distinction is discussed in section 4.3.2). As a consequence, our open-ended WTP values should be interpreted in comparison with the price of a given benchmark (Lusk and Shogren, 2007). By comparing the stated price estimation with the current price of regular rice in 2008, i.e. 3 ¥[34], WTP for FBR is calculated as a continuous WTP-variable, which allows one to distinguish people who want a discount, an equal price or a premium. Unlike the DC-CV method (Chern and Chang, 2009), a direct price estimation based on

[33] Jīn is the most common measure for rice bags in Shanxi and China: 1 jīn is equal to half a kilogram.

[34] The average Shanxi rice price in 2008 that is mentioned in the survey is slightly below the average price for Japonica rice in China, ca. 3.5 Yuan (National Bureau of Statistics of China, 2008a). For an overview of the evolution of Chinese rice prices, see Annex 3.

the current price of regular rice was asked, instead of presenting different price scenarios for FBR. Mentioning the conventional price as a benchmark before the sWTP valuation of FBR provides a common reference price and thereby facilitated consumers' valuation of this novel product.

### 4.2.2. Data analysis

Data preparation and analysis was based on SPSS, version 15. Data mining reveals one important outlier regarding sWTP, with a value of ¥ 27. This value has been excluded from the analysis. A 5 % threshold was used as the critical significant level in the statistical analyses. Due to the 'full bidding' approach, the stated WTP values can be handled in two ways. On the one hand, one could focus on those willing to pay more (positive), an equal price (zero) or less than the regular rice (negative). On the other hand, one could compare those willing to pay more with those not willing to pay more. While the former allows negative values when ones' stated WTP falls below the regular rice price of ¥ 3, the latter truncated the values at 0. To analyze sWTP and its determinants, the approach of WTP as a continuous variable ($-\infty$ to $\infty$) was followed, in line with other WTP studies (Dickinson and Bailey, 2002; Parkhurst et al., 2004; Hobbs et al., 2006; Chern and Chang, 2009; Wang and McCluskey, 2010). As a 0-value is categorized as an equal price for FBR as the suggested regular rice, those who did not want to buy this product, i.e. 37 favorable or indifferent consumers, were not entered in this analysis.
This is contrary to the experimental auctions where the latter would be identified as 'zero bidders', together with those who are not willing to be pay more (but less or an equal price). To compare sWTP with these auction-based WTP values, these 'zero bids' were distinguished from the positive WTP values, i.e. the values of those who are willing to pay more for FBR than for regular rice (see section 4.4.3).

Regarding the statistical analyses, the non-parametric Mann-Whitney U test was conducted to explore the socio-demographic differences in the stated values. Multiple, linear regression was used to determine the causality between the independent metric variable (sWTP) and several potential predictors, either dummies or continuous, interval scaled variables (Malhotra, 2004). Although several assumptions of linear regression were satisfied, e.g. minimum sample size (5 times the number of variables as a rule of thumb), absence of multicollinearity, control outliers, expected causality, appropriate scale of variables, independence of observations (residuals), not all assumptions were clearly met, e.g. normality (satisfied in histogram of standardized residuals, but not in the Shapiro-Wilk Test) and homoscedasticity (constant variance of residuals not fully met). Therefore, the obtained output should be interpreted with caution (Janssens et al., 2008). Nevertheless, as suggested by Chern and Chang (2009) and Wayua et al. (2009), multiple regression is an appropriate technique to apply to WTP valuation studies when dealing with both negative and positive values.

## 4.3. Experimental auction design, materials and data analysis

### 4.3.1. Selection of the auction mechanism

#### *4.3.1.1. Overview of auction mechanisms*

No matter which auction mechanism is applied, experimental auctions should theoretically obtain the same WTP. Such WTP values are measured through a number of sealed bidding rounds, where a bid is assumed to reflect consumer's true value (see section 1.3.2.1.).

There are several auction mechanisms to obtain consumers' price preference for a novel product (see Table 27). These mechanisms differ in terms of the bidding procedures, the method to select a winner, the number of winners and the determination of the price these winner(s) should pay, i.e. the 'market price'. But what these procedures have in common is that they are all considered incentive compatible. According to Lusk & Shogren (2007, pp. 16-17): *"An auction is said to be incentive compatible when it induces each bidder to submit a bid that sincerely reflects his or her value for the good. Meaning each bidder has a weakly dominant strategy*[35] *to submit a bid equal to their value. I.C. auctions can be identified in that they separate what people say from what they pay. That is, an auction mechanism is incentive compatible if the market price paid by a person is independent from what he or she bids".* Stated differently, from a theoretical point of view, incentive compatible auctions should all yield the same WTP values for the auctioned good, namely the bidder's true value. The theoretical background which supports the incentive compatibility of the English (Coppinger et al., 1980), BDM (Irwin et al., 1998), random *n*th price (Parkhurst et al., 2004) and 2nd price auction (Vickrey, 1961) is not demonstrated in this PhD dissertation, except for an intuitive interpretation in footnote 36.

Table 27 Incentive compatible auction mechanisms

| | English | $n^{th}$ price | Random $n^{th}$ price | $2^{nd}$ price (Vickrey) | BDM | Collective auction |
|---|---|---|---|---|---|---|
| **Bidding procedure** | Sequentially offer ascending bids | Simultaneously submit sealed bids | | | | |
| **# winners** | 1 | n-1 | n-1 | 1 | 0 to all | 0 to all |
| **Market price** | Last offered bid | $n^{th}$ highest bid | Randomly drawn ($n^{th}$) | $2^{nd}$ highest bid | Randomly drawn | Mean bid |
| **Buyer(s) = pays market price** | Last (= highest) bidder | If bid > market price | If bid > market price | Highest bidder | If bid > market price | ∑ bids > ∑ costs |
| **References** | Coppinger et al., 1980 | Shogren et al., 2001b | | Vickrey, 1961 | Becker et al., 1964; Irwin et al., 1998 | Smith, 1980 |
| **GM food related examples** | (Lusk et al., 2001b) | Depositario et al., 2009a | Tegene et al., 2003 | Alfnes and Rickertsen, 2003 | Rousu et al., 2005 | / |

BDM, Becker-Degroot-Marschak, GM, genetically modified
*Source:* Lusk & Shogren (2007), except for the GM food related examples.

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[35] A key feature of incentive compatible auctions is their ability to induce a weakly dominant strategy. This means that if an auction participant pursues the strategy that yields a payoff, the derived utility is at least as great as in all other strategies, regardless of the bidding strategy of the other competing participants in the auction.

The English auction is commonly used in practice and is widely recognized. During this open auction, people continuously raise the price for an auctioned product until the point where nobody offers a higher bid. The participant that offered the last bid, i.e. the highest bid, wins the auction and purchases the product at the last rejected bid (Coppinger et al., 1980). A variant of the English auction is the Dutch (declining) auction, where the starting price is very high and is automatically lowered (e.g. by using a clock) until a bidder signals his/her WTP (Hoffman et al., 1993). In the $n^{th}$ and random $n^{th}$ price auctions, for example, the winning bidders (*n*-1) are selected by drawing (randomly) a number *n*, by which the market price is defined as the $n^{th}$ highest bid (Shogren et al., 2001b).

The second price or Vickrey auction mechanism is a highly recognized auction technique. It is considered as a specific version of the $n^{th}$ price auction and uses a sealed bidding procedure to select only one winner at the end of the auction (Vickrey, 1961; Shogren et al., 1994; Lucking-Reiley, 2000). The highest bidder is the winner or buyer, and purchases the auctioned good at the amount of the $2^{nd}$ highest bidder[36].

The collective auction goes further by summing the sealed bids and comparing the mean WTP with the sum of the provision costs in order to evaluate whether the group wins or not. In practice, this method is less implemented. A variant of the mean bid, is the 'collective WTP' based on group consensus (Rutsaert et al., 2010).

On the other extreme, there is the Becker-Degroot-Marschak (BDM) mechanism, which uses the same principle as the (random) $n^{th}$ price auction, but on an individual basis, without the simulation of an active market (Becker et al., 1964).

Except for the English and Dutch auction, the bidding procedure is closed, which means that participants simultaneously offer a sealed bid.

#### *4.3.1.2. Second price (Vickrey) auction mechanism*

Several economists examined this hypothesis in practice by confronting the second price auction with other widely used auction mechanisms, such as the BDM (Noussair et al., 2004), the random $n^{th}$ price (Shogren et al., 2001a), or both (Lusk and Rousu, 2006), or the BDM, the random $n^{th}$ price and the English auction (Lusk et al., 2004a). Based on their findings, multiple reasons can be cited for selecting the *$2^{nd}$ price Vickrey auction mechanism* to elicit WTP for FBR in Shanxi Province. These arguments are mainly associated with the research location, i.e. a poor, rural region; the auctioned product, i.e. $2^{nd}$ generation GM staple crop with consumer benefits; and the sample characteristics, i.e. rice consuming women of childbearing age.

[36] To explain the theoretical rationale behind the incentive compatibility of $2^{nd}$ price auctions, a mere, intuitive interpretation of this theoretical predication will be provided, based on Lusk & Shogren (2007). If the Vickrey auction is incentive compatible, bidding the true value for an auctioned good should be the weakly dominant bidding strategy. This can be illustrated when looking at deviating bidders. Compared to the obtained utility of true value bidders, the utility of bidders that state an amount that diverges from their true value could be equal, but could also be lower. It is the latter finding that justifies the use of $2^{nd}$ price auctions. For instance, if a participant bids lower than his true value (under-bidding), he could lose the opportunity of buying the auctioned product for a price he would be willing to pay. On the other hand, a participant that decides to overbid may have to buy the auctioned good for a price that is higher than his true value, which is the case when the $2^{nd}$ highest bid exceeds his true value. Thus, because the derived level of utility of bidding a true value is at least as high as in other bidding strategies, such as over- and underbidding, true value bidding behavior is the weakly dominant strategy.

First of all, low educated, poor participants can relatively easily understand the 2nd price auction (Lusk and Shogren, 2007; Wayua et al., 2009), which facilitates its implementation in regions like Shanxi Province, which are characterized by low socio-economic levels.

Second, this mechanism is recommended when the participants have valuations near the market price, the so-called on-margin bidders, whereas the random nth price auction is more appropriate when dealing with off-margin valuations (Shogren et al., 2001b; Lusk and Rousu, 2006). As the women in Shanxi are mainly responsible for the food purchases in their household, it can be assumed that they will have a good view on the current rice prices. Besides, due their low socio-economic situation, they are expected to be price sensitive (Kim, 2009) and will more actively respond to a food valuation experiment (Rutsaert et al., 2009).

Third, unlike the BDM, the 2nd price mechanism puts a higher cost on overbidding behavior (Lusk and Shogren, 2007). Reducing the incentives to overbid is important, as it can be expected that the deviating behavior of consumers in an auction with a relatively inexpensive good is to overbid, which could be considered as a more socially desirable action.

Fourth, the obtained 2nd price auction bids are more accurate than in the BDM (Noussair et al., 2004). Especially the WTP of high value bidders will be more likely to correspond with true values (Lusk and Shogren, 2007). In our auctions, values are expected to be high, given the selection of the sample in favor of involved participants, namely rice consuming women of childbearing age from a folate deficient region.

Although the WTP values in our auctions should not differ when other incentive compatible price-discovery techniques are applied, the results of the Vickrey auction mechanism are sometimes prone to criticism. According to Rutström (1998), the 2nd price auctions generate higher mean bids than the values of the BDM and English auctions, which is in line with the postulated critique that the Vickrey auction encourages overbidding (Kagel et al., 1987; Bernard, 2005). Other studies countered this criticism, though (Lucking-Reiley, 2000; Shogren et al., 2001b; Parkhurst et al., 2004), at least for the initial bidding round (Lusk et al., 2004a). Some authors reported even lower mean bids, indicating potential underbidding (Hong and Nishimura, 2003; Noussair et al., 2004). Another shortcoming refers to the risk of low value bidders to deviate from their true value in multiple repeated bidding rounds (Lusk et al., 2004a). In our auctions this potential problem is addressed by differentiating the provided information in each additional bidding round, instead of using repeated rounds.

Despite this criticism, there are additional reasons not to implement one of the other auction mechanisms, given the nature of this study.

First, the open nature of the English auction increases the risk of affiliated bids. Bidder affiliation or interdependent bids in an auction is the phenomenon where a high value bidder influences the possibility that his competitors will be influenced and increase their values (List and Shogren, 1999). Although bid affiliation could also occur in 2nd price auctions, making this mechanism incentive incompatible (McAfee and McMillan, 1987; Harrison et al., 2004), our auction design addresses these issues. For example, bid prices are not posted (see section 4.3.2).

Second, the random n^th price auction stimulates competition and generates better results for low value bidders (Shogren et al., 2001b; Lusk and Rousu, 2006), but appears to cause difficulties both for the participants to understand and the research administrator to manage (Lusk and Shogren, 2007).
Third, the BDM has proved its usefulness to efficiently conduct WTP auctions in field settings (Lusk et al., 2001a) or developing regions (De Groote et al., 2011), and reduces the risk of a group competition effect where people just bid to win, known as the top-dog effect (Corrigan and Rousu, 2006a), but the absence of a market environment still outweighs these benefits (Shogren et al., 2001a).

## 4.3.2. Bidding procedures

This section describes the characteristics of the bidding procedures in the 2nd price rice auctions in relation to scientific literature. The experimental auctions followed a self-reported sealed-bid endowment approach, with multiple information/bidding rounds and the possibility of bidding on an alternative product in half of the auctions. In addition to the general personalized valuation approach throughout the auction process, an indirect, depersonalized valuation component is incorporated in the 3rd round to explore social desirability.

### *4.3.2.1. Bidding method*

One of the most important choices an auctioneer needs to make is the bidding method of his auction. Basically there are two types of bidding strategies, endowment versus full bidding, which are juxtaposed in Table 28. In the full bidding procedure, auction participants bid the total amount they think one or more simultaneously auctioned products are worth. This approach is in line with the applied stated preference method in section 4.2.1. The endowment bidding strategy requires people to bid the amount they are prepared to pay to exchange an initial given conventional product with the novel, auctioned product.

The Vickrey auctions on FBR were based on the *endowment approach*. Proponents of this method mainly refer to the directly obtained WTP values as the most important advantage over full bidding (Hoffman et al., 1993). Through the process of upgrading, consumers' endowed bids represent their valuation of the difference between the conventional and the auctioned good. Another advantage is the possibility of obliging winners to consume the auctioned product, while others have to consume the endowed good, which increases the participants' involvement (Shogren et al., 1994). A third important benefit relates to the fee in order to reward participants for their participants. By using the endowed bidding strategy, the endowed product can be used as (a part of) the participant fee and could thereby mitigate the effect of high monetary participant fees (Rutström, 1998; Loureiro et al., 2003; Cherry et al., 2004). According to Rutström (1998), the endowed product should be of low(er) quality, which can then be upgraded with the attributes of the auctioned one. Finally, due to the exchange procedure, the WTP values in endowed bidding are expected to be less influenced by external market price information (Corrigan, 2005).

The endowment procedure is criticized by advocates of full bidding (Corrigan and Rousu, 2006a; Colson and Huffman, 2009) and should be implemented with caution. First of all, endowing participants with a good could reduce the WTP values as they might become attached to the endowed product, just because they own this good. This is the risk of 'loss aversion' hypothesis, a phenomenon that occurs when valuations are 'reference-dependent', i.e. dependent on the endowed product (Tversky and Kahneman, 1991). As Lusk et al. (2004a) observed, the risk of loss aversion in 2nd price auctions becomes a major concern after conducting multiple similar rounds and is, thus, less relevant for the non-repeated FBR information rounds. Furthermore, endowing products could cause a 'reciprocal obligation effect', by which consumers are bidding higher to reward the auctioneer for their endowment (Corrigan and Rousu, 2006a). In our auctions, we attempt to address this by providing a separate part of the participant fee (¥ 5) at the start of the auction, which could be used to bid on the auctioned products.

In our rice auctions, regular rice was endowed in order to measure the premium a consumer is willing to pay for FBR. In auction literature, however, GM food studies mainly determined the premium for a GM-free product or the compensation to sell a regular for a GM product (Lusk et al., 2001b; Jaeger et al., 2004; Li et al., 2004; Lusk et al., 2004b; Lusk et al., 2005; Costa-Font et al., 2008). Contrary to our design, these auctions solely focused on GM food products with modified agronomic traits in typically reluctant (developed) countries. Given the clear health benefits of FBR to the study population, and the relatively high acceptance rates of GM food (Huang et al., 2006b), GM rice (Li et al., 2002) and FBR in China (see chapter 3), regular rice is assumed to be an 'inferior product' compared to FBR. Nevertheless, regular rice might become 'superior' when the use of GM technology is negatively evaluated, i.e. in bidding round 3.

Table 28 Main characteristics of the endowment versus full bidding procedure in 2nd price auctions

| | **Endowment** | **Full Bidding** |
|---|---|---|
| **Basic principle**[a] | Bid to upgrade from a conventional product to a novel product | Bid on both the conventional and novel product |
| **Obtained value**[b] | Marginal value directly reflects WTP | No direct comparison of the values between the products |
| **Consumption requirement**[c] | Yes, if necessary | No |
| **Risk of loss aversion**[d] | Yes (if greater value attached to endowed product) | No |
| **Risk of reciprocal obligation**[e] | Yes | No |
| **Alternative participant fee**[f] | Yes, endowed product used as (partial) participant fees | No |
| **Bidding behavior**[a,g] | Forced bids if people consider the endowed product as inferior | People only bid true value if it is lower than actual value (market price) |

[a]Lusk & Shogren (2007); [b]Hoffman et al. (1993); [c]Shogren et al. (1994); [d]Lusk et al. (2004a) and Tversky and Kahneman (1991); [e]Corrigan and Rousu (2006a); [f]Lusk et al. (2001a); [g]Corrigan (2005)

#### 4.3.2.2. Direct, indirect and negative valuation

*Direct valuations*

The general bidding rule of the WTP measure, where bids can range between 0 ('no WTP') to ∞, was applied. As in nearly all experimental auctions, consumers' WTP was obtained through their own, direct valuation, i.e. self-reported bids. Therefore, participants bid by stating the highest amount they are willing to pay to exchange the endowed product (regular rice) with the auctioned product (FBR).

*Indirect valuations and social-desirability bias*

Although direct, self-reported statements are the most commonly used valuations in experimental auctions, the nature of such values may lead to social desirability bias (SDB). Social desirability is a social psychological phenomenon defined as *"a tendency of individuals to manage social interactions by projecting favorable images of themselves, thereby maximizing conformity to others and minimizing the danger of receiving negative evaluations from them"* (Johnson and Van De Vijver, 2002, p. 196). Despite evidence of the prevalence of SDB when using self-reporting or self-administered research methods (Fisher, 1993; King and Bruner, 2000; Johnson and Van De Vijver, 2002; Leggett et al., 2003; Lusk and Norwood, 2006) and hypothetical value elicitation methods (Leggett et al., 2003; Lusk and Norwood, 2009; Olynk et al., 2010), non-hypothetical value elicitation studies are seldom the subject of social desirability bias research. Nevertheless, social desirability could also bias experimental auctions, when higher WTP values reflect bidders' tendency to make a good impression on the auctioneer. This could be of major concern in laboratory based auctions, as scrutinizing peoples' bidding behavior in a controlled environment could create a Hawthorne effect[37] (Shogren et al., 1999; Levitt and List, 2005), especially when the auctioned good may involve negative reactions and the targeted audience is female (Lusk and Norwood, 2006). As these conditions were present in our 'laboratory' based auctions, prudence is in order.

In an attempt to reduce social desirability beforehand, the following precautions were taken:
(1) reducing the incentives to overbid as a SDB, by using the 2nd price auction mechanism to penalize overbidding more than underbidding (see section 4.3.2.1);
(2) simplification of the auction procedure by using vulgarized words, removing difficult questions, extending the amount of training and emphasizing the weakly dominant strategy to obtain true values;
(3) making people at ease, e.g. by starting the auction with the easiest part of the survey;
(4) reducing the bidders' need to please the auctioneer for the incentives, by separating the participant fee (after the auction rounds) and the amount of money to bid (before the auction rounds). In that way, bidders are less prone to reciprocal obligation (Lusk and Shogren, 2007), which can be seen as an act of social desirability where conformity is triggered by the high participant fee.
(5) ensuring anonymity, through the use of participant ID codes;
(6) measuring SDB.

[37] The classic Hawthorne effect states that participants in an experiment are influenced by their participation in the research itself (see for instance, Levitt and List, 2009).

There are basically two ways to measure SDB in value elicitation research.

One option is to include one of many social desirability scales (SDC), which are originally developed for psychological ends. Among the most employed measurements are the Marlowe-Crowne SDC (M-CSDS, 33 items) and its short-item variants (Crowne and Marlowe, 1960; Ray, 1984; Hays et al., 1989; Fleming and Zizzo, 2011) and the Eysinck Lie-Scale (EPQ-L) and its short-item variants (Eysenck et al., 1985; Lajunen and Scherler, 1999).

A second approach uses indirect questioning or bidding as a way to depersonalize the personal character of the self-reported bids. Therefore, one could ask respondents to estimate what others think an auctioned product is worth more than the regular counterpart (Fisher, 1993; Lusk and Norwood, 2006).

Both measurements were tested and evaluated during the pilot trials. But as the former was more likely to provoke confusion, e.g. because people question the relevance of such questions in a rice auction; and to generate a high non-response rate, due to the awareness of being subject to a lie-test, only an indirect valuation question was included after the third bidding round (see survey design, section 4.3.5). Rather than using an indirect valuation bidding procedure, an indirect valuation stated preference question (iWTP) was included in the survey that accompanied the direct valuation bids of the auction. By doing so, it is possible to compare both direct and indirect valuations, which might reveal potential SDB and validate the direct auction values.

*Negative valuations*

An important drawback of using WTP measurement is the fact that one cannot distinguish if someone bid zero because she is reluctant or because she is indifferent (Jaeger et al., 2004). A negative value approach makes it possible to further analyze why people bid zero: because they refuse to buy the product or because they need an incentive (discount) to purchase it.

Contrary to the general bidding rule, i.e. values truncated at zero, some authors introduced negative bids in their Vickrey auction to distinguish indifferent from reluctant people. Broadening the bidding rule to allow for negative bidding is relatively new in auction literature (Dickinson and Bailey, 2002; Parkhurst et al., 2004; Hobbs et al., 2006; Chern and Chang, 2009; Wang and McCluskey, 2010) and could be particularly relevant when auctioning controversial goods (Parkhurst et al., 2004), such as GM food products.

Here, negative bids were allowed for those who bid zero in one certain bidding round of our auction, specifically when information about the GM technology is provided (round 3, see section 4.3.4). In comparison with previous negative valuation literature, there was an additional bidding option for zero bidders in the GM bidding round. By excluding negative bidding from the actual auction rounds, we can avoid large negative bids that were submitted in order to increase the monetary benefits.

#### *4.3.2.3. Bidding procedures*

Bidding procedures differ in terms of the openness of submitting bids (sealed versus orally), the type of bidding rounds (repeated rounds versus information rounds, selection of binding round), the number of binding auction rounds and the provision of price information (benchmark price versus posted prices). The application of each aspect will be shortly discussed in relation to our auction design.

*Sealed bids*

Although organizing the 2nd price auctions orally might be valuable to include illiterate people (Wayua et al., 2009), the original *sealed-bid approach* of the Vickrey auction was maintained because it reduces the potential risk of bidder affiliation (Jaeger and Harker, 2005).

*Information rounds*

The rice auctions consisted of a *within-subject design with 5 non-repeated information rounds*. This makes it possible to measure the effect of additional information treatments on a participants' WTP while controlling for other factors, which is widely done in (GM) food auctions (Noussair et al., 2002; Tegene et al., 2003; Jaeger et al., 2004; Hu et al., 2006; Hellyer, 2010; Wang and McCluskey, 2010). The innovative approach in our auctions is to capture the effect of different FBR attributes by assigning them to different information rounds (see section 4.3.4).

Although repeated bidding rounds have an important advantage over non-repeated counterpart in that they allow the consumers to further learn the procedures of the auction mechanism, several authors lend support for a design with non-repeated information rounds (Alfnes and Rickertsen, 2003; Harrison et al., 2004; Corrigan and Rousu, 2006b), if extensive training (Drichoutis et al., 2010) and single binding is incorporated (see below).

*Single binding approach*

An auction with multiple bidding rounds requires a *single binding approach* to avoid the situation of people bidding less on sequential bidding rounds, due to diminished marginal utility or reduced demand (Jaeger and Harker, 2005). If a participant won the first round, and had to buy the product, she would probably bid lower in the following rounds as the extra utility she will derive from winning the same product would be lower. The same holds true for bidding on multiple products.

Therefore, only one round (and one product in the case of the two-product auctions, see section 4.3.3) was randomly selected as binding after the last auction round. In that way, a participant had an equal chance to win each round/product, and was informed prior to the first round that the winner will only have to buy a single product from the selected round. As a consequence, participants were expected to bid honestly in each round (Hobbs et al., 2006) and should behave in the same way as when several separate auctions with one single round would have been conducted (Roosen et al., 1998).

*Benchmark price and price posting*

There is a lot of discussion whether *a benchmark price* should be provided or not (Harrison et al., 2004; Bernard and He, 2010). According to Drichoutis et al. (2008) all that can be surmised is that there is likely to be an effect of posted prices on bid values. In the rice auctions, only the benchmark price of the endowed rice product was posted during the auctions, similarly to other rice auctions in developing countries (Corrigan et al., 2009; Rutsaert et al., 2010). In that way, all participants had common knowledge of the quality of the auctioned rice product. In line with Harrison et al. (2004), the bids of the (winning) participants were not revealed during the auction. This reduces the risk of bidder affiliation (Corrigan and Rousu, 2006b), which is likely to occur in auctions with novel, unfamiliar goods, such as GM food (List and Shogren, 1999). Nonetheless, the problem of affiliated bids and posting prices is mainly associated with the use of repeated rather than information bidding rounds (List and Shogren, 1999).

Avoiding price feedback is further supported by the fact that low value bidders will be highly affected by high posted prices, reducing their engagement (Lusk and Shogren, 2007), by which all bids converge with the posted winning price (Nunes and Boatwright, 2004).

### 4.3.3. Study design and participants

When designing the study, an important organizational decision needs to be made: the setting of the auction. Recently, the location of experimental auctions tends to shift more and more from the laboratory to the field, such as a supermarket (Harrison and List, 2004; Rousu et al., 2005; Knight et al., 2007; Corrigan and Rousu, 2008). When comparing both, laboratory auctions typically generate higher bids than experiments in a field or retail setting (Shogren et al., 1999; Lusk and Fox, 2003). Proponents of the latter question laboratory auctions for the increased risk of social desirability (see section 4.3.2.2), the lack of alternative options and real market influences, the more homogenous nature of the sample (Rousu et al., 2005) and the requirement of higher participant fees (Lusk et al., 2001a). Still, laboratory auctions have great merit in that the experimenter can control the setting and separately measure the effect of potential, selected determinants on consumers' bidding behavior. Therefore, the rice auctions were organized in a *laboratory setting.*

Table 29 summarizes the main characteristics of the implemented experimental auction design to elicit consumer's WTP for FBR. The auction design was developed, adjusted and refined during two pilot auctions that were held with students in Nanjing Agricultural University, Jiangsu Province. In total, 14 auction sessions with 252 women of childbearing age were held in Taigu, a rural county of Shanxi Province in April 2011.

Table 29 Design of the experimental auctions in Shanxi Province

| Target group | Auction location | Auctioned product(s) | Timing | Number of auctions | Participants per auction | Total participants |
|---|---|---|---|---|---|---|
| **Female students = student sample** | School | FBR | Morning | 1 | 20 | 20 |
| | | | Afternoon | 1 | 20 | 20 |
| | | | Evening | 1 | 20 | 20 |
| | | FBR + FAR | Afternoon | 1 | 20 | 20 |
| | | | Evening | 2 | 20 | 40 |
| | | **ALL** | **Total** | **6** | **20** | **120** |
| **Women of cba = non-student sample** | Auction room near market | FBR | Morning | 2 | 9; 19 | 28 |
| | | | Afternoon | 1 | 19 | 19 |
| | | | Evening | 1 | 19 | 19 |
| | | FBR + FAR | Morning | 1 | 16 | 16 |
| | | | Afternoon | 2 | 15;16 | 31 |
| | | | Evening | 1 | 19 | 19 |
| | | **ALL** | **Total** | **8** | **16.5** | **132** |
| **Women of cba** | | **TOTAL** | **Total** | **14** | **18** | **252** |

cba, childbearing age; FBR, folate biofortified rice; FAR, folic acid pills + rice

Two different *auction types* can be distinguished, depending on the number of products that were involved in the auction.

In all auctions the endowed product was a regular rice bag of 1 kg (2 jīn), which is available in the market at about 5.2 Yuan or 0.8 dollar in 2011. This was the most commonly bought rice bag and represents the second lowest quality (see also Figure 14). By using a low quality rice bag to elicit the value for the folate trait, the risk of a loss aversion hypothesis is further reduced and the WTP measure can be applied. In the first type of auctions, only FBR was auctioned. As this GM rice product is not ready for commercialization, and given the assumption that FBR only differs in the folate trait, a similar rice bag was used as a GM rice bag. However, in our auctions, we claimed that it was FBR so that people actually bid on a product of which they think is genetically modified (see section 4.3.4).

In the second auction type, however, folic acid supplements were attached to a regular rice bag (FAR) and sold next to the FBR. In this way, one of the most important means to increase folate intake levels is brought into the auction. Hence, we partly address the need to include substitutes as an auction design effect in GM food auctions, as acknowledged by Kassardjian et al. (2005) and Corrigan et al. (2005; 2009). To measure the effect of this substitute on WTP for FBR, only half of the participants could bid on the two folate products.

Based on the research location, two target groups are distinguished.

In an auction room in Shanxi Agricultural University, 120 female Shanxi students (18 - 24 year) took part in 6 school based auctions. Due to the involvement of the local University staff, it was possible to recruit 20 participants per auction. This ‘student sample’ represents the future generation of pregnant women. Another 8 auctions were targeted towards Shanxi women of childbearing age (‘non-student sample'), i.e. 132 participants. Here, the auction room was closely situated to a small vegetable market and the largest supermarket of Taigu county.

Together, the total sample consists of 252 women of childbearing age. According to Liu (2009), auction samples typically vary between 100 and 200 participants, which supports our sample size. The size of the two subsamples is considered valuable to measure the effect of the target group and the auction type (FAR versus FBR). Due to practical constraints regarding the recruitment of the non-student sample, the assumption of a fixed set of bidders per auction was not satisfied. Moreover, the average number of participants per auction, 18 women, might be considered high compared to a common auction size of 10 people. Umberger and Feuz (2004), for instance, discovered a positive relation between auction size and the market price. A higher auction size decreases the expected cost of deviating from truthful bidding, because it lowers the probability of winning and experiencing monetary consequences. Given the limited evidence of negative influences of increasing the auction size, and the incentive compatibility of $2^{nd}$ price auctions, the auction size is expected to be of less primordial importance than, for instance, the amount of training these participants receive.

The auctions were held on different days of the week. As auctions during working hours may exhibit a sampling bias, leading to higher rates of unemployed people (Wang and McCluskey, 2010), weekend and evening auctions were included. Also the timing of the auctions differed, which increases the chance of a time-of-the-day effect (Hoffman et al., 1993). Previous auctions with staple crops in developing countries pointed out the existence of higher WTP values in the morning (Rutsaert et al., 2009; De Groote et al., 2010).

The effect of each of the above mentioned auction design characteristics, i.e. target group (student versus non-student sample), auction type (FBR versus FBR+FAR), auction size and the timing (time, day), is examined in the analysis.

### 4.3.4. Auction design

Figure 13 gives an overview of the different steps of the experimental auctions, from the recruitment of the participants to the debriefing stage.
Hereunder, each of the auction events will be discussed in the order of occurrence[38].

[38] For a detailed overview of the whole procedure of the experimental auctions, reference is made to the "FBR auction manual – guide for the Chinese researcher", which was developed to further assist the experimental auctioneers during the auctions in Shanxi Province. This guide is available at: http://users.ugent.be/~hdesteur/Auction_guide/

| STEP 1–3 | STEP 4. Rice auctions | | | | | STEP 5. |
|---|---|---|---|---|---|---|
| **STEP 1. Recruitment**<br>- recruitment form<br>- participant conditions | ***Auction round 1*** | ***Auction round 2*** | ***Auction round 3*** | ***Auction round 4*** | ***Auction round 5*** | **STEP 5. Debriefing & closing**<br>- selection buyer<br>- revealing the truth<br>- participant fee<br>- free rice bag |
| **STEP 2. Arrival & Introduction**<br>- consent form & ID<br>- explanation procedures<br>- ***survey pt. A***[a]<br><br>**STEP 3. Training & Practice**<br>- gas cooker example<br>- quiz with candy bar<br>- chocolate auction trial<br>- announcement winner | Folate content:<br><br>Same taste, appearance, … as regular rice<br><br>40 times more folate<br><br>Regular portion allows to achieve the RNI of folate | Folate benefits:<br><br>reduces the risk of:<br>- pregnant women: NTDs and stillbirths<br>- heart and cardio-vascular diseases<br>- Alzheimer, anemia<br><br>improves the overall resistance to diseases | GM technology:<br><br>FBR is made using genetic modification (GM)<br><br>Provision of GM food definition<br><br>*FAR is not made using GM technology*[b] | GM information:<br><br>randomly distributed GM information sheets<br>- positive<br>- negative<br>- objective<br>- positive + negative<br>- negative + positive<br>- all<br>(see Table 30) | Shanxi situation:<br><br>- folate deficiency rate<br>- burden of folate deficiency<br>- potential health impact of FBR | |
| | ***Bid 1+ survey pt. B***[a] | ***Bid 2 + survey pt. C***[a] | ***Bid 3 + survey pt. D***[a] | ***Bid 4*** | ***Bid 5***[c] | |

Figure 13 Sequence of steps in the experimental auctions in Shanxi Province

FAR, folic acid pills + rice; FBR, folate biofortified rice; GM, genetic modification; NTD, neural-tube defect; RNI, recommended nutrient intake; pt., Part

[a]The survey consisted of four parts, each related to a specific bidding round:
- Part A: socio-demographic information and knowledge of folate – before the start of the experiment;
- Part B: folate related questions (knowledge of benefits, of a women who delivered an NTD, of the National birth defect program, use of folic acid pills – before round 2;
- Part C: GM food objective knowledge and acceptance of GM food – before round 3;
- Part D: indirect valuation (estimated WTP of the average Shanxi women) – after round 3

[b]In half of the auctions, rice with free folic acid supplements is provided as a substitute. All information treatments in these 2-product auctions are similar, except for the 3rd and 4th auction round, where the non-GM nature of FAR is specifically mentioned.

[c]In the FBR + FAR auctions, a final question was added to the last bidding slip in order to determine consumers' final product preference.

*Step 1. Recruitment*

The participants were required to fulfill the following five criteria: female, of childbearing age, consuming and buying rice, living in Shanxi Province and capable of reading and writing. As a consequence, no illiterate consumers participated in the auctions. Although this might be interesting from a health intervention point of view, it would require oral bidding and an interviewing approach, which would have impeded auction procedures, such as sealed bidding (Wayua et al., 2009).

Participants were recruited by distributing a recruitment form with a schedule of the upcoming auction hours. To make sure that not only those who are interested in the study are taking part in the experimental auction, participants did not receive specific indications as to the nature (GM, folate,…), objective (WTP) and aim of the experimental auctions at the time of recruitment. Potential participants are asked to participate in a "consumer experiment with rice", organized on behalf of Nanjing Agricultural University and Shanxi Agricultural University. As people could react differently when they would be aware of the involvement of the foreign institute, Ghent University was never mentioned and their staff was not physically present during the auctions. To attract the participants, they were also informed about the monetary and material incentives, and the maximum duration of the study.

*Step 2. Arrival and introduction*

Upon arrival at the auction room, each participant was seated and received an informed consent form; a specific participant ID, to track her questionnaire and bidding slips; and the first part of the questionnaire (part A), which contains information about her socio-demographic profile and knowledge of folic acid. When all participants passed on their documents to one of the organizers, a short introduction of the partners and the purpose of the session was given, followed by a brief overview of the different steps and a summary of the general rules of the auction, including a reminder of the confidentiality and anonymity. People were asked not to talk during the session unless told otherwise.

*Step 3. Training and Practice*

Extensive training, learning through interaction and practice, is considered extremely important to avoid confusion and misunderstanding about the auction mechanism and its weakly dominant strategy (Brown, 2005; Plott and Zeiler, 2005; Drichoutis et al., 2010).

Before starting the training and the trial session, people learned the procedures of the 2nd price auction mechanism: what is an auction; what do you have to bid (i.e. the highest amount you are truly prepared to pay to exchange the conventional product, initially given to you, with an alternative auctioned product"); what can you bid (i.e. between 0 and ∞); who has to buy the product (i.e. highest bidder in randomly selected round); at what price (i.e. 2nd highest bid) and why to bid honestly (*"If you bid more than you actually value the product, and you win, you may have to pay more than you think it's worth. On the contrary, if you bid less than your true value, the product might be sold to another participant for a price you would have actually wanted to pay"*).

The training session consisted of two examples, one with a non-food (gas cooker[39]) and one with a food product (candy bar). Hypothetical, numerical bids were shown to illustrate the 2nd price auction mechanism. Afterwards, a small quiz was organized to find out if people understand the auction mechanism procedures. In the 'two products' auctions, the examples were extended to contain two auctioned products.

After the training, a real-money practice round with chocolate is conducted to further familiarize with the procedures. To reduce the impact of the trial auction and the improve the learning process, the endowed product was cheap, small and well known (Jaeger and Harker, 2005; Liu, 2009; Hellyer, 2010; Rutsaert et al., 2010). Each participant was given a small regular milk chocolate bar of ¥ 2, which was then considered their own chocolate bar, and a trial bidding slip. While the trial in the FBR auctions consisted of two rounds with a bigger, dark chocolate bar, two big chocolate bars (black versus hazelnut) were auctioned in the FBR+FAR trials.

*Step 4. Rice auctions: FBR versus FBR+FAR auctions*

Before the rice auction actually started, the general rules were presented once again, e.g. anonymity and confidentiality, best strategy, possibility of zero bids, and the selection of buyer. From this point on, all communication was prohibited.

Besides a regular rice bag of 1 kg or ¥ 5.2 (i.e. benchmark price), participants received a bidding slip and ¥ 5 as a budget, which could be used to bid on the product(s)[40]. Regardless of the number of auctioned products, five auction rounds were run in the same order, alternated with different parts of the questionnaire (see section 4.3.2.3). Each round contained new information about FBR and/or FAR, by which participants could adjust or maintain their previous bid.

Below, the different information rounds are described in more detail. Unless otherwise mentioned, the information refers to both products in the FBR + FAR auctions. To facilitate consumers' evaluation throughout the rice auctions, the word use was simplified and consequently used, as Tegene et al. (2003) suggests. Words, like micronutrients (round 1), biotechnology or genetic engineering (round 3), NTDs (round 5), were replaced by more vulgarized or common concepts.

In the *first information round*, the improved vitamin content of the product was mentioned. Regarding FBR, the only difference with the rice bag is its increased folate content, i.e. about 40 times more than in the endowed regular rice bag. Participants were informed that it is exactly the same rice bag, except for this folate content. All other rice attributes, such as taste, appearance and cooking quality, are assumed to be similar. Although the attribute changes are not fully mapped yet (see section 1.3.1.3), these assumptions were needed in order to measure the effect of the folate trait.

[39] The gas cooker example was chosen as it reflects a common exchange practice in Shanxi Province. New gas cookers are sold door-to-door, where people can decide whether they want to pay to upgrade their old gas cooker.

[40] Analogues to the chocolate trial round of the FBR+FAR auctions, the auctioned rice products were presented by a randomly assigned three-digit code.

In the case of the rice bag with folic acid pills, seven supplements were attached to a regular rice bag[41]. In this way, the folate content is exactly the same as in FBR, i.e. approximately 40 times higher than in the regular rice bag[42]. By consuming a regular FBR portion or a folic acid pill, one could achieve the daily recommended folate intake, which would not be possible with the regular rice bag. After reporting their WTP, the consumers received part B of the questionnaire. This part measured the knowledge related to folate benefits, and preceded round 2.

*The second information round* provided the participants with information about the benefits of the higher folate content of the auctioned product(s): *"Consuming this product (and achieving the daily recommended folate intake level) is good for the health of women, because it drastically reduces the risk of pregnant women to deliver a baby with a (neural-tube) birth defect, such as spina bifida (split spine or open back) or a still birth[43]. Consuming your regular rice product likely will not protect you against having a baby with a birth defect. It also reduces the risk of anemia (lack of oxygen in the blood), certain cancers, Alzheimer, coronary and cardiovascular diseases. In addition consuming more folate also improves the overall resistance to diseases".* People were then asked if this information changed their WTP. If so, they could report a different value, if not, they could indicate the same bid. This strategy was consequently followed throughout the auction process. After this round, part C of the survey was distributed to measure consumers' knowledge and acceptance of GM food.

The *third information round* is considered as the key bidding round. Because this round only mentions the GM nature of FBR, it is considered as the GM-round, i.e. the round where people evaluate this technology based on their prior believes, without the influence of additional GM related information (round 4). Half of the participants also learned about the folic acid pills as a non GM substitute, which might affect FBR bids, as Jaeger and Harker (2005) have shown. As the next round will be used to provide the participants with GM food information, only a general definition of GM food is mentioned here: *"GM food is food of which the genetic material has been modified by technology in order to introduce new characteristics from plants or animals to other kinds of plants or animals. By doing so, the food will be changed in shape, nutritional or consuming quality, and other aspects"* (derived from FAO, 2004a; Lusk et al., 2004b; HGP, 2008; Bansal et al., 2010). Although results could be influenced when consumers would be informed about the specific characteristics of the transgenic technology that has been applied (Jaeger and Harker, 2005; Colson and Huffman, 2009; Novotorova and Mazzocco, 2009), only a general GM food definition was provided to reduce the complexity of this auction round.

As this is the last round were all participants receive similar information about FBR, an additional bidding slip was given to those who bid zero in this round, i.e. who did not want to pay for FBR. Hereby, they were asked if – and how much - they would be willing to buy FBR if the price would be

[41] Although there is a clear difference between folic acid and folate (see section 2.3), Mandarin uses a common character for both, which avoids the need to clarify this technical difference between folic acid supplements and folate enriched rice to the participants.

[42] A regular rice bag of 1 kg contains 80 µg of folate, while a FBR bag of the same size contains approximately 3 000 µg (see section 2.4.4.2). To be able to compare this with FAR, we attached 7 folic acid pills to the bag (2 800 µg). Although the actual folate content between FBR and FAR slightly differs, we only mentioned that both products contain about 40 times more folate as the regular rice bag. Therefore, emphasis was put on the achievement of the recommended daily folate intake (RNI), rather than the specific folate concentrations.

[43] A drawn picture of neural-tube defects was shown (see Figure 9 in Chapter 2).

lower than the regular rice bag. Stated differently, the zero bidders in the 3rd round had the opportunity to bid a negative value (see section 4.3.2.2). Here, our approach differs from the study of Parkhurst et al. (2004) who incorporated negative values in the bidding procedure itself.
After this round, people were asked to fill in the last part of the questionnaire, which deals with indirect valuation to determine consumers' stated WTP of the average female consumer in Shanxi Province (see section 4.3.2.2 and 4.3.5).

In the *fourth information round*, each participant received one out of six information sheets which contain several statements about genetic modification: positive, negative, positive + negative, negative + positive, objective, all. As Table 30 shows, the different information treatments were equally divided between the participants of the FBR and FBR+FAR auctions on the one hand, and two target groups on the other.
While the positive GM information sheet mainly represents the view of the agricultural biotechnology industry and supporting organizations like ISAAA, the negative GM information is based on statements from the world leading environmental organization, i.e. Greenpeace (2011a), and the only major anti-biotech NGO in China, i.e. Utopia (2011). Third information was mainly derived from a study of Tegene et al. (2003) where the so-called objective, verifiable third party GM information had a significant positive impact on the opinion of reluctant US consumers.
When developing these sheets, special attention was paid to the relevance for the reader, as this positively influences their understanding and valuation (Jaeger et al., 2004). For example, each information forms contained a statement that refers to the Chinese context. The focus of the statements was also broadened to GM food in general, including 1st and 2nd generation GM, as both the environmental and health benefits are expected to have a significant impact on consumers' WTP (Frewer et al., 1996; Jaeger et al., 2004; Lusk et al., 2004b; Kassardjian et al., 2005).
The inclusion of these combined treatments makes it possible to assess whether negative information is dominating in two-sided GM information, as Tegene et al. (2003), Hu et al. (2006) and Depositario et al. (2009a) found, or whether positive information prevails, in line with other GM food valuation studies (Rousu et al., 2004b; Colson and Huffman, 2009; Corrigan et al., 2009). As a consequence, also the order of conflicting GM information, i.e. the presence of primacy or recency information order effects, could be examined. Therefore, the two-sided information treatment was assigned to twice the amount of participants who received another information sheet.

Table 30 GM information sheets, per auction type and location, and GM information descriptions.

| Information sheet | FBR auctions | | FBR + FAR auctions | | Total |
|---|---|---|---|---|---|
| | Student sample | Non-student sample | Student sample | Non-student sample | |
| Positive | 10 | 11 | 10 | 11 | **42** |
| Negative | 10 | 11 | 10 | 11 | **42** |
| Positive + negative | 10 | 11 | 10 | 11 | **42** |
| Negative + positive | 10 | 11 | 10 | 11 | **42** |
| Objective | 10 | 11 | 10 | 11 | **42** |
| All (positive + negative + objective) | 10 | 11 | 10 | 11 | **42** |
| **Total** | **60** | **66** | **60** | **66** | **252** |

**GM Food information descriptions**[a]

1. Agricultural Biotech Industry view on GM (positive information)

GM FOOD …
… is one of the **greatest discoveries in agriculture** and could **lower farmer costs and food prices**, e.g. by developing crops that are resistant to diseases and drought;
… could be **one of the most environmentally helpful discoveries ever**, e.g. by reducing the use of chemical insecticides by more than 50 %
… products, like GM rice, are **safe according to the China's Ministry of Agriculture**

*Source: Leading GM food developing companies and research institutes*

2. Environmental Group view on GM (negative information)

GM FOOD …
… is very dangerous because **unknown adverse effects** could be catastrophic;
… could pose **major health problems, such as the development of new allergens**;
… could **harm bio-diversity** and **disturb the eco-system,** e.g. some **insects developed tolerance** towards insect-resistant GM crops;
… is already **illegally sold in China without approval of its safety**;

*Source: Greenpeace, an international leading environmental group*

3. Independent view on GM (objective information)

GM FOOD …
… is a technology where **genes are transferred** across plants or animals, **a process that would not otherwise occur**;
… with improved vitamin content is **currently not commercialized in China**;
… has a **largely unknown** impact on the environment.
… are **produced by businesses that seek profits**

*Source: Parties with no financial stake in GM foods.*

FBR, folate biofortified rice; FAR, folic acid pills + rice; GM, genetically modified
[a]adapted from different pro-, anti-, and objective GM stakeholders (Tegene et al., 2003; Huffman et al., 2004; Lusk et al., 2004b; Huffman et al., 2007; Rousu et al., 2007; Greenpeace India, 2008; Colson and Huffman, 2009; James, 2009a; Waltz, 2010; Greenpeace China, 2011b).

Whereas the previous auction rounds focused on product-related information, such as the folate content (round 1), the health benefits (round 2), the production method (round 3) and information about the production method (round 4), the *fifth information round* introduced an information treatment related to the participants' residence, Shanxi Province.

This information treatment revealed the link between the folate benefits of the auctioned product(s) and the current situation in Shanxi Province: *"Of all Chinese Provinces, Shanxi Province could especially benefit from consuming more folate, either by consuming folate enriched GM rice, or rice sold together with folic acid pills, instead of regular rice. The current daily folate consumption of Shanxi women is far below the daily recommendations. About 40 % of Shanxi pregnant women are assumed to be folate deficient, the highest number in China, and one of the highest in the world. Due to their low folate intake, Shanxi women deliver every year one of the highest numbers of (neural-tube) birth defects, like spina bifida, in the world. About 1-2 out of 100 births in Shanxi Province are characterized by a birth defect, which may have been prevented if their mothers had been consuming more folate"* (adapted from section 2.3.2.1 and 2.3.3). As participants could feel uncomfortable when learning about the low, ‘unhealthy’ folate intake levels of women in this province, this issue is touched as the last auction round.

In the FBR+FAR auctions, the last bid is followed by a short question to determine which of the two auctioned products a participant would prefer if both would be available in the store. Such a product comparison is also used in contingent valuation methods with other biofortified products (Corrigan et al., 2009). After this round, a binding round and/or product, and a buyer was selected. However, in the case where FBR was selected as binding, debriefing was required (step 5).

*Step 5. Debriefing and closing*

No matter which auctioned product was selected as binding, the participants were informed about the purpose of the study and, more important, the truth behind the auctioned GM rice product. As our product is far from commercialized, we could not sell this product for real when it was selected as binding. As participants needed to believe that they were really bidding on a GM rice product with high folate content, in order to maintain the non-hypothetical character of the study, they were informed that it was necessary to claim that the auctioned product was genetically modified. When this product was selected as binding, the exchange was ultimately cancelled. When the FAR bag was selected, the exchange and payment took place. This procedure follows Kassardjian et al. (2005).

Another important debriefing issue is to mention that it is fairly important that participants could not communicate with others about the objectives and the true meaning of the experiment. People who enter an auction room with knowledge of the true nature of the auctioned GM product would bid significantly different than others. To reduce this risk all auctions were conducted in a short time (i.e. 6 days) at two different locations (i.e. auction room in school and close to the market place).

### 4.3.5. Auction survey

The auction questionnaire consisted of four parts, which were administered in between auction rounds (see Figure 13, section 4.3.4). This novel approach of conducting auction surveys requires that the experimental auctioneer carefully controls the immediacy of the answers so that a participant is not aware of future information treatments.

This section describes the content of each survey part in the order of occurrence. Some of the questions refer to the survey on FBR acceptance in 2008, which is elaborated in chapter 3.

*Part A* was distributed at the start of the auction and dealt with the socio-demographic profile of the female rice consumers. According to the review of Lusk et al. (2005), sample characteristics are largely responsible for differences in WTP values between GM food studies. Due to the complexity of the auctions, these questions were used to make the participant at ease. The following items are adopted from the 2008 survey (see section 3.2.2): age, education, income, farmer family[44] and residence. As this study is conducted in a poor, rural Chinese region and particularly targets women versus students of childbearing age, socio-demographic indicators (e.g. age and education) are biased. Furthermore, a yes/no question measured if women were responsible for the rice purchases in their household. Knowledge of folate was measured by giving three potential definitions and asking participants to pick the one they believed to be correct.

The folate and folic acid related questions of *Part B* followed the 1st bidding round. First, to see whether participants have knowledge of the folate benefits, three alternative options were provided, of which only one is correct. Second, two questions referred to the past use and the current intake of folic acid pills. The former consists of 5 answer categories (no, never; no, I don't know; yes, ever; yes, at least 2 months before pregnancy; yes, during pregnancy), of which the latter two categories indicate if they correctly use it. Current folic acid use (yes/no) is divided into two positive answers, depending if they received the supplements for free or not. Knowledge about the Chinese National Program to reduce birth defects (see section 2.4.1.2) is expected to be associated with free folic acid supplement use. Finally, involvement in the topic is further reflected in the question: "*Do you know a woman who delivered a baby with a birth defect ?"* (no; yes; yes, myself).

*Part C* precedes the GM related information of the 3rd auction round and, therefore, measures consumers' objective knowledge of GM food, as described in section 3.2.2. The variable GM food acceptance is similar to the FBR acceptance construct in the 2008 survey, but refers to the broader term of GM food.

*Part D* of the survey was situated between round 3 and 4 and encompassed indirect valuation to measure social desirability bias (see section 4.3.2.2). Indirect or depersonalized stated WTP (iWTP) was measured by included the following question after the third bidding round: *"Do you think the*

[44] Compared to the consumer survey in chapter 3, I broadened the farmer related variable to consumers that are living in a household with farming activities, rather than being the farmer.

*average female rice consumer in Shanxi would be willing to pay more to exchange her bag of rice with a GM rice bag with higher folate content (and more health benefits)?".* According to their answer, people could indicate how much the average Shanxi woman is willing to pay more to exchange her product. Although optimal indirect valuation would require attachment of monetary consequences to consumer bids, we decided to include this item in the questionnaire, rather than using it as a standard bidding procedure throughout the auctions. As such, iWTp must be considered as a stated value.

### 4.3.6. Data analysis

The data preparation was based on SPSS, version 18. First, some of the variables, such as folic acid use, income and education, needed to be recoded into dummy variables in order to be included in multivariate data analyses. Second, the objective GM knowledge score was operationalized as in the consumer acceptance study (see section 3.2.2). Third, extreme outliers which might be an indication of heavy auction fever are explored. There was only one participant, of which the data needed to be removed due to extremely high bids.

Because the WTP values were not normally distributed, but left-skewed, non-parametric tests were required. The Mann-Whitney U test and the Kruskall-Wallis test were applied as the non-parametric equivalent of one-way ANOVA to identify significant WTP differences between, respectively, two (e.g. number of auctioned products, target group) or more (e.g. auction timing, GM food acceptance) grouping variables. To test whether bids differ between two or more information rounds, the Wilcoxon (matched-pairs) signed-rank test (two) and the Friedman test (more) were selected[45]. $Chi^2$-test was applied to analyze differences between categorical variables.

Given the typically left censored distribution of mean bids in experimental auctions, with a large proportion of bids close or equal to zero, the Tobit regression (Tobin, 1958) or the double-hurdle model (Cragg, 1971) are considered as appropriate multivariate techniques to analyze the factors that influence WTP for FBR. By using STATA (version 10), the double-hurdle method was utilized because it addresses the need to distinguish the participation from the consumption decision process (Haines et al., 1988). The double-hurdle is based on a probit model to determine whether participants want to bid or not (first hurdle; participation effect), followed by a truncated regression model to explain the amount of those who actually bid (second hurdle; consumption effect), i.e. when bids are truncated at zero. All entered predictors are either continuous or (recoded into) dichotomous variables. A 10 % threshold was used as the least critical level of significance in the double hurdle estimates, which is common in WTP valuation studies (e.g. Lusk et al., 2001a; Maynard et al., 2004; Han and Harrison, 2006; Froehlich et al., 2009).

[45] The sign test is similar to the Wilcoxon signed rank test, but the latter is used as it assumed to be more powerful (Roosen et al., 1998).

## 4.4. *Results and discussion*

### 4.4.1. Stated willingness-to-pay for folate biofortified rice (sWTP)

#### *4.4.1.1. Stated WTP for folate biofortified rice*

The average price consumers stated to be willing to pay (sWTP) for 1 kg of FBR in 2008 is ¥ 5.15 (or US$ 0.8). This is significantly higher than the average price of 1 kg conventional rice, i.e. ¥ 3. Similar positive results are obtained in other GM food CV studies in China (Li et al., 2002; Lin et al., 2006).

As mentioned in the methodology section, sWTP is a continuous variable, based on the valuation of consumers that are not resistant to FBR. By using the Mann-Whitney U-test a significant difference ($p<0.03$) is found between the sWTP of favorable and indifferent consumers, with the former (¥ 2.25) more willing to pay for FBR than the latter (¥ 1.91). Comparison of these self-reported WTP values with the conventional rice price demonstrates that 94.1 % of these respondents want to pay a premium (¥ 2.32 on average), while 5.9 % do not accept a higher price, of which 51.1 % asks for a discount, ranging from ¥ -0.1 to ¥ -2.0. About 37 persons were excluded from the analysis, as these persons are not willing to buy FBR ('zero bidders'). The high number of people that are prepared to pay a premium could be an indication of hypothetical bias.

Table 31 presents sWTP as a continuous, a truncated or a positive value. The lower, truncated mean sWTP value (¥ 2.09) includes the 'zero bids' and is compared with the auction values in section 4.4.3.

Table 31 Stated willingness-to-pay

| WTP value | n | Mean | Std. dev. |
|---|---|---|---|
| sWTP (continuous[a]) | 801 | 2.15 | 2.09 |
| sWTP ≥ 0[b] | 838 | 2.09 | 2.06 |
| sWTP > 0 | 754 | 2.32 | 2.04 |

*Note*: 1 ¥ is about US$ 0.15.
[a]Including negative values. Zero values refer to an indifferent valuation, while those who did not want to pay are excluded; [b]Positive values and 'zero bidders', i.e. those who did not want to pay more for FBR.

Because the multiple regression analysis in the next section only includes consumers with subjective GM food knowledge, the table below presents the socio-demographic differences in mean sWTP of all indifferent and favorable rice consumers. The valuation differences reveal that, within this group, women, members of a small family, respondents with a high income or education level and rural consumers stated a higher sWTP value.

Table 32 Significant sWTP differences per socio-demographic variable, by Mann-Whitney U test (n=801)

| Variable | Categories | Mean sWTP | p |
|---|---|---|---|
| Gender | Male | 1.79 | 0.00 |
| | Female | 2.49 | |
| Family size | <2 persons | 2.85 | 0.01 |
| | >2 persons | 2.11 | |
| Education | Low | 2.00 | 0.01 |
| | High | 2.54 | |
| Income | Low | 2.08 | 0.00 |
| | High | 3.08 | |
| Residence | Urban | 2.51 | 0.00 |
| | Rural | 1.76 | |

*Note*: sWTP refers to the continuous values as shown in Table 31. 1 ¥ is about US$ 0.15.

#### *4.4.1.2. Explaining stated WTP for folate biofortified rice*

Multiple regression analysis focuses on those with subjective knowledge in order to identify the influence of key concepts of FBR acceptance (see also Figure 2, section 1.3) on sWTP. The model ($R^2$: 0.2) shows that age, the importance of health in rice purchase and the GM risk perception have a significant positive influence, while family size, residence, subjective GM rice knowledge and perceptions of the price impact negatively affects the stated preference (Table 33). The importance of each factor is reflected in the size of the standardized coefficients.
When looking at the socio-demographic profile, living in a rural area, being older than 40 years and having a small family increases sWTP. Despite the higher relevance of FBR to women, gender is not significant. This might be due to the fact that valuations of women are generally lower than of men (Feuz et al., 2004) or because men are less involved in rice purchases and, thus, have limited price awareness. Unlike previous research (Kinsey, 1997; 2008), positive income effects on WTP are not observed, at least not in the general sample of indifferent and favorable consumers.
Furthermore, if consumers attach large importance to the health characteristics of rice when purchasing it, sWTP for FBR will be higher.
In line with the acceptance study (chapter 3), there is no one-sided positive effect of objective GM knowledge. Instead, stated knowledge about GM rice negatively influences the stated preference. With respect to consumer perceptions, people stated higher WTP values when they are less concerned about the GM risks. Stated WTP for FBR is lower when people have better expectations of its price impact. Although the respondents were explicitly told not to, this relationship shows that some consumers might have linked their price expectations to their valuations, which is an important criticism of hypothetical (open-ended) valuation (Schkade and Payne, 1994; Lusk and Shogren, 2007). The insignificance of acceptance is most likely due to the sample of analysis, which does not contain reluctant consumers.

The explained variance of the model increases to 50 % when farmers are analyzed separately. For this particular group, sWTP is influenced by education, income and residence. Rural farmers with a low income and education level are less willing to purchase. These findings indicate that prosperous farmers would (or state to) be more interested in cultivating this GM rice. This lends support for the need to attract poor subsistence, rural farmers with more competitive prices (e.g. royalty-free policy; Brewster et al., 2005). The significant determinants of the non-farmers sample mainly correspond with those of the total sample.

It is important to note that this model is based on continuous WTP values, i.e. without zero bids. As a consequence, the results should be carefully interpreted and should not be compared with the regression model of the auction-based WTP values (see section 4.4.2.4). For this reason, the main focus in this chapter and in the respective research question (RQ4A) will be on the auctions.

Table 33 Determinants of sWTP for FBR, by multiple linear regression, split up between farmers and non-farmers

| | All | | Farmers | | Non-farmers | |
|---|---|---|---|---|---|---|
| | **β** | **p** | **β** | **p** | **β** | **p** |
| *Socio-demographic* | | | | | | |
| Gender | -0.11 | 0.38 | 0.02 | 0.90 | -0.09 | 0.44 |
| Age | **0.12** | 0.04 | 0.14 | 0.22 | **0.14** | 0.03 |
| Family size | **-0.13** | 0.02 | -0.11 | 0.27 | **-0.13** | 0.02 |
| Education | -0.05 | 0.46 | **0.25** | 0.02 | -0.04 | 0.52 |
| Income | 0.03 | 0.60 | **0.46** | 0.00 | -0.03 | 0.61 |
| Farmer family | 0.01 | 0.94 | NA | NA | NA | NA |
| Residence | **-0.27** | 0.04 | **-0.33** | 0.04 | -0.23 | 0.07 |
| *Perceived importance of rice attributes* | | | | | | |
| Health | **0.14** | 0.01 | 0.13 | 0.24 | 0.10 | 0.09 |
| *Knowledge* | | | | | | |
| Objective GM | 0.07 | 0.21 | 0.08 | 0.52 | 0.06 | 0.38 |
| Subjective GM rice | **-0.10** | 0.05 | 0.02 | 0.89 | **-0.11** | 0.05 |
| *Consumer perceptions* | | | | | | |
| Benefits | 0.02 | 0.77 | 0.08 | 0.44 | -0.01 | 0.87 |
| Risks | **0.11** | 0.04 | 0.01 | 0.91 | **0.17** | 0.01 |
| Safety | 0.05 | 0.38 | -0.16 | 0.21 | 0.07 | 0.27 |
| Price impact | **-0.16** | 0.00 | -0.01 | 0.91 | **-0.16** | 0.01 |
| *Acceptance (versus indifference)* | | | | | | |
| FBR | -0.01 | 0.92 | 0.01 | 0.90 | 0.02 | 0.76 |
| ***$R^2$*** | **0.21** | | **0.50** | | **0.15** | |

NA, not applicable

*Note*: This regression refers to the continuous sWTP variable, as shown in Table 31. To include the knowledge and consumer perception variables, only indifferent and favorable consumers with GM food knowledge are included (n=375). All socio-demographic variables are dummy coded, similar to the multinomial regression analysis in Table 15 (section 3.3.2).

## 4.4.2. Auction-based willingness-to-pay for folate biofortified rice (WTP)

The results of the experimental auctions in Shanxi Province are presented in seven different subsections. First, the sample descriptive statistics (section 4.4.2.1) and a summary of the bids are given (section 4.4.2.2), with a particular focus on the third key round (section 4.4.2.3). The determinants of WTP for FBR are mapped in section 4.4.2.4. Section 4.4.2.5 describes the role of the different information treatments, while section 4.4.2.6 further explores what information drives people to stop bidding (zero bidding behavior).

### *4.4.2.1. Sample descriptive statistics*

The characteristics of the sample are presented according to the target group (Table 34). The inclusion of a student subsample imposed limitations with respect to the representativeness of the Shanxi population. First, students are highly educated, young women without earnings who are seldom in charge of the rice purchase. On the contrary, low education and income levels are dominating in the non-student sample, which reflects the current socio-economic situation in Shanxi Province. Second, conducting auctions in a rural county led to a higher share of farming families and rural consumers, as compared to the province-wide sample in the consumer survey in chapter 3.
One needs to take into account these target group-based biases. Therefore, a 'target group' variable was included in the multivariate analysis as an indicator for different socio-demographic differences. Hence, when there is a significant target group effect, this will be very much attributable to the distinct socio-demographic profile of the two target groups.

The general target group, i.e. women of childbearing age, are better informed about folic acid, its benefits and the national birth defect program. This might be due to their age and their history of a pregnancy. The use of folic acid is relatively low among this group. Respectively 12.5 % and 22 % of the student and non-student sample have ever used folic acid. Current use is lower, but this is likely due to low number of pregnant women[46]. Moreover, only four participants indicated that they used it before and during pregnancy, which might be a partial explanation for the low effectiveness of folic acid supplementation programs in Shanxi Province (see section 2.4.1.1).
A large proportion of the sample is aware of a woman who delivered a baby with a birth defect (41.3 %), of which three participants delivered a birth defect themselves. Especially in the student auctions the knowledge of NTD affected pregnancies is high, which confirms the high prevalence of NTDs in Shanxi Province. As expected, knowledge of the birth defect program is significantly related with knowing folic acid ($\chi^2 \equiv 22.38(2)$, $p<0.001$) and its benefits ($\chi^2 \equiv 29.81(2)$, $p<0.001$), and the use of folic acid supplements ($\chi^2 \equiv 22.61(2)$, $p<0.001$).
The objective GM knowledge score is significantly higher in the student sample (67 %) than in the non-student sample (35 %), of which the latter is consistent with the consumer survey in 2008 (39 %; see section 3.3.1).

[46] Only 3 participants were pregnant at the time of the auctions.

Finally, the GM food acceptance rate of the general target group is almost twice as large as in the student sample. Nevertheless, the GM food acceptance rate in this 2011 study, with 78 % of the total sample not being reluctant, supports the optimistic view of Shanxi consumers in 2008.

Table 34 Socio-demographic and auction-related variables, per target group

| | | Student sample | | Non-student sample | | Total sample | |
|---|---|---|---|---|---|---|---|
| **Variable - continuous** | | **mean** | **st.dev** | **mean** | **st.dev** | **mean** | **st.dev** |
| *Socio-demographic indicators* | | | | | | | |
| Age | | 20.86 | 1.29 | 39.44 | 9.76 | 30.41 | 11.67 |
| *Knowledge* | | | | | | | |
| Objective GM | | 0.67 | 0.17 | 0.35 | 0.25 | 0.50 | 0.27 |
| **Variable** | **Categories** | **n** | **%** | **n** | **%** | **n** | **%** |
| *Socio-demographic indicators* | | | | | | | |
| Education[a] | Low | 0 | 0 | 101 | 76.5 | 101 | 40.1 |
| | High | 120 | 100.0 | 31 | 23.5 | 151 | 59.9 |
| Income[b] | Low | NA | NA | 124 | 93.8 | 124 | 93.8 |
| | High | 0 | 0 | 8 | 6.2 | 8 | 6.2 |
| Farmer family[c] | Yes | 48 | 40.0 | 55 | 41.7 | 103 | 40.9 |
| | No | 72 | 60.0 | 77 | 58.3 | 149 | 59.1 |
| Residence | Urban | 30 | 25.0 | 13 | 9.8 | 43 | 17.1 |
| | Rural | 90 | 75.0 | 119 | 90.2 | 209 | 82.9 |
| Rice purchase[d] | No | 113 | 94.2 | 19 | 14.4 | 132 | 52.4 |
| | Yes | 7 | 5.8 | 113 | 85.6 | 120 | 47.6 |
| *Knowledge* | | | | | | | |
| Folic acid | No | 89 | 74.2 | 84 | 65.2 | 173 | 69.2 |
| | Yes | 31 | 25.8 | 46 | 34.8 | 77 | 30.8 |
| Folate benefits | No | 99 | 82.5 | 95 | 72.0 | 194 | 77.0 |
| | Yes | 21 | 17.5 | 37 | 28.0 | 58 | 23.0 |
| NTD women[e] | No | 77 | 64.2 | 71 | 53.8 | 148 | 58.7 |
| | Yes | 43 | 35.8 | 61 | 46.2 | 104 | 41.3 |
| Birth defect program | No | 82 | 68.3 | 71 | 53.8 | 153 | 60.7 |
| | Not sure | 26 | 21.7 | 23 | 17.4 | 49 | 19.4 |
| | Yes | 12 | 10.0 | 38 | 28.8 | 50 | 19.8 |
| *Folic acid use*[f] | | | | | | | |
| (Ever) use | No | 105 | 87.5 | 103 | 78.0 | 208 | 82.5 |
| | Yes | 15 | 12.5 | 29 | 22.0 | 44 | 17.5 |
| Current use | No | 105 | 87.5 | 115 | 87.1 | 220 | 87.3 |
| | Yes | 11 | 9.2 | 9 | 6.8 | 20 | 7.9 |
| | Yes, for free | 4 | 3.3 | 8 | 6.1 | 12 | 4.8 |
| *Acceptance* | No | 28 | 23.3 | 28 | 21.2 | 56 | 22.2 |
| GM food | Indifferent | 67 | 55.8 | 54 | 40.9 | 121 | 48.0 |
| | Yes | 25 | 20.8 | 50 | 37.9 | 75 | 29.8 |

cba, childbearing age; NA, not applicable
[a]Low: primary or secondary school; high: college or above; [b]The threshold for the income variable is a yearly income of ¥ 40 000 (about 6 152 US$); [c]Farmer family' refers to being a member of a farming household; [d]Dummy variable indicating whether the respondent is responsible for the rice purchases in her household; [e]Awareness of a women who delivered a baby with an NTD; [f]Past or current use of folic acid supplements.

#### *4.4.2.2. Overview of the bids regarding WTP for FBR and FAR*

Table 35 summarizes the main results of the bidding process during the experimental auctions. Although this section focuses on the total average WTP values, the average WTP values without zero bids are also presented. The data does not reveal extreme outliers, which reduces the probability of auction fever. This phenomenon occurs when the auction conditions drive participants to bid high only because they want to win.

Table 35 Overview of average bids, standard deviations, zero bids, per auction type and per auction round

| | **Round 1** | | **Round 2** | | **Round 3** | | **Round 4** | | **Round 5** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **FBR** | **FAR** | **FBR** | **FAR** | **FBR** | **FAR** | **FBR** | **FAR** | **FBR** | **FAR** |
| *Student sample* | | | | | | | | | | |
| N | 119 | 60 | 119 | 60 | **119** | 60 | 119 | 60 | 119 | 60 |
| Average bid (in ¥) | 1.22 | 0.56 | 1.71 | 0.80 | **1.34** | 0.93 | 0.70 | 0.87 | 1.22 | 1.35 |
| Std. deviation | 1.06 | 0.98 | 1.40 | 1.20 | **1.48** | 1.27 | 0.92 | 1.10 | 1.20 | 1.37 |
| Zero bids (#) | 12 | 31 | 7 | 18 | **27** | 15 | 48 | 12 | 29 | 4 |
| Zero bids (%) | 10.00 | 51.67 | 5.83 | 30.00 | **22.50** | 25.00 | 40.00 | 20.00 | 24.17 | 6.67 |
| Av. bid w/o zero bids (in ¥) | 1.36 | 1.17 | 1.82 | 1.15 | **1.74** | 1.23 | 1.18 | 1.09 | 1.61 | 1.44 |
| Std. deviation | 1.04 | 1.15 | 1.38 | 1.29 | **1.47** | 1.33 | 0.93 | 1.13 | 1.12 | 1.36 |
| *Non-student sample* | | | | | | | | | | |
| n | 132 | 66 | 132 | 66 | **132** | 66 | 132 | 66 | 132 | 66 |
| Average bid (in ¥) | 1.59 | 0.97 | 2.23 | 1.17 | **2.08** | 0.94 | 1.43 | 0.97 | 2.09 | 1.21 |
| Std. deviation | 1.56 | 1.58 | 1.82 | 1.40 | **1.93** | 1.35 | 1.65 | 1.16 | 1.88 | 1.42 |
| Zero bids (#) | 15 | 30 | 5 | 19 | **17** | 27 | 37 | 21 | 11 | 13 |
| Zero bids (%) | 11.36 | 45.45 | 3.79 | 28.79 | **12.88** | 40.91 | 28.03 | 31.82 | 8.33 | 19.70 |
| Av. bid w/o zero bids (in ¥) | 1.79 | 1.79 | 2.32 | 1.64 | **2.39** | 1.60 | 1.99 | 1.31 | 2.28 | 1.51 |
| Std. deviation | 1.54 | 1.77 | 1.80 | 1.41 | **1.88** | 1.43 | 1.64 | 1.19 | 1.85 | 1.44 |
| *Total sample* | | | | | | | | | | |
| n | 251 | 126 | 251 | 126 | **251** | 126 | 251 | 126 | 251 | 126 |
| Average bid (in ¥) | 1.42 | 0.78 | 1.99 | 0.99 | **1.73** | 0.94 | 1.09 | 0.88 | 1.67 | 1.28 |
| Std. deviation | 1.36 | 1.34 | 1.65 | 1.32 | **1.77** | 1.31 | 1.40 | 1.13 | 1.65 | 1.39 |
| Zero bids (#) | 27 | 61 | 12 | 37 | **44** | 42 | 85 | 33 | 40 | 17 |
| Zero bids (%) | 10.71 | 48.41 | 4.76 | 29.37 | **17.46** | 33.33 | 33.73 | 26.19 | 15.87 | 13.49 |
| Av. bid w/o zero bids (in ¥) | 1.58 | 1.51 | 2.09 | 1.41 | **2.10** | 1.40 | 1.64 | 1.20 | 1.99 | 1.48 |
| Std. deviation | 1.34 | 1.55 | 1.63 | 1.37 | **1.74** | 1.38 | 1.43 | 1.16 | 1.61 | 1.39 |

FAR, folic acid pills + rice; FBR, folate biofortified rice; w/o, without
*Note*: 1 ¥ is about US$ 0.15 Bold indicates values of the key auction round regarding FBR.

The Mann-Whitney U test reveals significant differences between the two target groups in all FBR bidding rounds, but not for the FAR bids. Except for the first round, all mean FBR bids are significantly lower in the group of female students as compared to the non-student sample. The contradiction with the general assumption that student and non-student samples generate similar valuations (Lusk et al., 2005; Depositario et al., 2009b) is only reflected in the FBR bids. This leads to the conclusion that besides the socio-demographic characteristics of the two target groups, also the controversial nature of an auctioned good account for inter-group variations.

Other design characteristics that could account for bidding differences are the size, the timing, the day of the auction and the number of auctioned products. Regarding the auction size it is important to notice that only the number of participants in the student auctions could be controlled. Both the smallest (n=9) and the largest auction size (n=20) generated the lowest bids. As there is only a clear auction size difference for the FBR bids in round 4, where the group size of 16 participants has a significantly higher score ($p<0.001$), other factors are assumed to be more important in differentiating the sample. With respect to the time and the day, no significant bid differences were found. Unlike previous research (Rutsaert et al., 2009; De Groote et al., 2010), bidding behavior does not differ significantly between morning, afternoon or evening sessions, nor between auctions on weekdays versus weekends. Regarding the latter, only the 5$^{th}$ round is remarkably higher in the weekend, but the significance disappears when analyzing the target groups separately.

Another important finding is that, contrary to our expectations, bids are no less different when a folate substitute was offered. In every auction round, even in the 3rd auction round, having the option to bid on FAR did not result in a significant lower WTP for FBR.

Looking at the FAR bids of the third information round, only students increased their bid when lowering their FBR value. However, students who lacked the possibility to bid on the substitute reduced their WTP for FBR in the same way. Even more surprising is the fact that the general target group also lowered their FAR bids in the third round, which confirms the unattractiveness of FAR as a substitute. Compared to the compliance of taking pills, the convenience of folate incorporated in FBR seems to outweigh the absence of GM technology in FAR. Thus, it seems that FAR might be more successful for the future generation of mothers, but it is not likely to affect their valuation of folate enriched rice, which is lowered in the 3rd round, regardless of having a GM-free option.

At the end of the FBR + FAR auctions, i.e. in half of the auctions, the female rice consumers were asked to state their preference when both products would be available in the market. As such, consumers' preference reflects an 'informed' choice.

In general, 61.6 % of the sample prefers FBR over FAR[47]. The preference differs according to the target group ($\chi^2 \equiv 22.76(1)$, $p<0.001$). While the majority of participants in the non-student auctions are in favor of the GM rice variant (81.5 %), the preference of the female students is more oriented towards FAR (60 %). It is important to note that this does not mean that students do not want to buy FBR, but they generally prefer FAR over FBR, regardless of their value for FBR.

In nearly all cases, the product with the highest value is preferred. This is important, as it shows that the submitted WTP bids represent the valuation of the consumers, rather than their evaluation of the (preferred) cost of the auctioned product. Measuring product preference at the end of the auctions can be considered an additional tool to validate the bidding procedures and to examine whether consumers understand the purpose of bidding. For instance, if a participant expects that her response will influence the future price of a product, as Lusk (2007) states, she would probably prefer the product with the lowest value.

#### *4.4.2.3. WTP for folate biofortified rice*

The third round is considered the key auction round. Here, women bid on FBR with knowledge of the nutritional content (round 1), the health benefits (round 2) and the applied GM technology (round 3). This is also the last common information round and precedes the GM information treatment (round 4).

In general, female Shanxi rice consumers are willing to pay 1.73 ¥ (US$ 0.27) more for 1 kg of this GM rice variant (see Table 35). Although the premium of 33.7 % appears to be high, similar premiums are reported for other biofortified crops in developing countries, such as maize in Kenya (24 %, De Groote et al., 2011), rice in India (19.5 %, Deodhar et al., 2008), the Philippines (40.0 %, Depositario, et al., 2009), and China (38.0 %, Li et al., 2002). Some studies found even higher premiums, e.g. for

[47] Another indication of the substantial market demand for FBR is the feedback after the auction. For example, respondent 160, among many other participants, asked the auctioneer: "*When will this kind of folate rice actually be available, because I want to buy it.*" (translated from Chinese)

cassava in North-East Brazil (up to 60-70 %, Gonzalez et al., 2009). Nevertheless, one should be careful to draw conclusions by comparing premiums from different biofortification studies, as they differ in terms of the auctioned products, the targeted audience, the information treatment and research location. For example, endowing consumers with a rice product of a higher quality or increasing the rice bag weight would not necessarily lead to the same premium or value increase. The loss-aversion hypothesis (Tversky and Kahneman, 1991), for example, might reduce consumers' attractiveness to exchange their endowed rice.

Because the size of the premium share is dependent on the volume and the price of the endowed product, it is also interesting to look at the absolute increases. When adding this premium price to the price of the endowed, regular rice bag (¥ 5.2), FBR is worth ¥ 6.9 per kg. Figure 14 shows how this premium is ranked among the 'currently' available rice products in Shanxi Province. It illustrates how FBR, initially interpreted as a low quality (Q2) product with enhanced folate content, is valued as equal to the Q3 rice. In other words, folate biofortification raises the quality of a rice product to the next quality level. In this way, the premium is likely to be an indication for price-awareness of Chinese consumers (Kim, 2009)[48] and the rising demand for food quality in China, even in low income households (Wang and McCluskey, 2010), rather than a prove of auction fever.

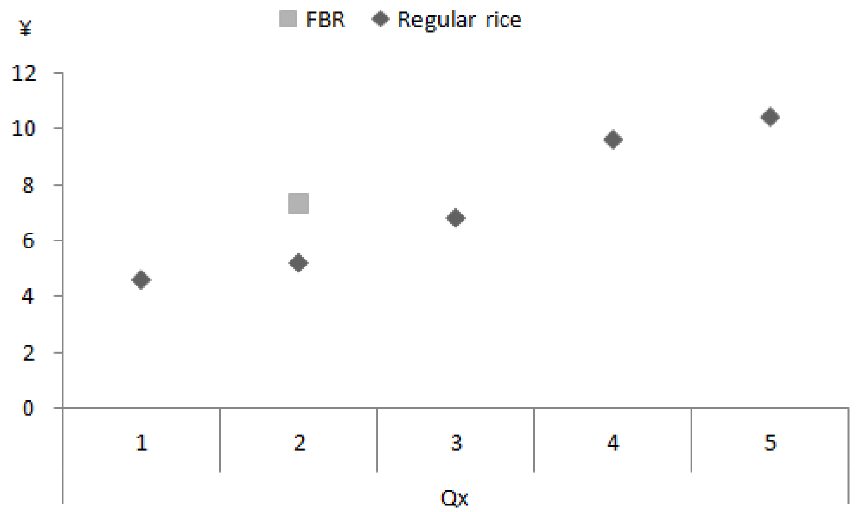

Figure 14 Benchmarking FBR within the range of market prices for rice in Shanxi Province, in ¥ per kg

*Note*: Regular rice prices refer to the Taigu retail market in April 2011. Qx indicates the quality level of the regular rice products. Except for the enhanced folate content, FBR is similar as Q2, i.e. the endowed product. 1 ¥ is about US$ 0.15

While the FBR bids are significantly higher in the non-student sample, i.e. 0.74 ¥ higher, the number of zero bidders is higher in the student auctions. Stated differently, the students more strongly oppose GM rice with folate related health benefits than the general Shanxi consumer, with a non-WTP share of 22.5 % and 12.9 %, respectively. This is in line with WTP research on vitamin enriched GM rice in China and Golden rice in India, where respectively 81.3 % (Li et al., 2002) and 70 % (IIM, 2007) were not reluctant to GM rice. The relatively low number of zero bids might be attributed to the recruitment conditions, by which the primary target group of FBR participate in the auctions. The difference

[48] In round 2 participant 147 state it as follows: *"Even though this rice is very healthy, I consider rice as a main food product in our daily life, so I don't bid too high"* (translated from Chinese).

between the two subsamples might be also attributed to the lower involvement of students, which is expected to lower the bids (Fox, 1995).

The value of rice with free folic acid pills (0.94 ¥) is lower than for FBR, regardless of the target group. As stated before, including FAR did not influence the FBR bids, even when people are informed about the non-GM nature of the former. Nevertheless, looking at the zero bids reveals an important discrepancy between the two subsamples. While the share of zero bids for FBR and FAR are more or less similar in the student sample, the FAR zero bidders dominate the non-student sample. Thus, the valuation of FBR is significantly lower for students, which is also reflected in the bigger opposition. Therefore, when the zero bids would not be taken into consideration, FBR and FAR values are slightly converging in the total sample.

One shortcoming of auction data is the lack of information on the factors that influence the bidding behavior. High bids could be due to the extensive training (Drichoutis et al., 2010), the positive information rounds about the high nutritional content, the similarities with regular rice (round 1) and the potential health benefits (round 2), the high involvement of the participant target groups, the general acceptance of the auctioned product and other personal characteristics. The inclusion of an auction survey which measures socio-demographic and auction design characteristics is an important step to discover the determinants. In the next section, the influence of the most relevant survey variables will be examined.

#### *4.4.2.4. Determinants of WTP for FBR*

In this section, the determinants of WTP for FBR in the first three rounds are analyzed, as these are the common information rounds. Based on the double hurdle model, the factors that influence the probability of bidding and the level of the bids are examined. The variable 'target group' is included to take into account the socio-demographic differences that characterize the two samples, such as education, age and the responsibility of rice purchases. As the objective of this study is to analyze WTP for FBR in a poor, rural high-risk region, income is generally low and with insufficient variation, by which it cannot be entered in the analysis. Only farmer family and residence are well distributed to be included. As several variables were highly correlated, e.g. folic acid use versus current folic acid use, the most relevant variable was selected to avoid multicollinearity.

The results of the double-hurdle model per information round (1-3) are presented in Table 36. The insignificant effect of auction type, i.e. offering FAR or not, is confirmed throughout the bidding rounds, which justifies our choice to analyze both types together. Having the option to bid on FAR does not significantly lower the FBR values. Therefore, one could argue that either the folic acid supplements are not attractive enough to compensate for potential negative perceptions of GM technology, or GM technology is not seen as unattractive enough to outweigh the perceived benefits.

In the first two rounds, where information about folate and its benefits is provided, FBR is presented as if it were a conventionally bred biofortified crop. No significant effects are found in the first hurdle during the first two rounds. It seems that the one-sided positive information about the consumer benefits is warmly embraced by most of the consumers. This is in line with the positive WTP values for conventional biofortified crops, as observed by De Groote et al. (2011). Regarding the level of the bids, a target group effect comes into play, with the general target group bidding higher than the female students.

Furthermore, knowledge of the folate benefits increases the level of WTP values, but only in the second round. When the experimenter informed participants about these benefits, this appears to confirm their initial knowledge by which they bid significantly higher. This supports the presence of a confirmation (Schulz-Hardt et al., 2000; Jonas et al., 2001) or congeniality bias (Hart et al., 2009), by which information that is consistent with preconceptions is preferred. Such a prior nutritional knowledge effect was not found in other valuation studies on biofortified crops (De Groote et al., 2011) but does seem to be an important success factor in Asian nutrition interventions (Hardjanti, 2005). However, nutritional knowledge does not influence the purchase decision as such. Other variables, such as residence, farmer family, current use of folic acid supplements or awareness of a woman with a NTD-affected pregnancy are insignificant.

Both hurdles of the GM related third round demonstrate an important target group effect. The general target group of women who are of childbearing age, represented in the non-student auctions, have a significantly higher probability of bidding and are prepared to pay more than the female students. The dummy variable 'GM food acceptance' is the most important effect of the model. It positively influences the probability of paying for FBR and the amount that is submitted. In other words, people who are not resistant to GM food are more willing to pay (more) for FBR. These effects correspond with findings from several valuation studies that investigated determinants of WTP for GM food (Bredahl et al., 1998; Verdurme et al., 2003b; Lin et al., 2006; Costa-Font et al., 2008), including the amount of WTP (Kassardjian et al., 2005; Lusk et al., 2005; Colson and Huffman, 2009).

Furthermore, the positive impact of objective GM knowledge on WTP is only significant in the first hurdle, i.e. higher objective knowledge associates with a higher probability of participation. When monetary consequences are attached to stated preferences for a controversial GM product, being less correctly informed about the GM technology leads to a higher chance of zero bidding, i.e. reluctance. Compared to the FBR acceptance study in chapter 3, where high objective GM knowledge was related to either FBR acceptance or reluctance, rather than indifference, these results highlight the importance of GM food knowledge when making a purchase decision regarding GM food (House et al., 2004). Although not investigated here, more positive GM food consumer perceptions could provide an answer to this discrepancy.

Although there is no direct evidence that socio-demographic characteristics influence WTP values - which has also been postulated by other researchers (Umberger and Feuz, 2004) - the significant effect of the 'target group' variable is very likely to have acted as a proxy of socio-demographic influences. Being higher educated (House et al., 2004), younger (see Table 33), less responsible for rice purchases and less involved are likely to account for such target group differences. With respect to the general low income levels in the non-student sample, the results show that even poor consumers are prepared to pay for quality, a finding that has been confirmed in other food auction studies in developing countries (Gonzalez et al., 2009; Wayua et al., 2009; Demont et al., 2011; Rutsaert et al., 2011).

Table 36 Determinants of WTP for FBR, double hurdle estimations, per information round (1-3)

| Round 1 | 1st hurdle coefficient | st. error | p | 2nd hurdle coefficient | st. error | p |
|---|---|---|---|---|---|---|
| Target group[a] | -0.094 | 0.220 | 0.668 | **1.511*** | 0.851 | 0.076 |
| Auction type[b] | 0.290 | 0.218 | 0.183 | 0.812 | 0.748 | 0.277 |
| Farmer family | 0.260 | 0.227 | 0.252 | -0.666 | 0.746 | 0.372 |
| Residence | 0.223 | 0.295 | 0.225 | 0.967 | 1.147 | 0.399 |
| Folate benefits | 0.098 | 0.270 | 0.717 | 1.300 | 0.849 | 0.127 |
| Constant | 0.549 | 0.497 | 0.269 | -3.096 | 2.533 | 0.222 |
| Sigma[c] | | | | 2.613 | 0.473 | <0.001 |
| Log likelihood | -83.698 | | | -317.045 | | |
| n | 251 | | | 224 | | |
| **Round 2** | **1st hurdle coefficient** | **st. error** | **p** | **2nd hurdle coefficient** | **st. error** | **p** |
| Target group[a] | 0.191 | 0.286 | 0.504 | **1.260*** | 0.666 | 0.059 |
| Auction type[b] | 0.006 | 0.282 | 0.982 | -0.612 | 0.605 | 0.312 |
| Farmer family | 0.004 | 0.295 | 0.989 | -0.207 | 0.619 | 0.738 |
| Residence | 0.011 | 0.389 | 0.978 | 0.073 | 0.868 | 0.933 |
| Folate benefits | 0.508 | 0.442 | 0.250 | **1.460**** | 0.706 | 0.039 |
| Current folic acid use | -0.483 | 0.358 | 0.177 | 0.266 | 0.896 | 0.766 |
| Knowledge NTDwomen | 0.154 | 0.299 | 0.606 | -0.130 | 0.609 | 0.831 |
| Constant | 1.501 | 0.657 | 0.022 | -0.689 | 1.668 | 0.680 |
| Sigma[c] | | | | 2.689 | 0.355 | <0.001 |
| Log likelihood | -46.107 | | | -400.145 | | |
| n | 251 | | | 239 | | |
| **Round 3** | **1st hurdle coefficient** | **st. error** | **p** | **2nd hurdle coefficient** | **st. error** | **p** |
| Target group[a] | **0.633**** | 0.263 | 0.016 | **2.503**** | 1.198 | 0.037 |
| Auction type[b] | 0.119 | 0.201 | 0.554 | -0.252 | 0.819 | 0.758 |
| Farmer family | 0.218 | 0.218 | 0.317 | 0.759 | 0.898 | 0.398 |
| Residence | 0.107 | 0.271 | 0.693 | -0.231 | 1.179 | 0.845 |
| Objective GM knowledge | **0.784*** | 0.468 | 0.094 | 0.156 | 1.868 | 0.933 |
| GM acceptance[d] | **1.008***** | 0.223 | 0.001 | **3.357**** | 1.592 | 0.035 |
| Constant | 0.044 | 0.541 | 0.935 | -3.269 | 2.862 | 0.253 |
| Sigma[c] | | | | 3.122 | 0.518 | <0.001 |
| Log likelihood | -102.162 | | | -348.515 | | |
| n | 251 | | | 207 | | |

*Note*: *, **, *** denote statistical significance at 10 %, 5 % and 1 %, respectively. Except for objective GM knowledge, all variables are dummy variables (see Table 34). First hurdle = participation model, based on probit regression. Second hurdle =consumption model, based on truncated regression.
[a]'0' = student-sample, '1' = non-student sample; [b]'0' = one auctioned product (FBR), '1' = two auctioned products (FBR and FAR). [c]Sigma is the error variance. [d]Acceptance of GM food is dichotomized: '0' = indifferent or favorable, '2' = reluctant. Other contrasts were excluded due to insignificance.

### *4.4.2.5. The role of information*

This section analyzes the influence of information on the valuation of FBR alone, and compared with FAR. Except for the 4$^{th}$ auction round, where six GM information treatments are randomly distributed, each round consists of one common information treatment, as shown in Table 30. As each participant received all information treatments in the same order, the valuation of new information has to be perceived as the consumers' trade-off between the latest information and the preceding information treatment(s). By doing so, one cannot interpret the valuation of the GM trait of FBR as an isolated information trait, but as an additional characteristic of the auctioned product. This resembles actual market behavior, where consumers' purchase intensions for GM food are determined by their evaluation of the different product attributes (Ganiere et al., 2006).

In order to analyze the effect of the five information rounds, the non-parametric Friedman test for repeated measures is applied. Table 37 marks significant differences between the different bidding rounds, regardless of the target group or the auctioned product. To analyze the effect of subsequent bids and capture the specific information round effects, the Wilcoxon signed-ranked test was used. As the null-hypothesis of this test focuses on the median of the paired differences, the median values are also presented. Not surprisingly, the FBR bids significantly differ after each information round, while consumers' bids were significantly different for FAR bids only after they received non-GM information.

Table 37 Significant average WTP differences between subsequent information rounds, per auctioned product and target group

| **Friedman test** | **FBR (n=251)** $\chi^2$ | **df** | **p** | **FAR (n=126)** $\chi^2$ | **df** | **p** |
|---|---|---|---|---|---|---|
| Student sample | 123.15 | 4 | 0.00 | 77.49 | 4 | 0.00 |
| Non-student sample | 83.90 | 4 | 0.00 | 22.25 | 4 | 0.00 |
| **Total** | **185.20** | **4** | **0.00** | **83.20** | **4** | **0.00** |

| **Wilcoxon signed-rank test** | **Information effect** | **FBR Δ mean** | **FBR Δ median** | **FBR st.dev** | **FBR p** | **FAR Δ mean** | **FAR Δ median** | **FAR st.dev** | **FAR p** |
|---|---|---|---|---|---|---|---|---|---|
| *Student sample* | | | | | | | | | |
| $WTP_{R2}$ - $WTP_{R1}$ | Folate benefits | 0.49 | 0.4 | 0.92 | 0.00 | 0.24 | 0.5 | 0.52 | 0.00 |
| $WTP_{R3}$ - $WTP_{R2}$ | GM technology | -0.37 | -0.4 | 0.89 | 0.00 | 0.12 | 0.0 | 0.58 | 0.11 |
| $WTP_{R4}$ - $WTP_{R3}$ | GM information[a] | -0.64 | -0.6 | 1.24 | 0.00 | -0.06 | 0.0 | 0.72 | 0.95 |
| $WTP_{R5}$ - $WTP_{R4}$ | Regional situation | 0.51 | 0.6 | 0.84 | 0.00 | 0.48 | 0.5 | 0.69 | 0.00 |
| *Non-student sample* | | | | | | | | | |
| $WTP_{R2}$ - $WTP_{R1}$ | Folate benefits | 0.65 | 1.0 | 1.37 | 0.00 | 0.19 | 0.5 | 1.04 | 0.00 |
| $WTP_{R3}$ - $WTP_{R2}$ | GM technology | -0.16 | -0.2 | 1.43 | 0.84 | -0.22 | -0.3 | 1.07 | 0.20 |
| $WTP_{R4}$ - $WTP_{R3}$ | GM information[a] | -0.65 | -0.8 | 1.60 | 0.00 | -0.05 | 0.0 | 1.03 | 0.58 |
| $WTP_{R5}$ - $WTP_{R4}$ | Regional situation | 0.66 | 0.9 | 1.17 | 0.00 | 0.32 | 0.4 | 0.83 | 0.00 |
| *Total* | | | | | | | | | |
| $WTP_{R2}$ - $WTP_{R1}$ | Folate benefits | 0.57 | 0.5 | 1.18 | 0.00 | 0.21 | 0.3 | 0.83 | 0.00 |
| $WTP_{R3}$ - $WTP_{R2}$ | GM technology | -0.26 | -0.2 | 1.21 | 0.00 | -0.06 | 0.0 | 0.89 | 0.86 |
| $WTP_{R4}$ - $WTP_{R3}$ | GM information[a] | -0.64 | -0.8 | 1.44 | 0.00 | -0.05 | 0.0 | 0.89 | 0.57 |
| $WTP_{R5}$ - $WTP_{R4}$ | Regional situation | 0.59 | 0.8 | 1.03 | 0.00 | 0.39 | 0.5 | 0.77 | 0.00 |

FAR, folic acid pills + rice; FBR, folate biofortified rice; R, Round; WTP, willingness-to-pay
*Note*: 1 ¥ is about US$ 0.15
[a]Aggregated information effect, based on six different information treatments. Specific GM information effects are described in Table 38.

*Round 1 and 2: Folate related information*

As expected, the provision of information about the higher folate content in FBR (round 1) led to substantial WTP values, which are significantly increased when participants learned about the health benefits of an improved folate intake level (round 2). A similar trend is observed for FAR, but the 2nd round increase is less pronounced.

*Round 3: GM technology*

Regarding the GM related rounds, only FBR bids are affected when participants are informed about the GM technology in FBR and after the GM information treatment (see also Figure 15). The WTP difference between the 2nd and 3rd round can be perceived as the difference in WTP for conventional versus transgenic biofortified rice. The results show that bids are lowered in the student sample, but did not change significantly in the general target group. Thus, women of childbearing age are not only willing to pay more for the folate benefits, but seem to be less concerned about the GM nature of FBR.

The evaluation of GM technology in FBR in the non-student auctions is not as controversial as what might have been expected. This might be caused by the high acceptance rate of GM food (see previous section). Reluctant consumers bid on average ¥ 0.92, while the premium of indifferent and favorable consumers amounts ¥ 1.71 and ¥ 2.37, respectively (Kruskall-Wallis test, $p<0.001$). However, it is striking that about 60 % of those who state to reject GM food are still bidding in round 3, though their bids are lower. This shows that the provision of positive health information can compensate for the negative perception of GM technology in food. On the contrary, approximately 11 % of the participants who claimed to accept GM food, bid zero.

*Round 4: GM information*

When consumers are provided with specific GM information, FBR bids are again lowered. As a consequence, the FAR bids in the student sample were higher than the FBR values (and zero bidding is lower). But this is mainly because they lowered their FBR bids, rather than increasing their FAR bids.

The overall average WTP difference in round 4 tends to be negative (Table 37). A distinction should be made according to the different GM information treatments. Table 38 and Figure 15 illustrates how the WTP values of FBR in the 'non-common' fourth round are affected by the type of GM information. Due to the high number of information sheets, the two subsamples are taken together. Despite the fact that the participants' 5th bid is based on the acquisition of different GM information, no significant 4th round effect could be observed in these valuations.

Furthermore, FAR values do not significantly differ according to the provided GM food information (Kruskall-Wallis test, $p=0.605$), even in the student auctions (Kruskall-Wallis test, $p=0.279$), which further supports the low attractiveness of FAR as an alternative to FBR. Nevertheless, the FAR values are higher, but not significant, when negative and objective information is provided, either alone or together.

Table 38 Significant GM information effects, per information treatment, by Wilcoxon signed-rank test

| **GM information effect** | **Descriptives** | | | | **Wilcoxon signed-rank test** | | |
|---|---|---|---|---|---|---|---|
| | **n** | **mean** | **st.dev** | **% zero bids** | **Δ mean** | **Δ median** | **st.dev** |
| Positive | 41 | 1.59 | 1.52 | 17.1 | 0.14 | 0.5 | 1.54 |
| Negative | 42 | 0.53 | 1.03 | 61.9 | **-1.28** | -1.0 | 1.69 |
| Positive + negative | 42 | 1.36 | 1.82 | 28.6 | -0.25 | -0.7 | 1.10 |
| Negative + positive | 42 | 0.89 | 0.96 | 31.0 | **-0.67** | -0.9 | 1.09 |
| Objective | 42 | 1.30 | 1.55 | 28.6 | **-0.98** | -0.7 | 1.33 |
| All | 42 | 0.87 | 1.11 | 25.7 | **-0.79** | -0.6 | 1.40 |

GM, genetic modification
Note: Figures in bold indicate information effects significant at 0.001. GM information effect = $WTP_{R4}$ - $WTP_{R3}$.

When evaluating how respondents adjusted their WTP for FBR after the specific GM information treatment, the Kruskall-Wallis test reveals a significant difference between the information treatments at 0.1 %. The decrease or increase in WTP is most pronounced when, respectively, one-sided negative or positive GM information is provided. Somewhat surprising, the objective information treatment is ranked 2$^{nd}$ when looking at the WTP reductions. This might be due to difficulties in understanding, e.g. ‘gene transfer’ GM definition; the negative connotation surrounding the economic impact, e.g. profit-seeking businesses; or the relevance of the biofortification statement, e.g. GM food with improved vitamin content is not commercialized in China (see Table 30). The average WTP difference of the ‘all’ and ‘negative + positive’ information group approximate the general 4$^{th}$ round effect. Contrary to Tegene et al. (2003), both positive and objective GM information in the ‘all’ treatment only slightly weakened the effect of the negative statements, further supporting consumers’ negative perception of the objective GM information treatment. In the ‘positive + negative’ treatment, the downward adjustment is substantially smaller. This lends partial support for the primacy effect, which is observed when the information is highly relevant to the consumer (Buda and Zhang, 2000).

Nevertheless, negative information still dominates in each conflicting information treatment, which confirms the general findings in literature (Fox et al., 2002; Tegene et al., 2003; Parkhurst et al., 2004; Hu et al., 2006). Although the provision of negative information alone resulted in the least favorable valuations, contrary to other GM food (Corrigan et al., 2009) and GM rice auctions (Depositario et al., 2009a), the participants with conflicting information seem to be also prone to an alarmist reaction. Our findings suggest that this hypothesis is not only applicable to two-sided (positive and negative, or vice versa) information, as Parkhurst et al. (2004) discovered, but also to the combined treatment (all = positive + negative + objective).

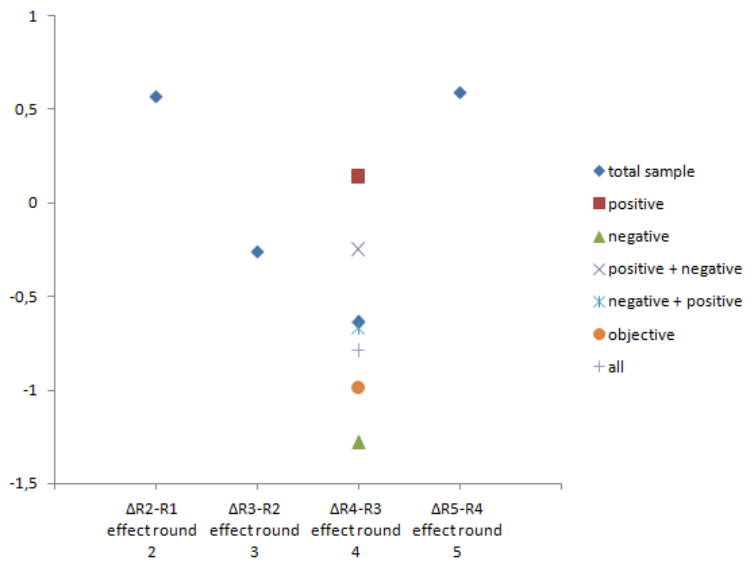


Figure 15 Significant mean WTP differences between subsequent bidding rounds and per GM information treatment in round 4, in ¥

R1: nutritional information; R2: health benefits; R3: GM technology, R4: GM information, R5: situation in Shanxi Province
*Note*: 1 ¥ is about US$ 0.15. Here, a GM information effect refers to the impact of the different treatments on the mean WTP in the 3rd round.

The acceptance of GM food could play a role to mitigate or reinforce the effect of the provided information. Overall, the more positive a participant is oriented towards GM food, the higher she will bid for FBR in the 4th round (Kruskall-Wallis test, $p<0.001$). Except for the one-sided positive information, where WTP values do not differ according to consumers' approval of GM food, all other information sheets generate higher bids for favorable consumers. The difference is most pronounced for objective and one-sided negative information.

However, to investigate the GM information effect, it is important to investigate the bid differences between round 4 and 3, rather than the absolute WTP values. In correspondence with Lusk et al. (2004b), favorable consumers are generally more susceptible to the provision of GM information (Kruskall-Wallis test, $p<0.01$). Upon reading the GM information, favorable consumers adapt their 3rd bid by drastically lowering their valuation, especially in the case of negative and objective information (Kruskall-Wallis test, $p<0.05$). Indifferent consumers behave similarly, by reducing their WTP, but to a lesser extent (Kruskall-Wallis test, $p<0.05$). People opposed to GM food are sensitive to positive information when it is provided alone or prior to negative information (positive + negative). The latter conclusion further supports the presence of a primacy effect. In all other cases, the negative information reinforced their attitude, by which they further reduced their initially low WTP values. Again, a confirmation bias might be responsible for activating the alarmist reaction of reluctant consumers.

Thus, consumer's GM food attitude is triggered when receiving GM food information, in line with attitude theory (Fazio et al., 1982), but it appears to be not strong enough to counter information that is opposed their acceptance. These findings are consistent with GM food studies of Colson and Huffman (2009) and Frewer et al. (2000). For example, reluctant bidders stop bidding when they received only negative information, but not when they also read positive statements. Providing positive or negative information alone drives most consumers towards, respectively, higher or lower bids. Thus, our study shows that one-sided information may be as persuasive as conflicting information treatments, which contradicts findings from Crowley and Hoyer (1994).

*Round 5: Shanxi situation*

In the fifth auction round people are confronted with the current situation in Shanxi Province regarding folate deficiency and NTDs. Whereas the FBR values are decreased in the GM related rounds, consumers generally react positively on this information by increasing their bid to a level that approximates the 2nd round values. Most of them either kept their previously submitted bid (33.1 %) or increased it (60.6 %). When the zero bidders are excluded, only 7.1 % reduced their bids, while 20.9 % maintained and 72.0 % raised the bid. Together with the fact that only 4 respondents turned their previous bid into zero, this provides a strong rejection of the hypothesis that many people would feel uncomfortable when they are informed about the problematic situation in their own province. The insignificant difference between WTP for FBR in the 3rd and 5th round indicates that the FBR bids recover from the reduction associated with round 4 (see also Table 35). As the FAR bids are not affected by GM information, the valuation of this product increases to its highest level, but still below the respective FBR value.

#### *4.4.2.6. Zero-bidding behavior*

This section examines the role of information on zero bidding, i.e. when people are not willing to purchase the auctioned product in certain rounds. Consistent zero bidding for FBR and FAR occurs in 0.02 % and 0.10 % of the sample, respectively. In the first two rounds, the number of zero bidders is higher for FAR (see Table 35). This shows a preference for FBR when auctioned together with FAR. When comparing the impact of GM technology (round 3) on zero bidding, a target group effect is shown for FAR. While FBR zero bidders are increased in both target groups, FAR zero bidding is only lowered in the students' sample. This is due to the higher GM food acceptance rate and the preference for FBR in the non-student sample. As a consequence, an opposite zero bidding pattern is observed after 5 auction rounds.

*New zero bidders*

Although the number of zero bids provides insight in the opposition towards both auctioned products, it does not reveal the information where a participant starts to bid zero. Figure 16 compares the new and the total number of zero bidders in each round. A 'new zero bidder' in round x is defined as a participant who starts to bid zero after she received the information treatment of this round.

In round 1 the number of new zero bidders equals the total number of zero bids. Reasons for zero bidding in this folate round might be related to the concerns regarding the high folate content or the reluctance or inconvenience of taking pills[49]. As expected, during the GM related information rounds,

[49] Examples of comments that were written on the bidding slip support this statement: Respondent 147: "*40 times more folate in our rice than regular rice is too much, I am afraid that it will have some negative effects to our health*"; Respondent 71: ***"****I don't want to take vitamin pills*"; Respondent 114: *The pills are not very convenient compared to folate in the rice*" (translated from Chinese).

the number of people that change their positive WTP into a zero bid is the highest[50]. Zero bids in the 2nd and 5th round are mainly submitted by participants who bid zero in the previous round.

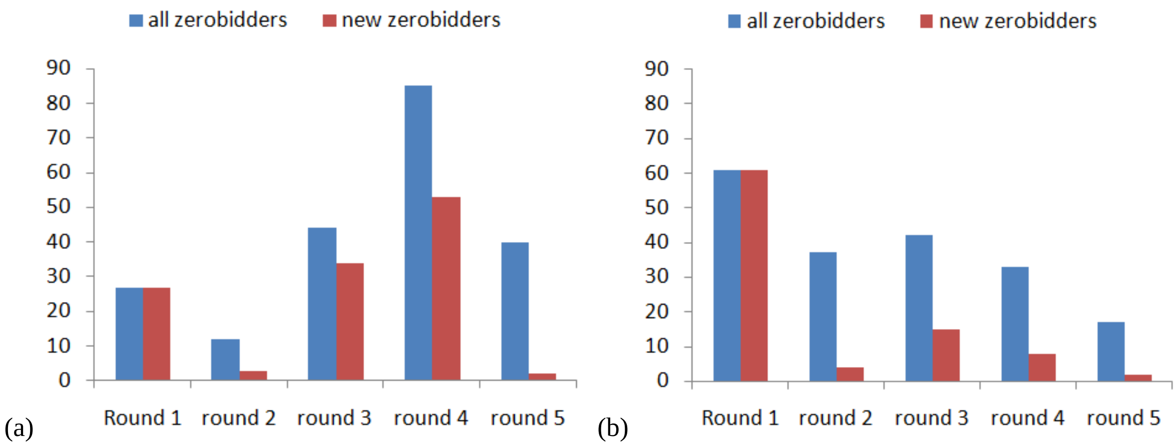


Figure 16 Zero bidders and new zero bidders regarding (a) FBR and (b) FAR, in number of participants.

Figure 17 focuses on the relationship between the number of zero bidders and the different GM information treatments. While zero bidding is most popular in the negative GM information treatment, the opposite is seen when only positive information about GM is given. Conflicting information treatments have more or less an equal share of new zero bidders.

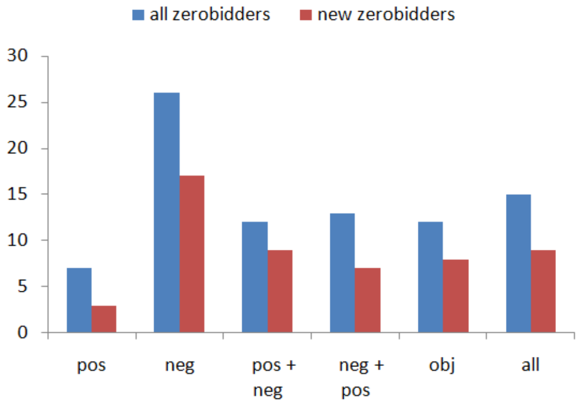


Figure 17 Zero bidding behavior for FBR after the GM information treatment, in number of participants

*Negative valuations*

Participants that were not willing to bid for FBR or FAR in the third round received an additional form to evaluate whether they would accept it if the price would be lower. Even though negative values are not incorporated in the auction process and are, strictly speaking, hypothetical, they help to gain insight in the motives behind zero bidding behavior. Out of 44 FBR zero bidders, only 22.7 % are consistent in their reluctance and are not willing to buy FBR, even if there would be a discount. The

[50] Reasons for zero bidding in the third round include, for example: Respondent: 21: "*I don't want to buy GM rice with more folate in it, because we have another way to consume folate". Respondent 55: "Until now, we don't know whether the advantage of GM food is bigger than its disadvantage, or vice versa, so I put my own health first.*"; Respondent 232: "*I believe there is no reason to think that this kind of food is safe, so I will not buy it, no matter what the price is*" ( translated from Chinese).

other participants claim to accept FBR if it would be cheaper, i.e. between ¥ 0.2 to ¥ 2.0. These figures are comparable with another Chinese GM rice study (Li et al., 2002).

In the case of the non-GM FAR, only 7.3 % of the zero bidders are not susceptible to a discount. This demonstrates that a large part of the zero bidders considers the additional free folic acid supplements not to be of more value than regular rice, but will not be averse of buying it when the price would be more competitive, i.e. on average ¥ 0.57 lower.

Comparison of both products shows that awareness of the GM technology causes more people to maintain their initial FBR zero bids, but not as much as would have been expected.

### 4.4.3. Comparing stated (sWTP), auction-based (WTP) and indirect valuations (iWTP)

This section compares the auction valuations with indirect or direct, stated valuations. Therefore, the latter refers to the same target groups as in the auctions (Table 39).

Table 39 Comparison between WTP, iWTP and sWTP, zero bidders, mean average bids and standard deviation, per target group

| WTP value | WTP[b] | | iWTP[c] | | sWTP[d] | | Δ | Δ | Δ |
|---|---|---|---|---|---|---|---|---|---|
| Source | Auctions | | Auction survey | | Cons. survey | | WTP - iWTP | WTP - sWTP[e] | iWTP - sWTP[f] |
| | Mean | st. dev | Mean | st. dev | Mean | st. dev | | | |
| *Student sample[a]* | | | | | | | | | |
| N | 119 | | 119 | | 81 | | NA | NA | NA |
| Zero bids (%) | 22.50 | | 27.73 | | 6.17 | | -5.23 | 16.33 | 21.56 |
| Average bid (in ¥) | 1.34 | 1.48 | 0.97 | 1.45 | 2.85 | 3.43 | 0.37 | -1.51 | -1.88 |
| w/o zero bids (in ¥) | 1.74 | 1.47 | 1.33 | 1.56 | 3.04 | 3.46 | 0.41 | -1.30 | -1.71 |
| *Non-student sample* | | | | | | | | | |
| n | 132 | | 127 | | 354 | | NA | NA | NA |
| Zero bids (%) | 12.88 | | 19.69 | | 12.43 | | -6.81 | 0.45 | 7.26 |
| Average bid (in ¥) | 2.08 | 1.93 | 1.19 | 1.37 | 2.34 | 2.32 | 0.89 | -0.26 | -1.15 |
| w/o zero bids (in ¥) | 2.39 | 1.88 | 1.48 | 1.27 | 2.67 | 2.30 | 0.91 | -0.28 | -1.19 |
| *All women* | | | | | | | | | |
| N | 251 | | 246 | | 435 | | NA | NA | NA |
| Zero bids (%) | 17.46 | | 23.58 | | 11.26 | | -6.12 | 6.20 | 12.32 |
| Average bid (in ¥) | 1.73 | 1.77 | 1.08 | 1.37 | 2.43 | 2.57 | 0.65 | -0.70 | -1.35 |
| w/o zero bids (in ¥) | 2.10 | 1.74 | 1.41 | 1.41 | 2.74 | 2.57 | 0.69 | -0.64 | -1.33 |

cba, childbearing age; FAR, folic acid pills + rice; FBR, folate biofortified rice; NA, not applicable; w/o, without
Note: 1 ¥ is about US$ 0.15
[a]Due to the use of age categories in the 2008 consumer survey, the student sample regarding sWTP is aged below 29 years (compared to 24 years in the student auctions); [b]Auction-based WTP as derived from the bidding slip in the 3rd auction round; [c]Consumers' estimation of WTP for FBR of the average Shanxi women; [d]Based on the 2008 consumer survey in Shanxi Province (see section 3.2.2). Average sWTP bids are truncated at zero (see Table 31); [e]Large differences indicate a potential hypothetical bias; [f]Large differences indicate a potential social desirability bias.

*Hypothetical bias*

The non-hypothetical auction-based values are used to evaluate potential hypothetical bias in sWTP valuations. In correspondence with the literature, the average stated values for FBR are 40.5 % higher than the average auction-based values, which might indicate the existence of a hypothetical bias in the former. One could argue that the differences between the hypothetical versus non-hypothetical bids, ¥ 0.7 on average, are not large enough to underpin this, especially in the case of the general target group (¥ -0.4). Indeed, several authors found that open-ended contingent valuation is less prone to hypothetical bias than other types (Brown et al., 1996; Balistreri et al., 2001). But when looking at the zero bidding behavior in the consumer survey, the number of zero bidders in the student sample (6.2 %) is remarkably lower than in the respective target group of the auctions (22.5 %). This demonstrates that a hypothetical bias is likely to occur when students are stating their preference for FBR. Although the (zero) bid differences are less pronounced in the non-student sample, it does not imply the absence of hypothetical bias. It is more likely that the generally high values in the auctions are responsible for the relatively small gap between direct and indirect valuations in this target group, which would mask hypothetical bias.

Several reasons can be cited for the high values in the auctions.

First, the more comprehensive information rounds in the experimental auctions, e.g. information of folate benefits by providing a picture of NTDs, are likely to increase the WTP values. Starting with positive information might have created an optimistic bias, by which consumers reduce their risk perceptions and become overly optimistic (Weinstein, 1980; Lee and Job, 1995). Second, the high involvement of the female sample in an experiment with a good that is beneficial to the respondents could have further increased WTP values and converged direct and indirect values. In addition, some authors found that women generally bid higher than men (Lusk et al., 2004a), although others disagreed (Feuz et al., 2004). Fourth, as mentioned in section 4.4.2.3, the extensive trial sessions are expected to raise WTP values (Drichoutis et al., 2010). Fifth, the consumer survey (sWTP) and auctions (WTP) are conducted in 2008 and 2011, respectively. Therefore, the 2009 approval of GM rice in China (Waltz, 2010) and the provincial initiatives regarding the national birth defect program in 2009 (Chinese Ministry of Health, 2001) could have raised awareness and valuations of the auction participants. The data collection might be also affect by the increased price of rice since 2008 (see Annex 3), by which the price for 1 kg rice in Shanxi was ¥ 2.2 higher in 2011 (National Bureau of Statistics of China, 2011a). Although the WTP values are compared with the current benchmark price of regular rice, and interpreted as the price of a product is worth more, the higher prices might have influenced the typically price-sensitive Chinese consumer (Kim, 2009). Sixth, the measurement of WTP could also play a role. While the survey participants were asked to state their full sWTP, the auction participants were subject to an endowment approach. Furthermore, the selection of the target groups in the stated valuation method is based on age categories, by which the age range of the sWTP student sample is larger than in the auctions. Finally, social desirability bias (SDB) and auction fever in experimental auctions could lead to overstated WTP values.

*Social desirability bias*

Social desirability can be explored by juxtaposing the WTP and iWTP values for FBR in the 3rd auction round. Indirect values are expected to avoid or, at least, reduce SDB because this method depersonalizes the valuation exercise in an auction setting. Although this indirect WTP measure is based on a survey-based stated preference method (see section 4.3.5) and does not impose monetary consequences, the risk of hypothetical bias might be lower due to its inclusion in a non-hypothetical experiment which simulates a market environment. Indirect valuation is also useful to provide insight in the presence of auction fever, i.e. high valuation driven by competitive behavior. Table 39 shows that consumers' estimation of the WTP of the average Shanxi women is ¥ 0.65 lower than their auction-based valuation of FBR. But even in the general target group the price difference is still below 1 ¥, which makes it hard to support high bidding behavior as an act of SDB or due to auction fever.

Due to the lower average WTP values in the student auctions, one would have expected that their indirect valuation would converge with the valuations of the non-student sample, which represents the average Shanxi female rice consumer, leading to a smaller direct-indirect WTP gap. Instead, a discrepancy is found between both target groups. This might be explained by a social phenomenon where people tend to believe that their own behavior is no different than that from others, i.e. 'the false consensus effect' (Ross and House, 1977), which could be reinforced by the timing of the indirect valuation, i.e. immediately after their WTP bid. Indeed, there is a correlation between ones' direct and indirect valuation ($p<0.01$). Even 22.4 % of the total sample did not change the value of their bid. However, when zero bidders are removed, this percentage drops to 6.9 % of the sample. Most of the people (62.2 %) decreased their direct bids, while 15.4 % increased their bids. As for the direction of both valuation methods, a similar tendency is observed. On the one hand, half of the zero bidders (16.7 %) turned their direct zero bid into a positive, indirect bid. On the other hand, 24.3 % of those who valued FBR positively think the average Shanxi women would not be prepared to pay for this product, and submitted a zero bid. In total, 41 % of the respondents expect that the average Shanxi woman would deviate from her own bids. This reduces the likelihood of a general false consensus effect. Another explanation could be that female students are less experienced to estimate the valuation of the average Shanxi consumer. This could be due to their lower familiarity with rice prices and because they are less responsible for rice purchases (see section 4.4.2.1).

## *4.5. Conclusions*

This chapter investigates WTP for FBR as a GM rice product with health benefits. By means of a standardized survey and experimental auctions in Shanxi Province, respectively stated (sWTP) and auction-based values (WTP), as well as indirect valuations (iWTP) are determined. As the latter is mainly used to explore SDB and validate the WTP bids in the experimental auctions, the focus in this chapter is on the hypothetical and non-hypothetical direct value elicitation methods. Although these two preference methods are clearly distinct from each other, they demonstrate that a large part of Shanxi consumers is willing to pay for FBR. When looking at women of childbearing age, the premium for FBR is valued between ¥ 1.73 (WTP) and ¥ 2.43 (sWTP). The number of zero bidders varies between 17.5 % and 11.4 %, respectively. These positive results are further supported when FBR is auctioned together with FAR as a folate substitute. About 61.6 % of the sample prefers FBR over FAR, regardless of their valuation of the latter. Although 39.4 % of consumers prefer FAR at the end of the auction, only 15.9 % are averse to FBR. These results confirm the supportive consumer valuations for GM food (Curtis et al., 2004; Hu et al., 2006), GM rice with agronomic (Liu, 2009) and nutritional benefits (Li et al., 2002) in China. It also underpins the supportive consumer reactions to FBR, as determined in chapter 3. Although FAR is generally evaluated as an unattractive product, it might be used as a complementary option for FBR when aiming to attract the future generation of mothers, i.e. young, female students of childbearing age.

When comparing the stated and auction-based values, the zero bidding behavior reveals potential hypothetical bias in the female student sample. In this target group, the number of zero bids is about 16.3 % higher when the students elicit their value through experimental auctions. But whether one assigns a hypothetical bias to the sWTP results or not, several findings advocate for use of the auction-based values. First, the auction values are validated through indirect valuation, as there is a minor chance of SDB. Second, the preference question in the 'two-product" auctions shows that people prefer the product with the highest value. Third, the investigated auction design characteristics, such as the auction size, time (morning, afternoon or evening) and day (weekend or weekday) of the auction, and the availability of folate substitute, did not reveal significant differences in WTP. The exception to this was the target group effect, which indicated that female students were less supportive of FBR than the general group of women. The latter reacted more positively towards FBR, but not towards FAR. This contradicts previous auction literature that found no differences between student and non-student samples (Lusk et al., 2005; Depositario et al., 2009b).

The effect of the socio-demographic profile could be examined in both valuation methods. Being old, having a small family and living in an urban area significantly increased consumers' stated WTP for FBR. The lower sWTP values of poor, low educated, rural farmers is an important finding, which needs to be further explored in order to detect the reasons they attach to their bidding behavior.
In the experimental auctions, the significant target group effect indirectly demonstrated that socio-demographic indicators, i.e. age and education, might influence the amount one is willing to pay for the increased folate content and, when GM information is provided, determine the purchase decision. However, the high acceptance rate of GM food in the non-student sample is more likely responsible for this discrepancy in bidding behavior. Students are also expected to be less involved, either because they are not concerned with pregnancy issues, or because they are not responsible for the rice purchases in their household.

The auction study also revealed important information effects that can be taken into account when developing a communication strategy or a promotion campaign for biofortified crops.
First, auctioning FBR as if it would be conventionally bred - although this is less likely to occur (see section 2.4.4.2) - shows that improving nutritional knowledge is important to increase WTP and, in line with confirmation bias, the effect of nutritional information on WTP for conventionally bred crops.
Second, mentioning the GM technology does not necessarily decrease consumers' valuation, even if a non-GM substitute is available. However, when specific information about GM is distributed, bids are significantly altered. When consumers have to deal with conflicting information, which is likely to be the case in reality, they seem to be subject to an alarmist reaction and a small primacy effect, by

which negative information largely prevails, unless positive information is presented prior to the negative statements.
Third, even more important is that favorable consumers are more susceptible to information that does not align with their approval of GM food. On the contrary, reluctant consumers are reinforcing their initial attitude when learning about negative statements of GM. This demonstrates that it will be hard to convince the latter through an information campaign, if it will be countered by opposite information. Moreover, such a situation could discourage those that are not averse of GM food, which is exactly what happened when the commercialization of Bt rice in China was put on hold (see section 6.5). Therefore, to extend the coverage rate of biofortification interventions, it is recommended to focus on improving the consumers' acceptance of GM (biofortified) food. GM food related knowledge and consumer perceptions are key factors to realize this, as chapter 3 has shown.
Another important finding is the positive effect of information about the current situation and the potential for FBR in Shanxi Province. Apparently, it further increases the involvement and awareness of the need to consume folate and has the potential to reduce negative GM information effects. Similarly, the effect of GM information might be attributed to the inclusion of country-specific statements.

Because the comprehensive methodology section of this chapter discusses the bottlenecks of the stated preference method (e.g. open-ended valuation and hypothetical bias) and the rice auction design (e.g. controlled laboratory setting and the Hawthorne effect, endowment and the loss aversion hypothesis), the emphasis is put on the recommendations for future research.
Besides its hypothetical nature, the main limitation and criticism of our open-ended WTP values is the assumption that consumers are capable of making a precise estimation of their value for FBR and do not feel forced to give a social desirable answer. Therefore, it might be interesting to use an interval approach, where consumers indicate a range of WTP values (Håkansson, 2008), rather than asking for a fixed WTP estimation, in order to overcome these limitations of open-ended questions.

Like every other valuation method, our experimental auction design is built upon methodological choices, which necessarily involve limitations. Future auction research can improve and validate our results in several ways, e.g. by exploring how these poor, low educated consumers react to another auction mechanism, such as the Becker-Degroot-Marschak (BDM) approach, which is also deemed appropriate in poor, rural areas (De Groote et al., 2011), by investigating the influence of the order of information rounds and its relation with optimism bias, price feedback, additional outside options (Cherry et al., 2004), or a consumption requirement of the purchased product (Corrigan and Rousu, 2006a). Regarding the latter, for example, previous research emphasized the importance of a (hypothetical) after-auction consumption requirement to stimulate truthful bidding behavior for a GM product (Fox et al., 1995).

As the experimental auctions solely focused on the consumer side, on women of childbearing age in particular, future research is needed to measure how much rice farmers' are willing to pay for FBR seeds among other seeds in order to investigate the potential demand on the supply side, i.e. the potential adoption rate of FBR. The stated preferences of such farmers is a first indication that poor, low educated, rural farmers are less willing to pay for FBR.

Furthermore, the insignificant auction type effect showed that selling folic acid supplements together with rice was not as successful as might have been expected. Although young women do not consider it as unattractive, it is seldom seen as a valid alternative when looking for a non-GM substitute. This is an important finding which helps to explain the ineffectiveness of folic acid supplementation programs (see section 2.4.1.2). Future research should take this into account and try to discover why folic acid supplements are not perceived as an attractive product. Convenience and compliance may be responsible for this negative perception, as put forward during the auction feedback.

It might be also interesting to determine the impact of different folate levels on WTP. This study, for instance, investigated consumers' valuation of a rice bag that contains 40 times more folate than in regular rice. There might be a folate threshold which drastically improves consumers' WTP. In addition, the effect of adding other micronutrients, or informing about improved agronomic traits, could be investigated in order to define consumers' preference for an improved folate content as one of many stacked traits in GM rice. Another novel approach in WTP studies is to combine quantity ('how many') and quality ('how much'), instead of focusing only on the latter. By doing so, one could determine the market demand for different prices, as Corrigan et al. (2009) successfully demonstrated. When FBR would be ready for consumption, future research could introduce a taste session in a specific auction round in order to evaluate the sensory aspects of this product. Such product attributes may influence consumers' acceptance and WTP, as shown in food auctions (Hobbs et al., 2006; Rutsaert et al., 2009; Hellyer, 2010)(see also section 3.3.4).

Also the way that information is provided could be improved and further explored. For example, the effect of uncensored photos of NTDs could further persuade female participants, either in a negative (too much confrontation), but most likely in a positive way (more involvement). Reference can be made to the effective current tobacco labeling regulations in China, which requires tobacco companies to include uncensored pictures (Fong et al., 2010). The results showed that 'picture' warnings are significantly more effective than 'text' warnings. As a consequence, also the GM information in the 4th round might become more effective and realistic if pictures, a newspaper lay-out or labels would be used (Ennekinga et al., 2007). Given that GM food labeling is mandatory in China, analyzing the effects of GM food labels instead of information could gain insight on how to bring biofortified crops most effectively into the market. In this respect, the efforts of De Groote et al. (2010), who simulated radio messages, are worth mentioning. With respect to Shanxi Province, such trustworthy audio-visual information channels (see section 3.3.3) could be also applied to the regional information about the current situation regarding NTDs and folate deficiency. Organizing a discussion information round about GM food is another example, suggested by Lusk et al. (2004b). Given that Asian consumers are typically more acquainted with negotiable prices, one could also introduce a collective bidding process or an individual auction which allows negotiation, such as the BDM.

# 5 Potential health impact and cost-effectiveness of folate and multi-biofortified rice in China

Adapted from:

De Steur, H., Gellynck, X., Storozhenko, S., Liqun, G., Lambert, W., Van Der Straeten D. & Viaene, J. 2010. The health benefits of folate biofortified rice in China. *Nat. Biotechnol*. 28, 554-556.

De Steur, H., Gellynck, X., Blancquaert, D., Liqun, G., Lambert, W., Van Der Straeten, D. and M. Qaim (2011). Potential impact and cost-effectiveness of multi-biofortified rice in China. *New Biotechnology.* In press.

## 5.1. Introduction and objectives

Folate biofortification and multi-biofortification of the world's major staple crop is expected to have a large impact on micronutrient deficiency related health problems, especially in a rice consuming country like China. This chapter estimates the potential health impacts of the introduction of FBR and MBR in China, by applying the Disability-Adjusted Life Year (DALY) framework (Murray and Lopez, 1996; Tan-Torres Edejer et al., 2003)(see section 1.3.2.2).

Although the DALY framework has been criticized in the past (Anand and Hanson, 1998; Lyttkens, 2003)(see also section 5.2), it is increasingly used as a method in health impact studies of 2nd generation GM products or biofortified crops (Stein et al., 2005b; Horton, 2006; Meenakshi et al., 2007; Fan et al., 2009). Previous impact studies evaluated the health effects of biofortified crops, such as iron fortified beans (Suárez, 2010) and provitamin A enriched crops, e.g. Golden Rice (Zimmermann and Qaim, 2004), cassava roots (Manyong, 2004) or sweet potatoes (Fan et al., 2009), in developing countries like Bangladesh, Philippines, Nigeria or India.

China is a relatively new area to evaluate biofortified staple crops (Ma et al., 2007; Fan et al., 2009). Due to the regional differences in folate intake, rice consumption and NTD prevalence, the health impact of FBR is assessed for both northern and southern provinces, at regional and administrative divisional level. Furthermore, as previous studies refer to crops biofortified only with single micronutrients, and poor people often suffer from multiple micronutrient deficiencies, a country-wide ex-ante analysis of the potential health benefits of rice multi-biofortification (MBR) in China is carried out. This study evaluates the effect of enriching rice with folate and the three main micronutrients, i.e. zinc, iron and vitamin A.

Figure 18 gives an overview of the application of the DALY framework to determine the health benefits of the potential introduction of FBR and MBR in China. Hereby, the health gap between a situation with and without biofortification is assessed (Figure 18). In a first step, the number of DALYs that are currently lost due to folate and other micronutrient deficiencies are assessed. This is the status quo without biofortification (current burden). The second step measures the number of DALYs that would still be lost when FBR or MBR is implemented. By comparing the number of DALYs lost with and without biofortification, the health benefits can be estimated and measured in terms of DALYs saved. This requires additional data and assumptions, as shown in Figure 18. The main concepts are further elaborated in section 5.2.

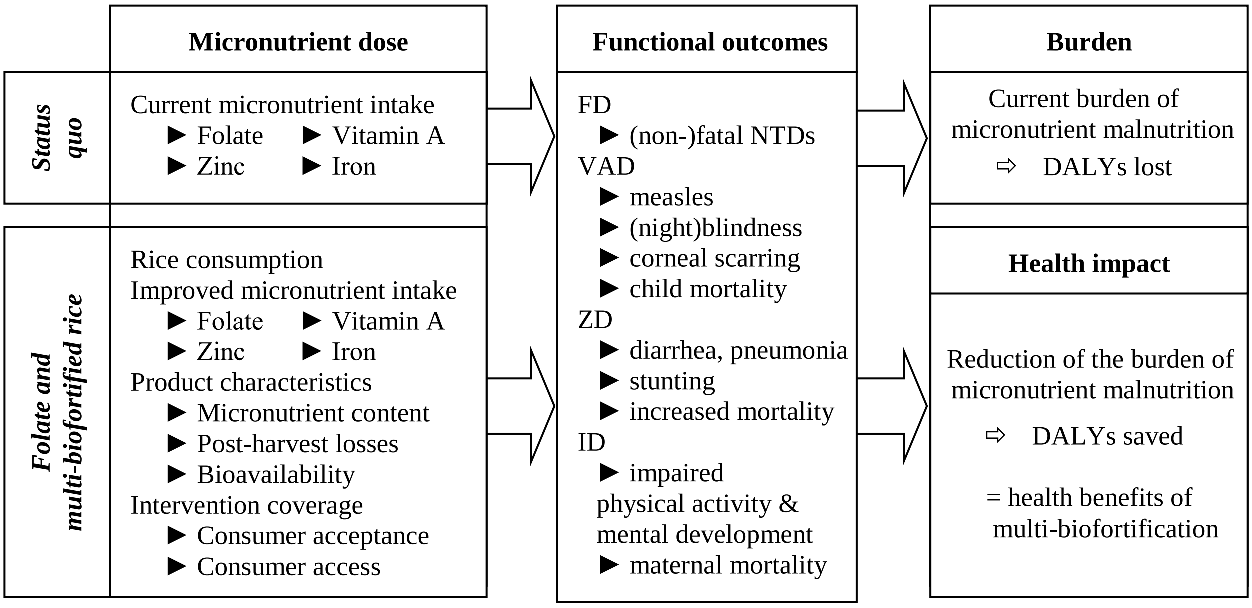


Figure 18 Application of the DALY framework to assess the potential health benefits of folate biofortified and multi-biofortified rice

DALY, disability-adjusted life year; FD, folate deficiency; ID, iron deficiency; NTD, neural-tube defects; VAD, vitamin A deficiency; ZD, zinc deficiency
*Source*: Own illustration, based on Zimmermann and Qaim (2004) and Stein et al. (2005b).

To evaluate the estimated health impact of FBR and MBR in China, the number of DALYs saved is compared with the costs to introduce these interventions. There is a lot of evidence that a well-designed, well-targeted policy intervention to tackle micronutrient malnutrition could be cost-effective (FAO, 2004b; Klemm et al., 2009; Micronutrient Initiative, 2009; CC, 2011), whether it is based on biofortification (Meenakshi et al., 2007; Meenakshi, 2008a), supplementation (Baltussen et al., 2004; Fiedler et al., 2008), fortification (Wallich et al., 2001; Horton, 2006; Fiedler et al., 2008) and - although less explored (Ruel, 2001), food diversification (FAO/ILSI, 1997; Thompson and Amoroso, 2010). When comparing supplementation and fortification programs of main micronutrients, the latter seem to be generally the most cost-effective strategy, due to their lower annual costs, while the health impacts of the former intervention is often more positive (World Bank, 1994; Mason et al., 1999; Mannar, 2001; WHO, 2002). However, when looking at the (recurring) costs of the biofortification strategy, this intervention has the potential to be more cost-effective than the currently available interventions (Stein, 2006; Meenakshi et al., 2007).

Section 5.4.3 of this chapter is devoted to the cost-effectiveness of FBR and MBR in China. Besides the use of a widely accepted threshold to evaluate micronutrient interventions, the costs and benefits are also compared with the results from studies on different biofortified products in various regions. In addition, specific attention is paid to the potential of other folate interventions in China and the comparison between Shanxi Province and another high-risk region of folate deficiency, i.e. the Indian Balrampur District. The sensitivity analysis focuses on the effect of different DALY parameters on the health impact analysis in Shanxi Province, and the impact of the applied technology in MBR (see section 5.4.5).

## 5.2. The Disability-Adjusted Life Year framework

The Disability-Adjusted Life Year approach is used to quantify the burden of folate deficiency or multi-micronutritional deficiency as a single index, i.e. the number of DALYs lost (Murray and Lopez, 1996; Tan-Torres Edejer et al., 2003). This number equals the sum of the “Years Lived with Disability” (YLD) and “Years of Life Lost” (YLL), which represent, respectively, disability-weighted morbidity and cause-specific mortality due to the micronutrient deficiency (see also section 1.3.3). The DALY formula that is used to estimate both the death and disease condition resulting from micronutrient malnutrition, including folate deficiency, is expressed as:

$$\mathrm{DALYs_{lost}} = \mathrm{YLD} + \mathrm{YLL} = \sum_j T_j I_{ij} D_{ij} \left(\frac{1-e^{-rd_{ij}}}{r}\right) + \sum_j T_j M_j \left(\frac{1-e^{-rL_j}}{r}\right)$$

*Source*: adapted from Murray and Lopez (1996)

The input parameters of the formula are: the total number of people in target group j ($T_j$), the mortality rate associated with the micronutrient deficiency in target group j ($M_j$), the incidence rate of functional outcome i in target group j ($I_{ij}$), the disability weight for functional outcome i in target group j ($D_{ij}$), the duration of functional outcome i in target group j ($d_{ij}$), the average remaining life expectancy for target group j ($L_j$)[51] and the discount rate for future life years (r).

Although this framework is widely recognized as one of the most important tools to measure the current health gap and the potential impact of health interventions, it has been criticized on different conceptual and ethical issues (Anand and Hanson, 1997; Murray and Acharya, 1997; Arnesen and Kapiriri, 2004). Given the specific application of the DALY approach in this PhD dissertation, only the three most relevant issues will be tackled.

First, an age-weighting component as used in the initial GBD study (Murray and Lopez, 1996) poses an ethical problem: a higher preference for - and a higher health impact when - saving young adult lives instead of those of children or the elderly (Musgrove, 2000). Although valuable socio-emotional reasons could be attributed to these weights, Lyttkens (2003) compares such a value statement with opening Pandora’s Box. Instead of using different age-weighting factors in a sensitivity analysis, as done by Murray (1996), I avoid this ethical discussion by removing any age-weighting factor in our analyses, following other health impact studies on biofortified crops (Stein et al., 2005b).

Second, the use of the disability weights is one of the most controversial aspects of the DALY approach (Paalman et al., 1998; Anand et al., 2007). Both the applied methodology to determine the disability weights (Lyttkens, 2003) and their socio-cultural applicability are questioned (Allotey et al., 2003). Anand and Hanson (1997), for instance, disapprove the disability scores because they are based on the subjective opinion of an expert panel, while others criticize the DALY approach for its lack to adequately include suffering, pain and conditions worse than death (Paalman et al., 1998). Another highly criticized issue when measuring DALYs refers to the use of a discount rate.

[51] Because tackling a single micronutrient deficiency is not expected to improve the average life expectancy, Chinese life expectancy rates are used. This differs from the initial GBD study (Murray and Lopez, 1996), where the maximum biological life expectancy is used, because the GBD affects the life expectancy. The need to use regional life expectancy rates when analyzing developing regions is further supported by Musgrove & Fox-Rushby (2006).

Discounting attaches a higher value to a saved life today than to saving one in later years. As such, it promotes early investment by increasing the benefits of the present generation at the expense of the next generations (Murray and Acharya, 1997). For example, applying a discount rate of 3 % to future benefits would imply that saving a healthy year this year is, respectively, 14 % or 52 % more worth than a healthy year that is saved 5 or 25 years from now on. By doing so, discounting aims to avoid excessive sacrifice by the current generation, rather than to claim that future health is less worth. Without discounting, the number of DALYs lost before and after biofortification will be also bigger. The need for discounting has been justified by three underlying motives: (1) there is a general tendency to prefer present over future benefits; (2) there is uncertainty whether a person or an intervention could not take advantage of future benefits, for example due to death or a technology that lost its value, respectively; and (3) the diminished marginal utility (see also section 4.3.2) (Bowie et al., 1997; Tan-Torres Edejer et al., 2003). When applied to cost-effectiveness analyses (CEA), both benefits and costs have to be discounted to avoid that funds can be invested to generate higher benefits in the future and health interventions can be postponed (Musgrove, 2000). Because most criticism refers to the level of the discount rate (Brouwer et al., 2005), rather than to the use of a discount rate as such, the standard discount rate in widely recognized disease burden and health impact studies, i.e. 3 % (Murray and Lopez, 1996; WHO, 2000, 2002; Zimmermann and Qaim, 2004; Evans et al., 2005; Stein et al., 2005b; Musgrove and Fox-Rushby, 2006), has been applied throughout this chapter.

With respect to the burden of folate deficiency, only NTDs caused by folate deficiency could be included as functional outcomes in the DALY formula. This is because the relationship of folate deficiency and other functional outcomes is not clearly defined (see section 2.3.3). The three main NTD types, i.e. spina bifida, encephalocele (also known as cranium bifidum) and anencephaly, in particular those NTDs that are attributable to folate deficiency, are considered as functional outcomes in this study. The target groups referring to these NTDs are births, both fatal and non-fatal, as those will be directly influenced by their mother's biofortified diet. The functional outcomes related to these target groups are split into a non-fatal (morbidity) and fatal (mortality) component. While the latter is determined by abortions and stillbirths, the former consists of live births suffering from spina bifida or encephalocele. The third NTD type, anencephaly, results in death before or shortly after birth and is considered as a part of the mortality component (Mathers et al., 1999; Access Economics, 2006). The values of the input parameters of the DALY framework are further described in the next sessions.

### 5.2.1. Assessing the current burden

#### *5.2.1.1. Data and assumptions to measure the current burden of folate deficiency in China*

China holds the first position in the world ranking of NTDs (see Figure 10), the most important functional outcome of (maternal) folate deficiency. This section further explores the number of NTDs in China, its 31 administrative areas and 4 regions[52].

[52] For a map of the administrative areas/regions, see Figure 24 (Annex 1).

Table 40 presents the most relevant demographic statistics to calculate the total number of NTDs according to its main type: spina bifida, anencephaly or encephalocele. In 2007, China is characterized by a total population of 1.3 billion people and, based on a birth rate of 11.2 births per 1 000 population, approximately 14 million births. As no recent regional life expectancy rates are available, the life expectancy of these births, 71.24 years for China, refers to the year 2000 (National Bureau of Statistics of China, 2008c). The regional NTD prevalence rates are expressed per 10 000 births and refer to NTD affected pregnancies within the period 1996 to 2000 (Dai et al., 2002). These rates are then used as approximate incidence rates. In Figure 19, a geographical presentation of the NTD prevalence rates per administrative area is shown.

Table 40 Demographic profile of China, total population, birth rate, total births and life expectancy at birth, and NTD prevalence rates per functional outcome, per administrative area and region

| **Administrative area/ Region** | **Population**[a] (x 1 000 persons) | **Births** | | | **NTD rate**[d] | | | |
|---|---|---|---|---|---|---|---|---|
| | | Rate[b] | Total | Life exp.[c] | Anenc. | Spina | Enceph. | Total |
| NORTH | 556 299 | 10.8 | 6 028 946 | 73.19 | 7.3 | 10.2 | 2.4 | **19.9** |
| Northeast | 458 688 | 10.4 | 4 761 446 | 73.59 | 6.6 | 10.3 | 2.3 | **19.2** |
| Beijing | 16 171 | 8.3 | 134 544 | 76.10 | 2.3 | 5.8 | 1.4 | **9.6** |
| Tianjin | 10 996 | 7.9 | 86 975 | 74.91 | 3.7 | 10.3 | 2.2 | **16.2** |
| Hebei | 70 557 | 13.3 | 940 520 | 72.54 | 5.1 | 9.2 | 2.6 | **16.9** |
| Shanxi | 34 521 | 11.3 | 390 089 | 71.65 | 27.2 | 27.2 | 6.6 | **60.9** |
| Inner Mongolia | 24 518 | 10.2 | 250 327 | 69.87 | 17.0 | 11.8 | 3.2 | **32.0** |
| Liaoning | 43 686 | 6.9 | 300 993 | 73.34 | 4.3 | 11.0 | 1.6 | **16.9** |
| Jilin | 27 852 | 7.6 | 210 284 | 73.10 | 5.0 | 8.2 | 0.9 | **14.0** |
| Heilongjiang | 39 103 | 7.9 | 308 134 | 72.37 | 4.6 | 5.2 | 1.3 | **11.1** |
| Shandong | 95 218 | 11.1 | 1 057 870 | 78.14 | 1.6 | 6.8 | 1.3 | **9.7** |
| Henan | 96 067 | 11.3 | 1 081 711 | 73.91 | 5.1 | 12.4 | 3.3 | **20.8** |
| Northwest | 97 611 | 13.0 | 1 267 500 | 72.39 | 9.4 | 9.9 | 2.9 | **22.2** |
| Shaanxi | 38 203 | 10.2 | 390 056 | 74.70 | 12.3 | 14.5 | 5.8 | **32.6** |
| Gansu | 26 656 | 13.1 | 350 254 | 71.85 | 11.7 | 12.2 | 2.6 | **26.5** |
| Qinghai | 5 606 | 14.9 | 83 691 | 72.55 | 6.6 | 6.6 | 2.0 | **15.3** |
| Ningxia | 6 178 | 14.8 | 91 431 | 68.95 | 9.2 | 10.1 | 1.8 | **21.1** |
| Xinjiang | 20 969 | 16.8 | 352 068 | 73.92 | 5.9 | 4.8 | 2.5 | **13.3** |
| SOUTH | 764 524 | 11.4 | 8 741 811 | 69.42 | 2.7 | 2.2 | 0.8 | **5.8** |
| Southeast | 565 087 | 11.5 | 6 524 892 | 69.96 | 2.7 | 2.1 | 0.8 | **5.6** |
| Shanghai | 18 564 | 9.1 | 168 380 | 71.54 | 0.7 | 0.8 | 0.4 | **1.8** |
| Jiangsu | 77 226 | 9.4 | 723 603 | 71.08 | 1.5 | 2.0 | 0.4 | **3.9** |
| Zhejiang | 50 938 | 10.4 | 528 734 | 70.66 | 2.6 | 2.8 | 0.3 | **5.7** |
| Anhui | 62 497 | 12.8 | 796 833 | 73.27 | 5.3 | 4.0 | 1.6 | **10.8** |
| Fujian | 36,393 | 11.9 | 433 081 | 71.29 | 4.3 | 1.5 | 1.2 | **6.9** |
| Jiangxi | 44 383 | 13.9 | 615 153 | 72.92 | 2.2 | 2.5 | 1.1 | **5.8** |
| Hubei | 58 231 | 9.2 | 535 144 | 71.73 | 2.9 | 2.0 | 1.3 | **6.2** |
| Hunan | 64 869 | 12.0 | 775 832 | 71.20 | 2.6 | 3.8 | 1.1 | **7.4** |
| Guangdong | 95 166 | 12.0 | 1 138 180 | 65.96 | 2.5 | 2.1 | 1.0 | **5.6** |
| Guangxi | 48 269 | 14.2 | 684 936 | 65.49 | 5.1 | 0.7 | 0.5 | **6.2** |
| Hainan | 8 551 | 14.6 | 125 017 | 64.37 | 2.7 | 1.0 | 0.2 | **3.9** |
| Southwest | 199 437 | 11.1 | 2 216 919 | 68.23 | 2.8 | 2.7 | 1.0 | **6.6** |
| Sichuan | 83 557 | 9.2 | 769 557 | 70.07 | 1.8 | 1.5 | 1.1 | **4.4** |
| Guizhou | 38 430 | 13.3 | 510 350 | 67.47 | 4.3 | 6.9 | 0.7 | **11.9** |
| Yunnan | 45 854 | 13.1 | 599 776 | 66.03 | 1.8 | 1.0 | 1.0 | **3.8** |
| Tibet | 2 874 | 16.4 | 47 141 | 70.17 | 3.6 | 3.6 | 0.0 | **7.3** |
| Chongqing | 28 722 | 10.1 | 290 094 | 67.41 | 4.0 | 2.0 | 1.6 | **7.6** |
| **CHINA** | **1 320 823** | **11.2** | **14 770 757** | **71.24** | **4.7** | **5.8** | **1.7** | **12.2** |

[a]Population figures of 2007 are based on the 2008 China Statistical Yearbook (2008c); [b]Birth rates are expressed per 1 000 population in 2007, derived from the 2008 China Statistical Yearbook (2008c); [c]Regional life expectancy at birth in 2000, in years (National Bureau of Statistics of China, 2008c); [d]NTD prevalence rates (1996 – 2000) are expressed per 10 000 births, based on a study of Dai et al. (2002).

*The number of neural-tube defects in China*

Based on the population, the birth rate and the NTD prevalence rate (Table 40), the total number of NTDs can be calculated for each administrative area (not presented). To define the number of NTDs per functional outcome, reference is made to the composition of NTDs in the study of Li et al. (2006), where NTDs were ascertained from live births, still births and induced abortions in Shanxi Province[53]. According to this Chinese study, 31 % of all NTDs are considered to be abortions, while live births and stillbirths account for 40.09 % and 28.91 % of all NTDs, respectively. These figures are in line with older studies in China (Moore et al., 1997). Within the group of NTD live births, the number of cases of spina bifida and encephalocele is determined by the proportion of their prevalence rate and the total NTD prevalence rate. Though some studies explored the occurrence of multiple NTDs (Tamura and Picciano, 2006; Gu et al., 2007), in which newborns are affected by several malformations, such double counts are not included.

Each year, a total of 18 020 pregnancies is affected with an NTD in China, most of them with a fatal result (De Steur et al. 2010a). It is important to notice that this total NTD figure refers to all NTDs, i.e. NTDs caused by folate deficiency or other factors, such as genetic or environmental factors (Sever, 1995), except for spontaneous NTD related abortions. Although there is evidence on the positive relationship between a history of spontaneous abortions and an increased prevalence of NTDs (Todoroff and Shaw, 2000), the number of spontaneous NTD related abortions is not included due to data constraints. If information on the number of NTDs that result in a spontaneous termination was available, the number of NTDs in China would be higher.

When comparing Chinese regions, the NTD prevalence rate is a more appropriate indicator than the total number of NTDs. Although Shanxi Province, situated in the Northeast, obtains the highest NTD prevalence rate (60.9), Northwest China is considered the most problematic Chinese region, with 22.2 NTDs per 10 000 births. The significant difference between Northern and Southern China is shown in both the NTD prevalence rate and the total number of NTDs (see Figure 19). While 31 % of all NTD affected pregnancies occur in Southern China, its northern counterpart accounts for more than two thirds of all Chinese NTDs (see De Steur et al. 2010a).

[53] While abortions are considered as a voluntary or spontaneous termination of a pregnancy, stillbirths are defined as births of a baby with no signs of life (WHO, 2001a). Due to a lack of data on spontaneous abortions, only voluntary (induced) NTD abortions are calculated.

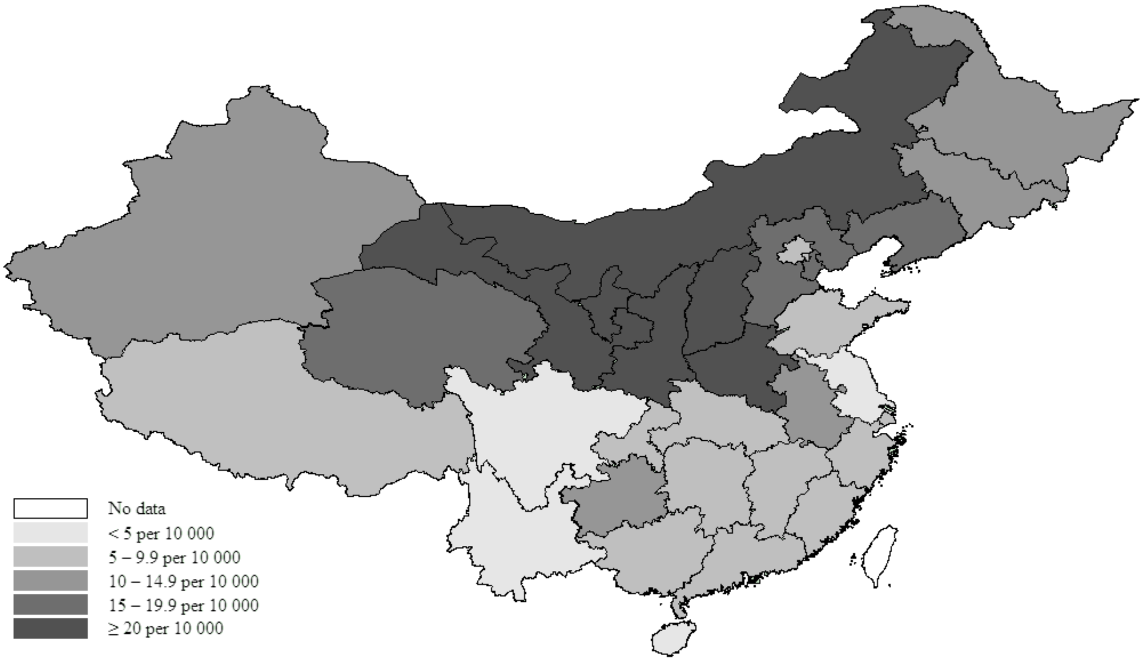


Figure 19 NTD prevalence rates in China, per administrative region (1996-2000), in the number of NTDs expressed per 10 000 births

*Source:* Own illustration, based on Table 40 and Dai et al. (2002)

*The number of neural-tube defects caused by folate deficiency in China*

Although the total number of NTDs is generally acknowledged as the indicator of the magnitude of folate deficiency (see section 2.3.3), only a part of these NTDs are attributable to the suboptimal intake of this micronutrient. As there is a lack of data on the attribution of folate deficiency to other functional outcomes, NTDs caused by folate deficiency are the only functional outcomes of folate deficiency that will be included in the DALY framework. This implies an underestimation of the global burden of folate deficiency. Nevertheless, as NTDs are not only considered as the main adverse health outcome of folate deficiency, but also as the world's major congenital malformation, the number of NTDs caused by folate deficiency is a valuable indicator to measure its current burden. Due to the lack of data on the attribution of folate deficiency to NTDs in each administrative area, two regional attribution levels are used to determine this number: 40 % in Southern and 85 % in Northern provinces (Berry et al., 1999)(see also section 2.3.3).

Based on these regional attribution levels and the total number of NTDs, the number of NTDs caused by folate deficiency is calculated (Table 41). The use of different attribution levels further demonstrate the discrepancy between Northern and Southern China. No less than 83 % of all these NTD affected pregnancies in China occur in the north, and in particular, in the northwest. Even more striking is the number of the NTDs in Shanxi Province, which is almost as high as the whole southern part. With respect to the different functional outcomes, almost 60 % of the NTDs has a fatal outcome. If the NTD results in a live birth, malformations in the back (i.e. spina bifida) are the most frequent outcome.

Table 41 Neural-tube defects caused by folate deficiency in China, per functional outcome, per administrative area and region

| **Region/ Administrative area** | **Non-Fatal** | | | **Fatal** | | | **Total** |
|---|---|---|---|---|---|---|---|
| | Spina | Enceph. | Total | Abort. | Stillb. | Total | |
| NORTH | 3 363 | 877 | 4 240 | 3 279 | 3 058 | 6 336 | **10 576** |
| Northeast | 2 599 | 624 | 3 223 | 2 492 | 2 324 | 4 816 | **8 038** |
| Beijing | 35 | 9 | 44 | 34 | 32 | 66 | **110** |
| Tianjin | 40 | 8 | 48 | 37 | 35 | 72 | **120** |
| Hebei | 424 | 119 | 543 | 420 | 392 | 812 | **1 355** |
| Shanxi | 652 | 158 | 809 | 626 | 584 | 1 209 | **2 019** |
| Inner Mongolia | 215 | 58 | 273 | 211 | 197 | 407 | **680** |
| Liaoning | 151 | 22 | 173 | 134 | 125 | 259 | **433** |
| Jilin | 91 | 9 | 101 | 78 | 73 | 150 | **251** |
| Heilongjiang | 93 | 23 | 117 | 90 | 84 | 175 | **291** |
| Shandong | 293 | 55 | 348 | 269 | 251 | 520 | **868** |
| Henan | 604 | 162 | 766 | 593 | 553 | 1 145 | **1 912** |
| Northwest | 765 | 253 | 1 018 | 787 | 734 | 1 521 | **2 538** |
| Shaanxi | 310 | 123 | 433 | 335 | 312 | 647 | **1 080** |
| Gansu | 261 | 55 | 316 | 244 | 228 | 472 | **788** |
| Qinghai | 33 | 10 | 44 | 34 | 32 | 65 | **109** |
| Ningxia | 56 | 10 | 66 | 51 | 47 | 98 | **164** |
| Xinjiang | 105 | 55 | 159 | 123 | 115 | 238 | **397** |
| SOUTH | 634 | 261 | 894 | 692 | 645 | 1 337 | **2 231** |
| Southeast | 470 | 195 | 666 | 515 | 480 | 995 | **1 660** |
| Shanghai | 3 | 2 | 5 | 4 | 4 | 7 | **12** |
| Jiangsu | 38 | 7 | 45 | 35 | 33 | 68 | **113** |
| Zhejiang | 43 | 5 | 48 | 37 | 35 | 72 | **121** |
| Anhui | 99 | 39 | 138 | 107 | 100 | 206 | **345** |
| Fujian | 27 | 21 | 48 | 37 | 35 | 72 | **120** |
| Jiangxi | 40 | 18 | 57 | 44 | 41 | 85 | **143** |
| Hubei | 32 | 21 | 53 | 41 | 38 | 79 | **132** |
| Hunan | 72 | 20 | 92 | 71 | 67 | 138 | **230** |
| Guangdong | 68 | 34 | 102 | 79 | 74 | 152 | **255** |
| Guangxi | 41 | 27 | 68 | 53 | 49 | 102 | **171** |
| Hainan | 6 | 1 | 8 | 6 | 6 | 12 | **19** |
| Southwest | 163 | 65 | 229 | 177 | 165 | 342 | **571** |
| Sichuan | 32 | 22 | 54 | 42 | 39 | 81 | **135** |
| Guizhou | 88 | 10 | 98 | 75 | 70 | 146 | **243** |
| Yunnan | 18 | 18 | 36 | 28 | 26 | 54 | **90** |
| Tibet | 6 | 0 | 6 | 4 | 4 | 8 | **14** |
| Chongqing | 20 | 15 | 35 | 27 | 25 | 53 | **88** |
| **CHINA** | **3 997** | **1 137** | **5 134** | **3 970** | **3 703** | **7 673** | **12 807** |

*Note:* These figures are determined by the total number of NTDs (see De Steur et al. 2010a) and the attribution level of folate deficiency to NTDs in Northern (85 %) and Southern China (40 %).

*Input parameters of the DALY formula to measure the current burden of folate deficiency in China*

The table below summarizes all input parameters that are included in the DALY formula. The combined input parameters $T_jI_{ij}$ and $T_jM_j$ refer to, respectively, the non-fatal and fatal functional outcomes of NTDs caused by folate deficiency, which are also shown in Table 41. The disability weights of the functional outcomes ($D_{ij}$) differ according to the level of severity or disability, and range from 0 (‘healthy’) to 1 (‘death’) (Murray and Lopez, 1996). The average remaining life expectancy ($L_j$) of stillbirths and abortions refers to the average life expectancy at birth (see Table 40, column 5). The duration of a non-fatal NTD ($d_{ij}$) is assumed to be permanent, by which $d_{ij}$ equals $L_j$. Based on the global burden of disease study of Mathers et al. (1999), a disability weight of 0.593 and 0.52 is attributed to spina bifida and encephalocele, respectively. The discount rate for future life years (r) amounts to 3 percent, as this is the widely acknowledged standard rate in health impact analyses (Evans et al., 2005).

Table 42 Overview of the input parameters of the DALY formula, applied to folate deficiency in China

| Functional outcome | $T_jI_{ij}$ | $T_jM_j$ | $D_{ij}$ | $L_j$=$d_{ij}$ | r |
|---|---|---|---|---|---|
| *Morbidity* | | | | | |
| Spina bifida | Table 41, column 2 | NA | 0.593 | Table 40, column 5 | 3 % |
| Encephalocele | Table 41, column 3 | NA | 0.520 | | |
| *Mortality* | | | | | |
| Stillbirths | NA | Table 41, column 6 | NA | Table 40, column 5 | 3 % |
| Abortions | NA | Table 41, column 5 | NA | | |

$d_{ij}$, the duration of functional outcome i in target group j; $D_{ij}$, the disability weight for functional outcome i in target group j; $I_{ij}$, incidence rate of functional outcome i in target group j; $L_j$, the average remaining life expectancy for target group j; $M_j$, the mortality rate associated with the deficiency in target group j; NA, not applicable; r, discount rate for future life years; $T_j$, total number of people in target group j.

### *5.2.1.2. Data and assumptions to measure the current burden of vitamin A, iron and zinc deficiency in China*

Table 43 summarizes the parameter values for all included functional outcomes of micronutrient malnutrition in China, applied to the relevant target group and split up between fatal and non-fatal results. All data sources and calculation methods are provided in the table footnotes. Functional outcomes on which there is robust evidence on the attribution level (AL) of one of the four deficiencies are included. In the case of folate deficiency, for instance, there is evidence on its causal relationship with NTDs, but conclusive data on its potential association with anemia and other adverse health outcomes is lacking. Furthermore, as the incidence of functional outcomes is not always available, prevalence rates are transformed into incidence rates.

The data on folate deficiency refer to the national figures of the previous section and are only presented for the sake of completeness.

Vitamin A deficiency primarily affects children under 5 through measles, blindness and corneal scarring, with an attribution level of 10 %, and is responsible for all nightblindness in children and pregnant women. The vitamin A related functional outcomes also differ in duration, with a relatively short period of nightblindness compared to permanent outcomes, such as corneal scarring and blindness. The biggest problem of vitamin A deficiency, however, is its association with child mortality. West et al. (2010) found that between 23 % and 34 % of childhood mortality in Sub-Saharan Africa and Southern Asia is attributable to vitamin A deficiency. As a conservative assumption, the lower value of 23% is applied here.

Zinc deficiency is also associated with child mortality, but the AL of 4% is much lower (Jones et al., 2003). Other adverse functional outcomes of zinc deficiency include stunting and infectious diseases such as diarrhea and pneumonia. Incidence rates of diarrhea and pneumonia among children refer to infants and children between 1-5 years of age.

The DALY parameters to estimate the burden of iron deficiency (ID) are derived from Chinese iron deficiency anemia (IDA) data for four target groups and two groups of functional outcomes, namely impaired physical activity and impaired mental development. Mild IDA is excluded due to the uncertain link with functional outcomes.

Through IDA related fatal pregnancies, IDA mortality affects mothers, newborns and, due to the lack of breastfeeding, children. Maternal IDA related deaths occur in 5% of all fatal pregnancies (Stein et al., 2005b). Thirty percent of these fatal pregnancies lead to stillbirth, while 9.1% of the surviving births die because they could not be breastfed (Jones et al., 2003).

Common parameters of the DALY formula, such as the disability weights and the remaining life expectancies are derived from the Global Burden of Disease (GBD) study (Murray and Lopez, 1996) and the Chinese WHO life tables (WHO, 2008b). As in the previous section, a discount rate of 3 % is applied.

Table 43 Input parameters of the DALY framework to measure the current burden of micronutrient malnutrition (folate, vitamin A, zinc, iron) in China, non-fatal and fatal functional outcomes per micronutrient deficiency.

| **FOLATE** | **Demographic indicators** | | **All causes** | | **FD** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Non-fatal outcomes | Target groups | Population size ($T_j$)[a] | Prevalence rate | Incidence rate[b] | AL FD (%)[c] | Incidence rate (Iij)[b] | $T_j I_{ij}$ | Disability weight ($D_{ij}$)[d] | Av. age of onset | Duration ($d_{ij}$)[e] |
| spina bifida | births | 14 770 757 | / | 3.81 | 71.07 | 2.71 | 3 997.18 | 0.593 | 0 | 73.8 |
| encephalocele | births | 14 770 757 | / | 1.08 | 71.07 | 0.77 | 1 137.26 | 0.52 | 0 | 73.8 |
| Fatal outcomes | | | | Mortality rate[b] | | Mortality rate ($M_j$)[b] | $T_jM_j$ | | Av. age of death | Av. remaining life exp. ($L_j$)[e] |
| abortions | births | 14 770 757 | / | 3.78 | 71.07 | 2.69 | 3 970.26 | (1.00) | 0 | 73.8 |
| stillbirths | births | 14 770 757 | / | 3.53 | 71.07 | 2.51 | 3 702.59 | (1.00) | 0 | 73.8 |
| **VITAMIN A** | **Demographic indicators** | | **All causes** | | **VAD** | | | | | |
| Non-fatal outcomes | Target groups | Population size ($T_j$)[a] | Prevalence rate | Incidence rate | AL VAD (%) | Incidence rate (Iij) | $T_j I_{ij}$ | Disability weight ($D_{ij}$)[d] | Av. age of onset | Duration ($d_{ij}$) |
| measles | children < 5 yrs | 85 803 286 | 1.98[f] | 72.09[j] | 10[m] | 7.21 | 6 185.34 | 0.35 | / | 0.03 (10 days) |
| measles w complic. | children < 5 yrs | 85 803 286 | 1.98[f] | 36.04[j] | 10[m] | 3.60 | 3 092.67 | 0.7 | / | 0.05 (20 days) |
| nightblindness | children < 5 yrs | 85 803 286 | 0.10 %[g] | 0.10 %[j] | 100 | 0.10 | 85 803.29 | 0.05 | / | 1 |
| corneal scarring | children < 5 yrs | 85 803 286 | 0.10 %[g] | 0.02 %[k] | 10[n] | 0.002 | 1 716.07 | 0.2 | 1 | 74.20[e] |
| blindness | children < 5 yrs | 85 803 286 | 0.20 %[h] | 0.04 %[k] | 10[n] | 0.004 | 3 432.00 | 0.5 | 1 | 74.20[e] |
| nightblindness | pregnant women | 14 770 757 | 4.20 %[i] | 10.08 %[j] | 100 | 10.08 | 148 889.23 | 0.1 | / | 0.42 yr (5 months) |
| Fatal outcomes | | | | Mortality rate | | Mortality rate ($M_j$) | $T_jM_j$ | | Av. age of death | Av. remaining life exp. ($L_j$)[e] |
| mortality | children < 5 | 85 803 286 | / | 19[l] | 23[o] | 4.37 | 64 548.21 | (1.00) | 1 | 74.20 |
| **ZINC** | **Demographic indicators** | | **All causes** | | **ZD** | | | | | |
| Non-fatal outcomes | Target groups | Population size ($T_j$)[a] | Prevalence rate[p] | Incidence rate[q] | AL ZD (%) | Incidence rate (Iij)[q] | $T_j I_{ij}$ | Disability weight ($D_{ij}$)[d] | Av. age of onset | Duration ($d_{ij}$) |
| diarrhea | infants | 17 170 674 | 13.18 | 16.04[j] | 18[r] | 2.88 | 49 574 312 | 0.2 | / | 0.008 (3 days) |
| pneumonia | infants | 17 170 674 | 22.58 | 20.61[j] | 41[r] | 8.45 | 145 074 849 | 0.3 | / | 0.011 (4 days) |
| stunting | infants | 17 170 674 | / | 5.95 | 100 | 5.95 | 1 021 655 | 0.0001 | 0.5 | 73.8[e] |
| diarrhea | children (1-5 yrs) | 68 682 698 | 8.70 | 7.94[j] | 18[r] | 1.43 | 98 145 858 | 0.15 | / | 0.011 (4 days) |
| pneumonia | children (1-5 yrs) | 68 682 698 | 23.00 | 20.99[j] | 41[r] | 8.61 | 591 006 029 | 0.2 | / | 0.011 (4 days) |
| Fatal outcomes | | | | Mortality rate | | Mortality rate ($M_j$) | $T_jM_j$ | | Av. age of death | Av. remaining life exp. ($L_j$)[e] |
| increased mortality | infants | 17 170 674 | / | 17[l] | 4[s] | 0.68 | 10 044.12 | (1.00) | 0.67 | 74.1 |
| increased mortality | children (1-4 yrs) | 51 512 023 | / | 19[l] | 4[s] | 0.76 | 11 225.78 | (1.00) | 2.00 | 73.2 |

Table 43 (continued)

| IRON | Demographic indicators | | All IDA types | | IDA types | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Non-fatal outcomes | Target groups | Population size ($T_j$)[a] | Prevalence rate | Incidence rate[k] | AL IDA types (%)[w] | Incidence rate ($I_{ij}$) | $T_j I_{ij}$ | Disability weight ($D_{ij}$)[d] | Av. age of onset[g] | Duration ($d_{ij}$) |
| impaired physical activity | | | | | | | | | | |
| moderate | children < 5 | 85 853 372 | 8.00[t] | 1.33 | 0.562 | 0.75 | 643 327.94 | 0.11 | 0.5 | 4.50 |
| severe | children < 5 | 85 853 372 | | | 0.038 | 0.05 | 43 499.04 | 0.087 | 0.5 | 4.50 |
| moderate | children 6-14 | 150 231 072 | 17.94[u] | 1.99 | 0.562 | 1.12 | 1 682 499.54 | 0.11 | 6 | 8.00 |
| severe | children 6-14 | 150 231 072 | | | 0.038 | 0.08 | 113 763.31 | 0.087 | 6 | 8.00 |
| moderate | men 15+ | 487 312 627 | 9.52[u] | 0.16 | 0.562 | 0.09 | 448 750.35 | 0.11 | 15 | 58.70[e] |
| severe | men 15+ | 487 312 627 | | | 0.038 | 0.01 | 30 342.55 | 0.09 | 15 | 58.70[e] |
| moderate | women 15+ | 473 856 262 | 16.92[u] | 0.27 | 0.562 | 0.15 | 730 078.87 | 0.11 | 15 | 62.90[e] |
| severe | women 15+ | 473 856 262 | | | 0.038 | 0.01 | 49 364.76 | 0.09 | 15 | 62.90[e] |
| impaired mental development | | | | | | | | | | |
| moderate | children < 5 | 85 853 372 | 8.00[t] | 1.33 | 0.562 | 0.75 | 643 327.94 | 0.006 | 5 | 70.40[e] |
| severe | children < 5 | 85 853 372 | | | 0.038 | 0.05 | 43 499.04 | 0.024 | 5 | 70.40[e] |
| Fatal outcomes | | | | Mortality rate | AL IDA (%) | Mortality rate ($M_j$)[v] | $T_j M_j$ | | Av. age of death | Av. remaining life exp. ($L_j$)[e] |
| maternal mortality | births | 14 770 757 | / | 41.3[v] | 5 | 2.07 | 305.02 | (1.00) | 27[z] | 52.1 |
| stillbirths | fatal pregnancies | 14 770 757 | / | / | / | 0.06[x] | 91.50 | (1.00) | 0 | 73.8 |
| child mortality | fatal pregnancies | 14 770 757 | / | 19.0[l] | / | 0.00099[y] | 0.15 | (1.00) | 1 | 74.2 |

AL= attribution level; FD = folate deficiency; IDA = iron deficiency anemia; VAD = vitamin A deficiency; ZD = zinc deficiency

*Note:* Input parameters are based on Stein et al. (2005b), unless otherwise stated. The discount rate (r) is set at 3 %.

[a]National Bureau of Statistics of China (2008c). The number of pregnant women is derived from the number of reported births. This figure is both an under- or overestimation, because this figure does not take into account the non-reported births and the share of women that are pregnant of a twin or triplet, respectively; [b]Expressed per 10 000 births. The share of the different non-fatal and fatal outcomes is derived from Dai et al. (2002) and Li et al. (2006), respectively: spina bifida (31.21 %), encephalocele (8.88 %), abortions (31 %) and stillbirths (28.91 %); [c]The percentage of NTDs that is attributable to folate deficiency is based on the Chinese national attribution level of 71.07 % (see Table 40); [d]Disability weights of the Global Burden of Disease study, as defined by Murray and Lopez (1996); [e]The remaining life expectancy at different ages are based on the Chinese WHO life tables in 2008 (WHO, 2008b); [f] The total prevalence of measles in children below 5 years is 3.95 per 100 000 children (Hao et al., 2010). An estimated 50 % of these cases involve complications (Stein et al., 2008b); [g]Based on a large-scale nationwide survey on vitamin A deficiency (Lin et al., 2002; Jingxiong et al., 2006; WHO, 2009b); [h]Own calculations, based on Chinese estimates of childhood blindness (WHO, 1999) and applied on the most recent figure of the blind population in China, i.e. 6.6 million (CDPF, 2006). [i]WHO Global Database on Vitamin A Deficiency (WHO, 2009b); [j]The incidence rate of a temporary functional outcome is based on the formula: 'prevalence rate'/'duration of the disease' (Stein et al., 2005b); [k]The incidence rate of a permanent functional outcome is based on the formula: 'prevalence rate'*'size 1st age cohort'/'size target group' (Stein et al., 2005b); [l]Mortality rates refer to 2009, expressed per 1 000 births (National Bureau of Statistics of China, 2008b; UNICEF, 2011); [m]Expressed in % of all measles, with or without complications; [n]Expressed in % of all corneal scarring (children under 5 years); [o]Based on a meta-analysis of West et al. (2010); [p]The prevalence rates of non-fatal outcomes of zinc deficiency in China are based on Chen et al. (2004), expressed in %; [q]Expressed in times per year, except for the stunting incidence rate of Chen et al. (2004), i.e. 5.95 % of all infants; [r]Based on a zinc supplementation study by Bhutta et al. (1999); [s]Attribution level as reported by the Bellagio Child Survival Study Group (Jones et al., 2003); [t]The prevalence of IDA in children below 5 years refers to 2004 (Micronutrient Initiative, 2011b); [u]Own calculations, derived from the total anemia rates in children/men (WHO, 2006b) and women (Ma et al., 2007), and the attribution level of ID to anemia, i.e. 85 % in China (Ma et al., 2007). Depending on the target group, the IDA prevalence rate refers to the year 2000 (children/men) or 2002 (women); [v]The mortality rate of pregnant women is expressed per 100 000 births (National Bureau of Statistics of China, 2008b); [w]According to Rastogi and Mathers (2000), three different IDA types can be distinguished, depending on their severity. In China, the estimated share of each type is as follows: mild (0.4 %), moderate (0.562 %) and severe IDA (0.038 %); [x]About 30 % percent of all IDA-related fatal pregnancies are assumed to result in a stillbirth (Jones et al., 2003); [y]Of the 70 % newborns that survive their mothers death that is caused by iron deficiency, about 13 % would not die during childhood if they would have been breastfed (Jones et al., 2003). Taking into account the share of exclusively breastfed children, i.e. 28 % in China (UNICEF, 2011), the incidence of deaths in children below 5 years that is indirectly related to maternal IDA, is calculated as: 0.019*0.7*0.13*0.28*'maternal mortality'; [z]The average age of fatal pregnancies refers to the average age of Chinese women at the time of their first birth, i.e. 27 years in 2007 (CPDRC, 2010).

## 5.2.2. Evaluating the potential health impact

The framework to assess ex-ante the health benefits of FBR and MBR is built upon previous health impact studies (Zimmermann and Qaim, 2004; Qaim et al., 2007) and depends on different factors, as Figure 20 depicts.

Two important determinants are directly related to these folate interventions, namely the product characteristics of the biofortified food vehicle and the coverage rate. While the former determines the micronutrient dose, the latter defines the market potential of the crop and, thus, the response to this dose. Information about the micronutrient dose, the current folate intake levels and the current rice consumption patterns is used to calculate the total folate intake after biofortification, which reduces the number of maternal folate deficiencies and, thus, reduces the number of NTDs, i.e. the health benefits. As for MBR, additional data about other micronutrient intake levels, before and after biofortification, is required to estimate the potential impact of MBR on China's nutritional health status.

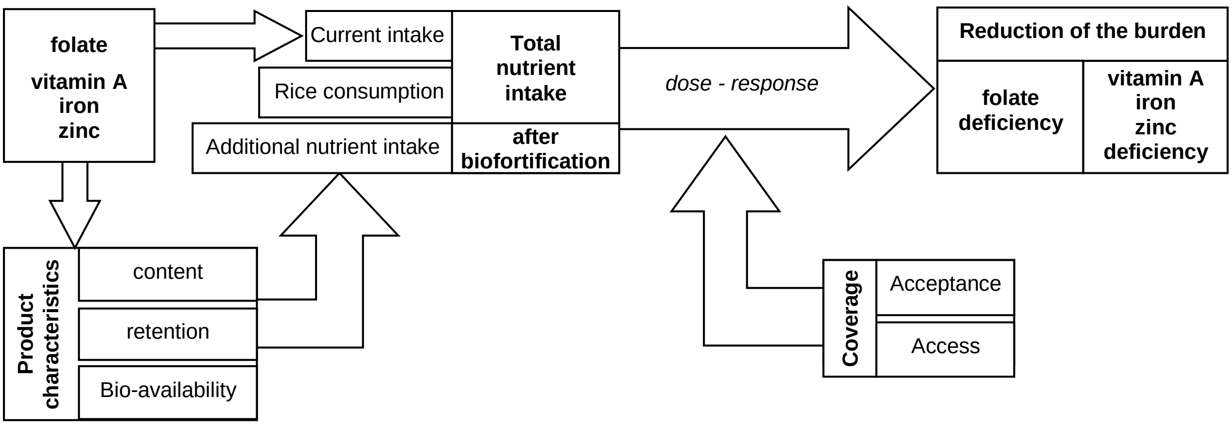


Figure 20 The potential health impact of folate biofortified and multi-biofortified rice

*Note*: Product characteristics = (nutritional content in rice, µg per g)*(nutrient retention after processing, %)*(degree of bio-availability, %)
Additional nutrient intake = (Product characteristics, µg per g) - (nutritional content in rice, µg per g)
Coverage rate = (acceptance rate, %)*('access' = farmers' acceptance rate, %)
Total nutrient intake after biofortification = (current intake, µg) + (additional intake, µg per g)*(rice consumption, g)

*5.2.2.1. Data and assumptions to calculate the health impact of folate biofortification*

The calculation method and the assumptions to measure the potential health benefits of FBR in China are described below. Because the health impact of FBR is closely related to the number of NTDs in China, two target groups are considered. On the one hand, due to the relationship between maternal folate deficiency and the risk of delivering a baby with an NTD, women of childbearing age are the target group for FBR consumption. On the other hand, newborns are considered as the primary beneficiaries of the health benefits, as they carry the risk of having an NTD.

Based on the product characteristics of FBR, the folate content of FBR is calculated by multiplying the amount of additional folate in rice with the retention of folate after processing the rice and the bioavailability of folate.

Through genetic modification, different transgenic lines of FBR were obtained (see section 2.4.4.2). For the calculations, the amount of 1 200 µg per 100 g raw polished grains is used. This folate content will be reduced by 50 % during rice processing, i.e. cooking (Storozhenko et al., 2007). To take into account the bioavailability upon ingestion, the remaining folate concentration will then be reduced by 50 % (Bailey, 2004; FSAI, 2006). Combining these three product parameters results in a total folate intake of biofortified rice of 300 µg per 100 g rice. Given the initial folate content of rice, 8 µg per 100 g (USDA, 2008), the total added folate intake amounts 292 µg per 100 g. In the multi-biofortification scenario we will also show a pessimistic scenario, where the folate losses due to processing amounts 75 % (see Table 45).

Assuming that the current rice patterns do not differ after introducing FBR, the total folate intake of Chinese women of childbearing age after biofortification can be estimated by adding the additional folate intake to the current folate consumption levels. The average daily rice consumption of women of childbearing age can be calculated for each administrative area, based on the China National Nutrition and Health Survey 2002 (Zhai and Yang, 2006) and updated with data from the China's National Grain and Oils Information Center (CNGOIC, 2009a). On average, a Chinese women of childbearing age consumes 218.32 g of rice per day. However, rice consumption in Southern China is twice as large as in Northern China. Also the current daily folate intake of woman of childbearing age is higher in Southern China (212.9 µg) than in Northern China (188.0 µg).

Based on the current rice consumption, the current folate intake and the additional folate intake of biofortifying rice, a scenario where Chinese women completely switch to FBR and do not alter their rice consumption pattern results in an average folate intake of 837.3 µg per day, per woman of childbearing age (Table 44). This is more than two times the required intake or 209 % of the recommended nutrient intake (RNI). Regional folate intake levels after biofortification vary from 433.7 µg, per day, per person in Xinjiang (northwest) to 1 410.7 µg, per day, per person in Hunan (southeast). The contribution of the total folate intake after biofortification to the recommended dose varies between 108.4 % in Xinjiang (northwest) and 352.7 % in Hunan (southeast). Although rice consumption and folate intake levels in the northern regions are significantly lower, the daily folate recommendation can still be achieved if FBR would be consumed.

Below the table, a geographical presentation of this relationship shown, where rice consumption (Figure 21) and production (Figure 22) and folate intake after biofortification (Figure 23) in China are juxtaposed.

Table 44 Folate biofortification of rice in China in an optimal scenario (100 % consumption of biofortified rice). Current rice and folate consumption, added and total folate intake after biofortification, and % of RNI, per administrative area and region

| **Region/ Administrative area** | **Current** | | **Added** | **Total** | |
|---|---|---|---|---|---|
| | rice cons.[a] | folate intake[b] | folate intake[c] | folate intake[d] | % of RNI[e] |
| | g /day/person | µg /day/cba | µg /day/cba | µg /day/cba | |
| NORTH | 125.43 | 188.0 | 366.25 | **554.25** | 138.56 |
| Northeast | 129.13 | 190.9 | 377.05 | **567.95** | 141.99 |
| Beijing | 262.78 | 190.9 | 767.32 | **958.22** | 239.56 |
| Tianjin | 198.41 | 190.9 | 579.36 | **770.26** | 192.57 |
| Hebei | 93.03 | 190.9 | 271.65 | **462.55** | 115.64 |
| Shanxi | 108.81 | 190.9 | 317.73 | **508.63** | 127.16 |
| Inner Mongolia | 115.29 | 190.9 | 336.65 | **527.55** | 131.89 |
| Liaoning | 193.68 | 190.9 | 565.55 | **756.45** | 189.11 |
| Jilin | 222.73 | 190.9 | 650.37 | **841.27** | 210.32 |
| Heilongjiang | 203.76 | 190.9 | 594.99 | **785.89** | 196.47 |
| Shandong | 85.68 | 190.9 | 250.17 | **441.07** | 110.27 |
| Henan | 92.22 | 190.9 | 269.28 | **460.18** | 115.05 |
| Northwest | 108.06 | 182.7 | 315.54 | **498.24** | 124.56 |
| Shaanxi | 110.24 | 182.7 | 321.91 | **504.61** | 126.15 |
| Gansu | 106.05 | 182.7 | 309.66 | **492.36** | 123.09 |
| Qinghai | 111.68 | 182.7 | 326.12 | **508.82** | 127.20 |
| Ningxia | 175.04 | 182.7 | 511.10 | **693.80** | 173.45 |
| Xinjiang | 85.95 | 182.7 | 250.96 | **433.66** | 108.42 |
| SOUTH | 285.91 | 212.9 | 834.86 | **1047.76** | 261.94 |
| Southeast | 301.58 | 215.1 | 880.61 | **1095.71** | 273.93 |
| Shanghai | 249.34 | 215.1 | 728.08 | **943.18** | 235.79 |
| Jiangsu | 270.23 | 215.1 | 789.06 | **1004.16** | 251.04 |
| Zhejiang | 341.89 | 215.1 | 998.33 | **1213.43** | 303.36 |
| Anhui | 197.31 | 215.1 | 576.15 | **791.25** | 197.81 |
| Fujian | 335.18 | 215.1 | 978.74 | **1193.84** | 298.46 |
| Jiangxi | 360.33 | 215.1 | 1052.15 | **1267.25** | 316.81 |
| Hubei | 273.33 | 215.1 | 798.14 | **1013.24** | 253.31 |
| Hunan | 409.43 | 215.1 | 1195.55 | **1410.65** | 352.66 |
| Guangdong | 248.19 | 215.1 | 724.70 | **939.80** | 234.95 |
| Guangxi | 398.53 | 215.1 | 1163.70 | **1378.80** | 344.70 |
| Hainan | 193.01 | 215.1 | 563.59 | **778.69** | 194.67 |
| Southwest | 241.52 | 210.4 | 705.23 | **915.63** | 228.91 |
| Sichuan | 247.48 | 210.4 | 722.64 | **933.04** | 233.26 |
| Guizhou | 208.32 | 210.4 | 608.30 | **818.70** | 204.67 |
| Yunnan | 212.66 | 210.4 | 620.96 | **831.36** | 207.84 |
| Tibet | 99.00 | 210.4 | 289.08 | **499.48** | 124.87 |
| Chongqing | 328.93 | 210.4 | 960.48 | **1170.88** | 292.72 |
| **CHINA** | **218.32** | **199.8** | **637.49** | **837.29** | **209.32** |

cba, woman of childbearing age; RNI, the recommended nutrient intake (i.e. folate)
[a]The daily rice consumption is expressed per women of cba, in 2007 (Zhai and Yang, 2006; CNGOIC, 2009b); [b]The current, regional folate intake before biofortification refers to findings from Zhao et al. (2009); [c]The total added folate intake due to biofortification is based on the total current rice intake (column 1), folate intake (column 2) and additional folate content of biofortified rice, 2.92 µg per g (based on optimistic product parameters, as defined in Table 45); [d]Sum of the current and additional folate intake; [e]Calculated by comparing the total folate intake after biofortification with the RNI of folate, i.e. a daily average folate intake of 400 µg folate per person.

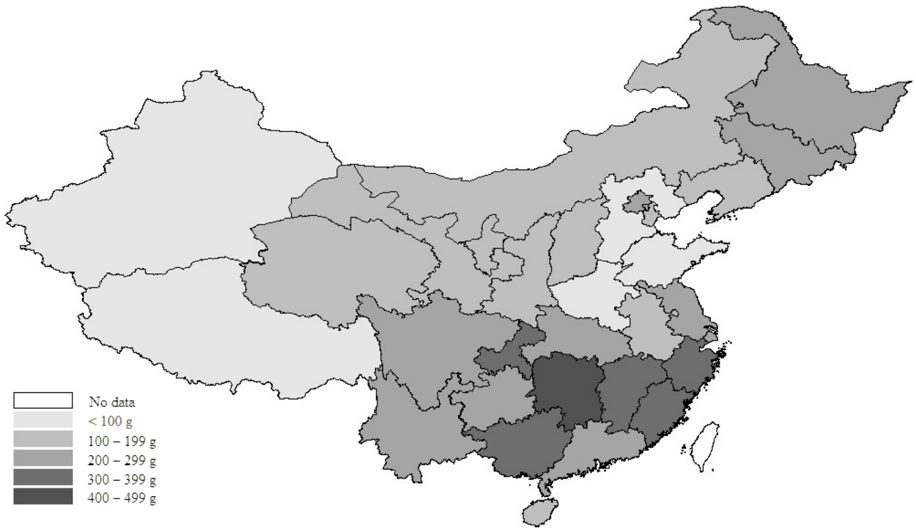


Figure 21 Current rice consumption patterns, in g per day per women of childbearing age, in China, per administrative region

*Source*: Own illustration, based on Table 44

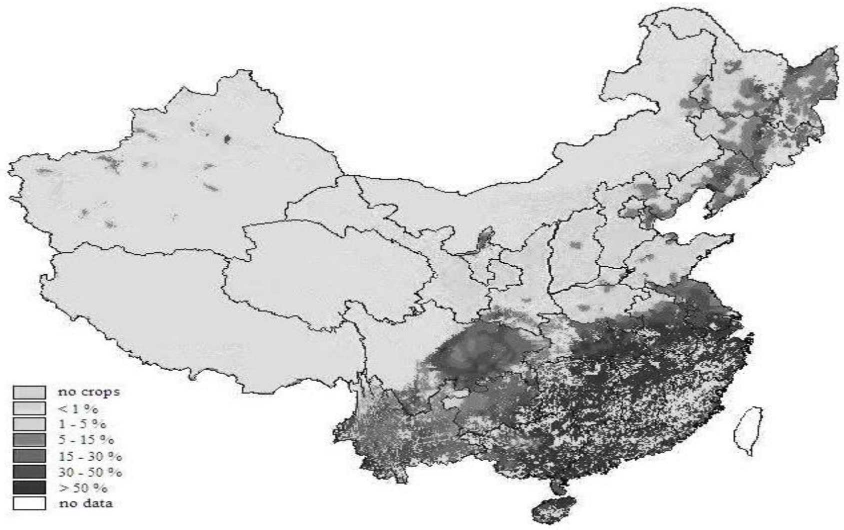


Figure 22 Share of rice production in cropland usage in %, in China, per administrative region

*Source*: Based on IIASA, International Institute for Applied Systems Analysis

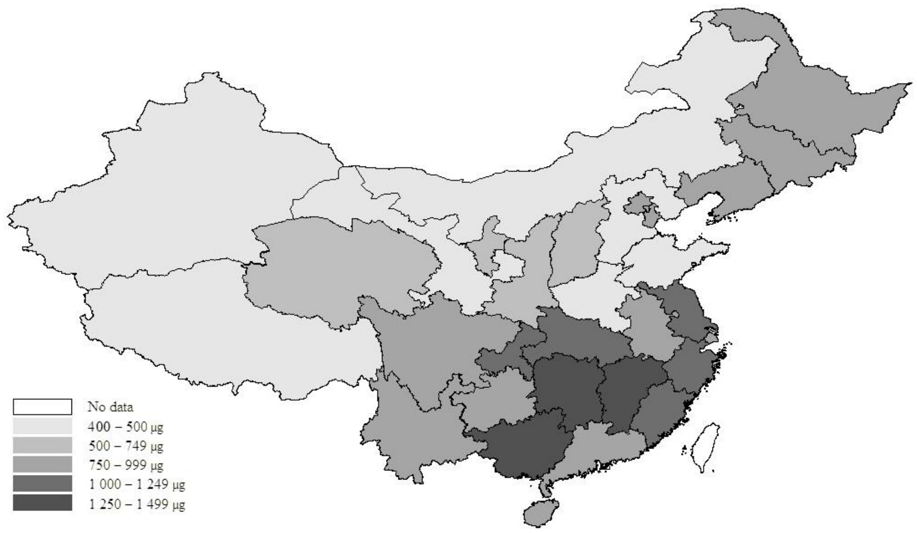


Figure 23 Total daily folate intake after biofortification in China, per women of childbearing age
*Source* : Own illustration, based on Table 44

In order to assess the health impact of folate biofortification, assumptions have to be made with respect to the effect of additionally absorbed folate on folate deficiency, the so-called "dose-response". According to the state transition model, this relationship should define the share of a population that moves to or through different possible health states, ranging from the various degrees of illness, including death, to complete health (Chisholm, 2006).
Here, the 'dose' is understood as the average daily folate intake after biofortification in China and its regions (see Table 44, column 5). Although a few studies investigated the effect of different folate doses on the reduction of NTD incidence (Daly et al., 1997; Moore et al., 2003), there is still a lack of scientific evidence to measure the health impact of each of the regional total folate intake levels in China. To overcome this problem, the "response" is defined by evaluating whether the total folate intake level of women of childbearing age in each of the Chinese administrative areas achieves the recommended folate intake (see Table 44, column 6). In accordance to previous literature, the 'response' to a daily folate intake of 400 µg or higher is understood as the prevention of folate deficiency and its adverse health outcomes, e.g. NTDs (Lumley et al., 2001; Molloy and Scott, 2001). The introduction of this benchmark is useful when applying average instead of individual nutrient intake data, especially if the impact of different micronutrient doses on functional outcomes is not known. Given that each administrative area in China exceeds the recommended daily folate intake of 400 µg per childbearing woman, consumption of FBR with an initial folate content of approximately 1 200 µg per 100 g rice is assumed to prevent maternal folate deficiency and the risk of having a baby affected with an NTD caused by folate deficiency.

Because only women who agree to consume FBR will recover from folate deficiency and its health risks, the dose after biofortification only refers to a part of the market. This part is determined by the coverage rate, which combines the FBR acceptance of women and their access to favorable farmers. According to the consumer study in Shanxi Province (see chapter 3), 55.4 % of female rice consumers are willing to accept rice with high folate content, while 32.3 % react indifferent and 12.3 % are reluctant. The findings for farmers are even more positive, with 66.7 % accepting and only 6.6 % of the farmers rejecting the rice. When one would combine acceptance and access to farmers, a low and high coverage rate would amount 37 % and 82 %, respectively.

However, in close consultation with scientists from the Golden Rice Project, we have decided to adjust these figures for two main reasons. First, the results are derived from a consumer study in Shanxi Province, a high-risk region of folate deficiency. Although it still needs to be proven, the acceptance rates could be lower in regions where the need to improve folate intake levels is less high. Second, in order to compare the different single biofortification interventions in the study on multi-biofortification (see Table 45), we decided to use the same coverage rate for each biofortified crop.

Therefore, the coverage rates in this study amounts 20 % in the pessimistic and 60 % in the optimistic scenario. These coverage rates are defined as the percentage of women that switch completely to FBR, compared to women that hold on to traditional rice. In this way, they determine the percentage of women that can recover from folate deficiency by a biofortified diet. As these coverage rates are lower than what would be obtained from the Shanxi consumer study, they are assumed to be conservative estimates. The reasons to select these specific coverage rates is further elaborated in the next section.

#### *5.2.2.2. Data and assumptions regarding the health impact of multi-biofortification*

The multi-biofortified crop of interest contains not only an enhanced zinc and iron content, which can be delivered through conventional technology, but also involves GM technology to elevate the folate and beta-carotene (pro-vitamin A) levels. Although genetic modification of rice could further raise the levels of both minerals, as shown by Vasconcelos et al. (2003) and Johnson et al. (2011), it may be advantageous to include two conventional traits, as this could reduce complications in the approval process and speed up the commercialization. Because folate or vitamin A enriched rice can only be successfully developed through transgenic engineering, multi-biofortification as explored in this study refers to a combined GM rice crop, which will influence both product and market characteristics (see also Figure 20).

The data and assumptions regarding the main product parameters are presented in Table 45. To account for uncertainty with respect to key parameters, two scenarios have been designed, one with pessimistic and the other one with more optimistic assumptions. The initial folate and vitamin A content of rice is marginal to non-existent, which also explains why conventional approaches are less likely to be as successful. This is different for iron and zinc, where the conventional rice varieties contain certain amounts that can be further increased through cross-breeding. The assumptions on improved micronutrient contents after biofortification, as well as on post-harvest losses and bioavailability, are based on the previous literature, as detailed in the footnotes to Table 45. Some of the values were updated based on statements by scientists involved in the respective biofortification projects.

Building on the current micronutrient intake levels in China, and assuming that current rice consumption patterns are maintained, total vitamin and mineral intakes after multi-biofortification were calculated for each target group, as shown in Table 46. As in the previous section, the dose-response relationship, i.e. the effect of a higher nutrient intake level on functional outcomes for each micronutrient, is interpreted by evaluating the degree to which improved intakes reach recommended levels (RNI). While levels beyond the RNI will fully protect consumers from any adverse functional outcomes, improvements below the RNI can still be associated with positive health impacts. If the RNI for a specific target group and micronutrient is not achieved, the technological efficacy (E) is calculated as follows (Zimmermann and Qaim, 2004):

$$\text{Efficacy (E)} = \frac{\ln\left(\frac{\text{MIL}_{after}}{\text{MIL}_{before}}\right) - \left(\frac{\text{MIL}_{after} - \text{MIL}_{before}}{\text{RNI}}\right)}{\ln\left(\frac{\text{RNI}}{\text{MIL}_{before}}\right) - \left(\frac{\text{RNI} - \text{MIL}_{before}}{\text{RNI}}\right)}$$

MIL, micronutrient intake level; RNI, recommended nutrient intake

*Note:* before = scenario without biofortification; after = scenario with biofortification

In addition to the technological efficacy, the health impact is further determined by the coverage rate of multi-biofortified rice varieties. The addition of vitamin A into the multi-biofortified rice crop has important implications for the coverage rate. The yellowish color of Golden Rice might lead to a diminished acceptance rate (Brooks, 2010). Our consumer survey in Shanxi Province, for example, showed that the acceptance rate of favorable and indifferent Chinese rice consumers would be 16.4 % lower if the external appearance of FBR is negatively affected (see chapter 3, section 3.3.4.1). However, value elicitation studies demonstrated that WTP values of Golden Rice and other vitamin A enriched biofortified crops are not consequently lower than the WTP values for FBR (Lusk, 2003; Deodhar et al., 2008; Depositario et al., 2009a; Gonzalez et al., 2009; De Groote et al., 2011)(see section 4.4.2.3).

Although recent acceptance studies on single GM biofortified rice in Southeast Asia are optimistic, it is unclear how Chinese consumers will react to the yellowish transgenic rice with multiple health and nutrition benefits. As a consequence, we build on previous coverage rate assumptions that were used for Golden Rice studies in India (Stein et al., 2006) and the Philippines (Zimmermann and Qaim, 2004). One of the big advantages of multi-biofortification is that all micronutrients are included in the same rice varieties. We assume that several varieties will be multi-biofortified, catering for different agro-ecological environments. Accordingly, 20% and 60% of the Chinese consumers are assumed to switch to multi-biofortified rice in the pessimistic and optimistic scenario, respectively (see in Table 45).

Table 45 Estimates of the technology characteristics and coverage of multi-biofortification, per micronutrient and impact scenario

| | Pessimistic Scenario | | | | Optimistic Scenario | | | |
|---|---|---|---|---|---|---|---|---|
| | Folate[c] | Vitamin A[b] | Zinc[f] | Iron[g] | Folate[c] | Vitamin A[e] | Zinc[f] | Iron[g] |
| **Technology characteristics** | | | | | | | | |
| Initial micronutrient content (µg per g rice)[a] | 0.08 | 0 | 16 | 3 | 0.08 | 0 | 16 | 3 |
| Improved micronutrient content (µg per g rice) | 12 | 20 | 25 | 8 | 12 | 30 | 35 | 14 |
| Post-harvest losses, incl. cooking (%) | 75 | 80 | 0 | 0 | 50 | 20 | 0 | 0 |
| Bioavailability (%) | 50[d] | 4:1[e] | 100 | 100 | 50[d] | 2.3:1[e] | 100 | 100 |
| Added micronutrient content (µg per g rice) | 1.4 | 1.0 | 9.0 | 5.0 | 2.9 | 6.52 | 19.0 | 11.0 |
| **Coverage rate (%)[b]** | | 20 | | | | 60 | | |

NA, not applicable
[a]Based on USDA (2008); [b]Based on Zimmerman and Qaim (2004) and Stein et al. (2006), and updated by scientists from the Golden Rice Project; [c]The optimistic scenario is derived from section 5.2.2.1. In the pessimistic scenario, post-harvest losses refer to folate degradation after cooking (50 %) but takes also into account long-term storage losses (unpublished work); [d]Based on Bailey (2004); [e]Bioconversion factors are based on Tang et al. (2009) and additional feeding trials carried out within the Golden Rice project. They refer to the bioavailability of provitamin A (beta-carotene) and its conversion into vitamin A; [f]Based on Stein et al. (2007), and updated by scientists from the International Rice Research Institute; [g]Based on Stein et al. (2008a), and updated by scientists from the International Rice Research Institute.

Table 46 Rice consumption, micronutrient intake with and without multi-biofortification in China, per micronutrient and impact scenario

| | Daily rice consumption (per person)[c] | Daily micronutrient intake (per person) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Status Quo[d] | With biofortification | | | | | | RNI |
| | | | Pessimistic | | | Optimistic | | | |
| **Vitamins** | ***g*** | ***µg*** | ***µg*** | ***% RNI*** | ***% Efficacy*** | ***µg*** | ***% RNI*** | ***% Efficacy*** | ***µg*** |
| **Folate** | | | | | | | | | |
| Women of cba[a] | 218.32 | 199.8[e] | 509.81 | 127.45 | RNI | 837.29[e] | 209.32[e] | RNI | 400[f] |
| **Vitamin A** | | | | | | | | | |
| Children < 5 years | 119.70 | 276.0 | 395.70 | 79.14 | 82.7 | 1056.65 | 211.33 | RNI | 500[g] |
| Pregnant women | 224.20 | 572.4 | 796.63 | 99.58 | 99.9 | 2034.61 | 254.33 | RNI | 800[g] |
| **Minerals** | ***g*** | ***mg*** | ***mg*** | ***% RNI*** | ***% Efficacy*** | ***mg*** | ***% RNI*** | ***% Efficacy*** | ***mg*** |
| **Zinc** | | | | | | | | | |
| Infants | 92.12 | 4.9 | 5.73 | 83.07 | 69.0 | 6.65 | 96.42 | 98.7 | 6.9[h] |
| Children 1-5 years[b] | 119.70 | 6.0 | 7.04 | 88.06 | 80.2 | 8.24 | 103.02 | RNI | 8.0[h] |
| **Iron** | | | | | | | | | |
| Children < 5 years | 119.70 | 11.9 | 12.50 | 87.59 | 45.9 | 13.21 | 92.63 | 81.6 | 14.3[i] |
| Children 6-14 years | 204.20 | 18.7 | 19.67 | 83.71 | 39.8 | 20.90 | 88.92 | 73.2 | 23.5[i] |
| Men 15 + | 256.00 | 24.4 | 25.70 | 93.78 | 68.5 | 27.23 | 99.39 | 99.7 | 27.4[i] |
| Women 15 + | 218.32 | 21.2 | 22.31 | 37.94 | 0.08 | 23.62 | 40.17 | 17.5 | 58.8[i] |
| Pregnant women | 224.20 | 21.2 | 22.34 | 37.99 | 0.09 | 23.68 | 40.28 | 17.9 | 58.8[i] |

cba, childbearing age NA, not applicable; RNI, recommended nutrient intake
[a]Due to the focus on NTDs as the main outcomes of folate deficiency, women of childbearing age are included as the target group of biofortified rice consumption, whereas the health impact refers to the newborns; [b]Due to a lack of data on the below 4 years age category, this category is covered by the 1-5 years age category. [c]Based on the China National Nutrition and Health Survey 2002 (Zhai and Yang, 2006). Due to data constraints, rice consumption of women of childbearing age (15-64) and women 15+ is assumed to be equal; [d]Based on the China National Nutrition and Health Survey 2002 (Chai et al., 2009); [e]See Table 44; [f]Based on the WHO folic acid supplementation recommendations for pregnant women, i.e. 400 µg folate per day, per person (WHO, 2006a); [g]International RNI for children and pregnant women, as proposed by IOM (2002) and FAO/WHO (2004); [h]Based on the WHO recommended RNI levels for zinc, adjusted for developing countries (Allen et al., 2006); [i]Based on the FAO/WHO RNI levels for developing countries (FAO/WHO, 2004).

## 5.3. *Measuring the cost-effectiveness*

Without evaluating the importance of the DALY-based health impact analyses of folate and multi-biofortified crops, potential stakeholders, like policy makers and health planners, look for a complementary evaluation tool in order to compare, prioritize, underpin and justify their decisions to support, fund and implement such public health interventions. Given the budgetary constraints for allocating resources to public health interventions, the costs of the health strategy need to be incorporated in this health impact study. An essential tool is CEA, which compares the expected costs and benefits of an intervention to assess its 'value for money' (Musgrove and Fox-Rushby, 2006). As a primary economic evaluation technique to evaluate whether a health intervention is eligible for implementation or not, CEA measures the cost per unit of the health benefits (see section 1.3.3.3). The 'cost per DALY saved' is a common indicator to evaluate the cost-effectiveness of health programs (World Bank, 1993; Jamison et al., 2006), in Asia (Liu et al., 2008) and, in particular, with respect to policy interventions to combat micronutrient malnutrition (Stein et al., 2005b). Similar to the DALY framework, the result is a single indicator, US$ per gained DALY.

Because the cost-effectiveness is expressed in natural health units, unlike cost-benefit analysis (see section 1.3.3.3), the results can only be compared with other health impact studies if there is a common health measure unit (e.g. DALYs) and a common currency (e.g. US$). Although some declare that using a cut-off level in CEA is arbitrary and inappropriate (Laxminarayan et al., 2006), the need for a reference point to interpret the profitability of this relative measure is generally acknowledged (Musgrove and Fox-Rushby, 2006). In most cases, an international benchmark is selected as the reference value to evaluate whether the intervention is considered cost-effective. According to the World Bank (1993), a highly cost-effective intervention in 1990 amounts between US$ 50 and US$ 150 per DALY saved. Converted into 2011 US dollars, the recommended threshold of a saved DALY increases to US$ 86.04 and US$ 258.12 (BLS, 2011). At present, intervention costs below US$ 43.21 per DALY saved are considered to be remarkably low, with costs per gained DALY below US$ 5.19 categorized as the most cost-effective. WHO (WHO, 2001b; Tan-Torres Edejer et al., 2003) and its CHOICE (Choosing Interventions that are Cost-Effective) project (Evans et al., 2005) on the other hand, propose to use the national (or regional) single or triple per capita income level to evaluate whether the cost-effectiveness of an intervention is, respectively, moderate or very high (WHO, 2011a).

Building upon the investigated health impact, the cost-effectiveness of the introduction of FBR and MBR in China can be assessed by juxtaposing the costs to develop and distribute the biofortified rice and the estimated health benefits. The time frame used in this study is 30 years, which corresponds with previous health impact studies (Horton, 2006; Stein et al., 2008b), and includes the key steps of implementing the biofortified crop. From development to commercialization, the following categories of costs occur: (advanced) R&D costs, country-specific costs (field trials, backcrossing costs, large scale feeding tests and regulatory costs), social marketing costs and maintenance breeding costs. In this way, the CEA aims to evaluate the intervention from the point of view of the broad society, in line with the WHO (Evans et al., 2005), U.S. Panel on Cost-Effectiveness in Health and Medicine (Gold et al.,

1996) and CDC (Grosse et al., 2007). The WHO states: *"Costs are measured from the perspective of society as a whole, to understand how best to use resources regardless of who pays for them, or indeed, whether they are paid for at all"* (Evans et al., 2005, p. 1137). Following Musgrove & Fox-Rushby (2006), the underlying CEA does not include indirect costs, such as individual costs of buying and consuming the biofortified crop (travel costs, work time losses), nor the costs related to the decreased share of other interventions (e.g. potential economic losses due to diminished production/use of supplements). Health interventions could also reduce the costs related to health care and, thereby, further improve the cost-effectiveness. These cost savings refer to the lower diagnostic, clinic attendance, hospitalization (Grosse et al., 2008) and rehabilitation costs (Hertrampf and Cortes, 2008), and the related travel costs (Jentink et al., 2008); the reduced use of medication (Bentley et al., 2009) and the absence of special education costs (Jentink et al., 2008).

Based on the number of DALYs saved through the introduction of biofortification and the cost estimates of the intervention, the cost-effectiveness is measured by comparing the Net Present Value (NPV) of the two components, both discounted at 3 % (see section 5.2):

$$\frac{\mathrm{NPV_{costs}}}{\mathrm{NPV_{DALYs\ saved}}} = \frac{\sum_{t=1}^{30}\left[(C_t)(1+r)^{-t}\right]}{\sum_{t=1}^{30}\left[(\mathrm{DALYs\ saved}_t)(1+r)^{-t}\right]}$$

The input parameters of the formula are year (t), ranging from 1 to 30, the total costs at year t ($C_t$), and the discount rate for future life years (r).

## 5.4. *Results and Discussion*

### 5.4.1. Burden and potential health impacts of folate biofortified rice in China

#### *5.4.1.1. Current burden of folate deficiency (DALYs lost)*

The present burden of folate deficiency in China, i.e. the situation 'without' biofortification, can be calculated by entering the input parameters of Table 42 into the DALY formula. This burden is expressed as the number of DALYs lost per administrative area (Table 47).

Table 47 Burden of folate deficiency in China, per functional outcome, expressed in the number of DALYs lost, per year, per region and administrative area

| **Administrative Area/ Region**[a] | **Non-Fatal** | | | **Fatal** | | | **Total** |
|---|---|---|---|---|---|---|---|
| | Spina | Enceph. | Total (YLD) | Abortions | Stillbirths | Total (YLL) | |
| NORTH | 59 067 | 13 502 | 72 569 | 97 100 | 90 554 | 187 654 | **260 223** |
| Northeast | 45 642 | 9 600 | 55 242 | 73 791 | 68 816 | 142 608 | **197 849** |
| Beijing | 623 | 137 | 760 | 1 016 | 948 | 1 964 | **2 724** |
| Tianjin | 702 | 129 | 831 | 1 107 | 1 032 | 2 139 | **2 970** |
| Hebei | 7 429 | 1 832 | 9 261 | 12 411 | 11 574 | 23 986 | **33 246** |
| Shanxi | 11 381 | 2 414 | 13 794 | 18 429 | 17 187 | 35 616 | **49 411** |
| Inner Mongolia | 3 725 | 879 | 4 604 | 6 165 | 5 749 | 11 913 | **16 517** |
| Liaoning | 2 660 | 341 | 3 001 | 3 976 | 3 708 | 7 684 | **10 685** |
| Jilin | 1 601 | 146 | 1 747 | 2 305 | 2 150 | 4 455 | **6 202** |
| Heilongjiang | 1 637 | 359 | 1 995 | 2 668 | 2 488 | 5 155 | **7 151** |
| Shandong | 5 239 | 861 | 6 100 | 8 112 | 7 565 | 15 677 | **21 777** |
| Henan | 10 645 | 2 502 | 13 148 | 17 602 | 16 415 | 34 018 | **47 165** |
| Northwest | 13 425 | 3 902 | 17 327 | 23 309 | 21 737 | 45 046 | **62 374** |
| Shaanxi | 5 473 | 1 907 | 7 380 | 9 972 | 9 300 | 19 272 | **26 652** |
| Gansu | 4 560 | 845 | 5 404 | 7 202 | 6 716 | 13 918 | **19 323** |
| Qinghai | 586 | 158 | 744 | 999 | 931 | 1 930 | **2 674** |
| Ningxia | 963 | 150 | 1 113 | 1 479 | 1 379 | 2 858 | **3 971** |
| Xinjiang | 1 843 | 843 | 2 686 | 3 657 | 3 411 | 7 068 | **9 754** |
| SOUTH | 10 978 | 3 954 | 14 931 | 20 194 | 18 832 | 39 026 | **53 957** |
| Southeast | 8 169 | 2 968 | 11 137 | 15 066 | 14 050 | 29 115 | **40 252** |
| Shanghai | 57 | 25 | 82 | 112 | 104 | 216 | **299** |
| Jiangsu | 667 | 106 | 773 | 1 028 | 958 | 1 986 | **2 759** |
| Zhejiang | 753 | 79 | 832 | 1 099 | 1 025 | 2 125 | **2 957** |
| Anhui | 1 742 | 600 | 2 343 | 3 165 | 2 951 | 6 116 | **8 459** |
| Fujian | 466 | 327 | 793 | 1 094 | 1 021 | 2 115 | **2 908** |
| Jiangxi | 695 | 271 | 966 | 1 309 | 1 221 | 2 529 | **3 495** |
| Hubei | 565 | 315 | 880 | 1 205 | 1 124 | 2 329 | **3 209** |
| Hunan | 1 257 | 309 | 1 565 | 2 098 | 1 956 | 4 054 | **5 619** |
| Guangdong | 1 159 | 508 | 1 667 | 2 266 | 2 114 | 4 380 | **6 047** |
| Guangxi | 698 | 408 | 1 107 | 1 518 | 1 415 | 2 933 | **4 040** |
| Hainan | 110 | 19 | 129 | 172 | 160 | 332 | **461** |
| Southwest | 2 809 | 985 | 3 794 | 5 128 | 4 783 | 9 911 | **13 705** |
| Sichuan | 554 | 340 | 894 | 1 228 | 1 145 | 2 373 | **3 267** |
| Guizhou | 1 511 | 143 | 1 654 | 2 184 | 2 036 | 4 220 | **5 874** |
| Yunnan | 308 | 270 | 578 | 803 | 749 | 1 553 | **2 131** |
| Tibet | 96 | 0 | 96 | 125 | 116 | 241 | **337** |
| Chongqing | 340 | 232 | 572 | 789 | 736 | 1 524 | **2 097** |
| **CHINA** | **70 044** | **17 456** | **87 500** | **117 294** | **109 386** | **226 680** | **314 180** |

DALYs, Disability-Adjusted Life Years; YLD, years lived in disability; YLL, years of life lost
[a] A geographical presentation of the different administrative areas and regions is shown in Annex 1.

Based on the present consumption pattern, folate deficiency in China is responsible for an annual loss of 314 180 DALYs. With respect to the regional differences, the number of DALYs lost is significantly higher in Northern China, especially in the northeast. But when these numbers are weighted according to the total population, the current situation is worst in Northwest China, with 6.39 DALYs lost per 10 000 persons, per year (see also Table 49, column 3). By way of comparison, the annual number of DALYs lost in the northeast is 4.31 per 10 000 persons. Due to the differences in NTD prevalence and the regional attribution level of folate deficiency to NTDs, the relative burden in Southern China is significantly lower with 0.71 DALYs lost. The burden of morbidity and mortality caused by folate deficiency amounts to 27.85 % and 72.15 %, respectively. Within these categories, spina bifida obtains the highest number of years lived with disability, while the lost life years are more or less equally divided between the two fatal outcomes.

#### *5.4.1.2. Potential health benefits of folate biofortified rice (DALYs saved)*

Based on the estimated product and market characteristics of FBR, described in the previous sections, the benefits to public health can be assessed by comparing the number of DALYs lost under the current situation ('without') with two biofortification scenario's ('with'). A low and high impact scenario are defined by the coverage rate of FBR, i.e. 20 % (low) and 60 % (high) of Chinese women who are willing to accept and have access to this crop. These scenarios start from the assumption that the total folate intake under biofortification in each administrative area in China is significantly higher than the threshold to recover from folate deficiency and the associated risk of delivering a baby that is affected with an NTD (see Table 44).

Table 48 summarizes the potential health benefits of FBR in China under a low and high impact scenario. The results are expressed as the number of DALYs saved through the implementation of folate enriched rice. This is the difference between the number of DALYs lost under the current situation, shown in Table 47, and the DALYs lost under a folate biofortification scenario. The health impact is based on the number of mothers that recover from folate deficiency through a biofortified diet, i.e. the coverage rate. This rate also represents the percentage of NTDs caused by folate deficiency that can be prevented by a mother's biofortified diet.

The potential introduction of FBR in China increases the folate intake for women of childbearing age to 837 µg per day, and saves annually 62 836 DALYs in the low and 188 508 DALYs in the high biofortification scenario. Fatal outcomes gain the largest number of DALYs, followed by spina bifida and encephalocele. While the burden in the low biofortification scenario is still around 250 000 DALYs per year, the high impact scenario reduces the annual number of DALYs lost to approximately 125 000.

When focusing on the four Chinese regions, the highest number of DALYs saved is obtained in Northeast China. Shanxi Province, characterized by one of the highest NTD prevalence rates in the world, benefits the most from the introduction of FBR. The health impact in the northwest, southwest and southeast of China is significantly lower.

Table 48 The health impact of folate biofortification of rice in China, per impact scenario, functional outcome and region, in the number of DALYs saved, per year

| **Region/ Administrative area** | **Low impact** | | | | | | | **High impact** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Non-Fatal** | | | **Fatal** | | | **Total** | **Non-Fatal** | | | **Non-Fatal** | | | **Total** |
| | Spina | Enceph | YLD | Abortions | Stillbirths | YLL | | Spina | Enceph. | YLD | Abortions | Stillbirths | YLL | |
| NORTH | 11 813 | 2 700 | 14 514 | 19 420 | 18 111 | 37 531 | **52 045** | 35 440 | 8 101 | 43 541 | 58 260 | 54 332 | 112 592 | **156 134** |
| Northeast | 9 128 | 1 920 | 11 048 | 14 758 | 13 763 | 28 522 | **39 570** | 27 385 | 5 760 | 33 145 | 44 275 | 41 290 | 85 565 | **118 709** |
| Beijing | 125 | 27 | 152 | 203 | 190 | 393 | **545** | 374 | 82 | 456 | 610 | 569 | 1 178 | **1 634** |
| Tianjin | 140 | 26 | 166 | 221 | 206 | 428 | **594** | 421 | 77 | 499 | 664 | 619 | 1 283 | **1 782** |
| Hebei | 1 486 | 366 | 1 852 | 2 482 | 2 315 | 4 797 | **6 649** | 4 457 | 1 099 | 5 557 | 7 447 | 6 944 | 14 392 | **19 948** |
| Shanxi | 2 276 | 483 | 2 759 | 3 686 | 3 437 | 7 123 | **9 882** | 6 829 | 1 448 | 8 276 | 11 057 | 10 312 | 21 370 | **29 647** |
| Inner Mongolia | 745 | 176 | 921 | 1 233 | 1 150 | 2 383 | **3 303** | 2 235 | 527 | 2 762 | 3 699 | 3 449 | 7 148 | **9 910** |
| Liaoning | 532 | 68 | 600 | 795 | 742 | 1 537 | **2 137** | 1 596 | 205 | 1 801 | 2 386 | 2 225 | 4 610 | **6 411** |
| Jilin | 320 | 29 | 349 | 461 | 430 | 891 | **1 240** | 961 | 88 | 1 048 | 1 383 | 1 290 | 2 673 | **3 721** |
| Heilongjiang | 327 | 72 | 399 | 534 | 498 | 1 031 | **1 430** | 982 | 215 | 1 197 | 1 601 | 1 493 | 3 093 | **4 291** |
| Shandong | 1 048 | 172 | 1 220 | 1 622 | 1 513 | 3 135 | **4 355** | 3 143 | 517 | 3 660 | 4 867 | 4 539 | 9 406 | **13 066** |
| Henan | 2 129 | 500 | 2 630 | 3 520 | 3 283 | 6 804 | **9 433** | 6 387 | 1 501 | 7 889 | 10 561 | 9 849 | 20 411 | **28 299** |
| Northwest | 2 685 | 780 | 3 465 | 4 662 | 4 347 | 9 009 | **12 475** | 8 055 | 2 341 | 10 396 | 13 985 | 13 042 | 27 028 | **37 424** |
| Shaanxi | 1 095 | 381 | 1 476 | 1 994 | 1 860 | 3 854 | **5 330** | 3 284 | 1 144 | 4 428 | 5 983 | 5 580 | 11 563 | **15 991** |
| Gansu | 912 | 169 | 1 081 | 1 440 | 1 343 | 2 784 | **3 865** | 2 736 | 507 | 3 242 | 4 321 | 4 030 | 8 351 | **11 594** |
| Qinghai | 117 | 32 | 149 | 200 | 186 | 386 | **535** | 352 | 95 | 446 | 599 | 559 | 1 158 | **1 604** |
| Ningxia | 193 | 30 | 223 | 296 | 276 | 572 | **794** | 578 | 90 | 668 | 887 | 827 | 1 715 | **2 383** |
| Xinjiang | 369 | 169 | 537 | 731 | 682 | 1 414 | **1 951** | 1 106 | 506 | 1 612 | 2 194 | 2 047 | 4 241 | **5 852** |
| SOUTH | 2 196 | 791 | 2 986 | 4 039 | 3 766 | 7 805 | **10 791** | 6 587 | 2 372 | 8 959 | 12 116 | 11 299 | 23 416 | **32 374** |
| Southeast | 1 634 | 594 | 2 227 | 3 013 | 2 810 | 5 823 | **8 050** | 4 901 | 1 781 | 6 682 | 9 040 | 8 430 | 17 469 | **24 151** |
| Shanghai | 11 | 5 | 16 | 22 | 21 | 43 | **60** | 34 | 15 | 49 | 67 | 62 | 130 | **179** |
| Jiangsu | 133 | 21 | 155 | 206 | 192 | 397 | **552** | 400 | 64 | 464 | 617 | 575 | 1 192 | **1 655** |
| Zhejiang | 151 | 16 | 166 | 220 | 205 | 425 | **591** | 452 | 47 | 499 | 659 | 615 | 1 275 | **1 774** |
| Anhui | 348 | 120 | 469 | 633 | 590 | 1 223 | **1 692** | 1 045 | 360 | 1 406 | 1 899 | 1 771 | 3 670 | **5 075** |
| Fujian | 93 | 65 | 159 | 219 | 204 | 423 | **582** | 280 | 196 | 476 | 656 | 613 | 1 269 | **1 745** |
| Jiangxi | 139 | 54 | 193 | 262 | 244 | 506 | **699** | 417 | 163 | 580 | 785 | 733 | 1 517 | **2 097** |
| Hubei | 113 | 63 | 176 | 241 | 225 | 466 | **642** | 339 | 189 | 528 | 723 | 674 | 1 397 | **1 925** |
| Hunan | 251 | 62 | 313 | 420 | 391 | 811 | **1 124** | 754 | 185 | 939 | 1 259 | 1 174 | 2 432 | **3 371** |
| Guangdong | 232 | 102 | 333 | 453 | 423 | 876 | **1 209** | 695 | 305 | 1 000 | 1 360 | 1 268 | 2 628 | **3 628** |
| Guangxi | 140 | 82 | 221 | 304 | 283 | 587 | **808** | 419 | 245 | 664 | 911 | 849 | 1 760 | **2 424** |
| Hainan | 22 | 4 | 26 | 34 | 32 | 66 | **92** | 66 | 11 | 77 | 103 | 96 | 199 | **277** |
| Southwest | 562 | 197 | 759 | 1 026 | 957 | 1 982 | **2 741** | 1 685 | 591 | 2 276 | 3 077 | 2 870 | 5 947 | **8 223** |
| Sichuan | 111 | 68 | 179 | 246 | 229 | 475 | **653** | 332 | 204 | 536 | 737 | 687 | 1 424 | **1 960** |
| Guizhou | 302 | 29 | 331 | 437 | 407 | 844 | **1 175** | 907 | 86 | 992 | 1 310 | 1 222 | 2 532 | **3 524** |
| Yunnan | 62 | 54 | 116 | 161 | 150 | 311 | **426** | 185 | 162 | 347 | 482 | 449 | 932 | **1 279** |
| Tibet | 19 | 0 | 19 | 25 | 23 | 48 | **67** | 58 | 0 | 58 | 75 | 70 | 145 | **202** |
| Chongqing | 68 | 46 | 114 | 158 | 147 | 305 | **419** | 204 | 139 | 343 | 473 | 442 | 914 | **1 258** |
| **CHINA** | **14 009** | **3 491** | **17 500** | **23 459** | **21 877** | **45 336** | **62 836** | **42 026** | **10 474** | **52 500** | **70 376** | **65 632** | **136 008** | **188 508** |

As the health benefits of FBR depend on demographic characteristics, such as the population size and the birth rate, a comparison of these regional results should be carefully interpreted. One way to overcome this, is to standardize the regional saved DALYs (Table 49). When the number of DALYs is expressed per 10 000 persons, the burden and health impact is relatively the highest in the Northwest China, while the absolute numbers are the highest in the Northeast. The current situation is most problematic in Shanxi (northeast), Gansu (northwest), Anhui (southeast) and Guizhou (southwest).

Table 49 Burden of folate deficiency (DALYs lost) and the health impact of folate biofortification (DALYs saved) in China, expressed in absolute and relative (per 10 000 persons) numbers, per year, per region and administrative area

| **Region/ Administrative area** | **Current burden (DALYs lost)** | | **Folate biofortification (DALYs saved)** | | | |
|---|---|---|---|---|---|---|
| | | | Low impact | | High impact | |
| | Total | Relative | Total | Relative | Total | Relative |
| NORTH | 260 223 | 4.68 | 52 045 | 0.94 | 156 134 | 2.81 |
| Northeast | 197 849 | 4.31 | 39 570 | 0.86 | 118 709 | 2.59 |
| Beijing | 2 724 | 1.68 | 545 | 0.34 | 1 634 | 1.01 |
| Tianjin | 2 970 | 2.70 | 594 | 0.54 | 1 782 | 1.62 |
| Hebei | 33 246 | 4.71 | 6 649 | 0.94 | 19 948 | 2.83 |
| Shanxi | 49 411 | **14.31** | 9 882 | **2.86** | 29 647 | **8.59** |
| Inner Mongolia | 16 517 | 6.74 | 3 303 | 1.35 | 9 910 | 4.04 |
| Liaoning | 10 685 | 2.45 | 2 137 | 0.49 | 6 411 | 1.47 |
| Jilin | 6 202 | 2.23 | 1 240 | 0.45 | 3 721 | 1.34 |
| Heilongjiang | 7 151 | 1.83 | 1 430 | 0.37 | 4 291 | 1.10 |
| Shandong | 21 777 | 2.29 | 4 355 | 0.46 | 13 066 | 1.37 |
| Henan | 47 165 | 4.91 | 9 433 | 0.98 | 28 299 | 2.95 |
| Northwest | 62 374 | 6.39 | 12 475 | 1.28 | 37 424 | 3.83 |
| Shaanxi | 26 652 | 6.98 | 5 330 | 1.40 | 15 991 | 4.19 |
| Gansu | 19 323 | **7.25** | 3 865 | **1.45** | 11 594 | **4.35** |
| Qinghai | 2 674 | 4.77 | 535 | 0.95 | 1 604 | 2.86 |
| Ningxia | 3 971 | 6.43 | 794 | 1.29 | 2 383 | 3.86 |
| Xinjiang | 9 754 | 4.65 | 1 951 | 0.93 | 5 852 | 2.79 |
| SOUTH | 53 957 | 0.71 | 10 791 | 0.14 | 32 374 | 0.43 |
| Southeast | 40 252 | 0.71 | 8 050 | 0.14 | 24 151 | 0.43 |
| Shanghai | 299 | 0.16 | 60 | 0.03 | 179 | 0.10 |
| Jiangsu | 2 759 | 0.36 | 552 | 0.07 | 1 655 | 0.22 |
| Zhejiang | 2 957 | 0.58 | 591 | 0.12 | 1 774 | 0.35 |
| Anhui | 8 459 | **1.35** | 1 692 | **0.27** | 5 075 | **0.81** |
| Fujian | 2 908 | 0.80 | 582 | 0.16 | 1 745 | 0.48 |
| Jiangxi | 3 495 | 0.79 | 699 | 0.16 | 2 097 | 0.47 |
| Hubei | 3 209 | 0.55 | 642 | 0.11 | 1 925 | 0.33 |
| Hunan | 5 619 | 0.87 | 1 124 | 0.17 | 3 371 | 0.52 |
| Guangdong | 6 047 | 0.64 | 1 209 | 0.13 | 3 628 | 0.38 |
| Guangxi | 4 040 | 0.84 | 808 | 0.17 | 2 424 | 0.50 |
| Hainan | 461 | 0.54 | 92 | 0.11 | 277 | 0.32 |
| Southwest | 13 705 | 0.69 | 2 741 | 0.14 | 8 223 | 0.41 |
| Sichuan | 3 267 | 0.39 | 653 | 0.08 | 1 960 | 0.23 |
| Guizhou | 5 874 | **1.53** | 1 175 | **0.31** | 3 524 | **0.92** |
| Yunnan | 2 131 | 0.46 | 426 | 0.09 | 1 279 | 0.28 |
| Tibet | 337 | 1.17 | 67 | 0.23 | 202 | 0.70 |
| Chongqing | 2 097 | 0.73 | 419 | 0.15 | 1 258 | 0.44 |
| **CHINA** | **314 180** | **2.38** | **62 836** | **0.48** | **188 508** | **1.43** |

DALYs, Disability-Adjusted Life Years
*Note*: In each of the four regions, the administrative area with the highest burden and health impact is indicated in bold.

### 5.4.2. Burden and potential health impacts of multi-biofortified rice in China

Table 50 summarizes how the most important micronutrient deficiencies affect the Chinese population, i.e. the current burden, and how multi-biofortification could help to reduce this burden. At present, micronutrient malnutrition in China is responsible for 10.6 million DALYs lost per year. Iron deficiency causes by far the biggest burden, followed by zinc, vitamin A and folate deficiency. The important role of vitamin A in the body's immune system and the close association with child mortality make VAD the most fatal micronutrient deficiency in China. The relatively low burden of folate deficiency is partly caused by the limited focus in this study, where only one folate related functional outcome (NTDs) and one target group (women of childbearing age) is included. Still, due to the high folate intake after multi-biofortification, raising this vitamin level results in substantial health benefits. The findings confirm that both conventional and transgenic traits in multi-biofortified rice are effective in tackling their respective micronutritional deficiency.

Depending on the assumptions made, the introduction of multi-biofortified rice in China could save between 1.2 and 4.9 million DALYs per year. Stated differently, the Chinese burden of micronutrient malnutrition could be reduced by 11 % in the pessimistic and by 46 % optimistic scenario, respectively. These combined results assume that the effects for each individual micronutrient can simply be added up. This is the best assumption one can make, because knowledge about micronutrient interactions is extremely thin. On the one hand, adding up may potentially lead to an overestimation of the health burden and the impacts of multi-biofortification, because of potential double-counting with respect to some functional outcomes. For instance, vitamin A and zinc deficiency are both associated with child mortality and certain infectious diseases. On the other hand, adding up may also lead to an underestimation of the positive impacts, as simultaneously improving the intake of multiple micronutrients may potentially lead to synergistic health benefits (Sandstrom, 2001). As these effects work in opposite directions, we do not expect a systematic bias in our analysis, but the assumptions should be improved when better knowledge on micronutrient interactions becomes available.

Table 50 Multi-biofortified rice in China, current burden and potential health impacts, per micronutritional deficiency and impact scenario, in the number of DALYs

| | | Folate | Vitamin A | Zinc | Iron | ALL |
|---|---|---|---|---|---|---|
| **Current Burden** (DALYs lost) | | | | | | |
| | YLD | 87 500 | 71 799 | 2 017 847 | 5 679 207 | 7 856 354 |
| | YLL | 226 680 | 1 919 321 | 631 115 | 10 693 | 2 787 809 |
| | Total | 314 180 | 1 991 120 | 2 648 962 | 5 689 900 | 10 644 163 |
| | % all | 3 | 19 | 25 | 53 | 100 |
| **Health impact** (DALYs saved) | | | | | | |
| Pessimistic | YLD | 17 500 | 12 083 | 310 983 | 389 105 | 729 671 |
| | YLL | 45 336 | 317 304 | 94 531 | 182 | 457 353 |
| | Total | 62 836 | 329 387 | 405 514 | 389 287 | 1 187 024 |
| | % all | 5 | 28 | 34 | 33 | 100 |
| | % burden | 20 | 17 | 15 | 7 | 11 |
| Optimistic | YLD | 52 500 | 43 080 | 1 206 480 | 1 944 587 | 3 246 646 |
| | YLL | 136 008 | 1 151 592 | 376 420 | 1 148 | 1 665 168 |
| | Total | 188 508 | 1 194 672 | 1 582 900 | 1 945 735 | 4 911 814 |
| | % all | 4 | 24 | 32 | 40 | 100 |
| | % burden | 60 | 60 | 60 | 34 | 46 |

DALY, Disability-Adjusted Life Year; YLD, years lived in disability; YLL years of life lost

### 5.4.3. Cost-effectiveness of folate and multi-biofortified rice in China

Based on a 30-year time horizon, Table 51 provides an overview of the different costs that are incurred for the development to the commercialization of multi-biofortified rice in China. The costs of each individual trait, thus each single biofortified crop, are separately included and summed. Although the first research initiatives regarding Golden rice date goes back to the 1990's, and subsequent biofortification research, such as enriching folate, definitely builds upon these efforts, the same time frame is applied to each cost-calculation. Given that GM rice is not produced and due to the uncertainty regarding the process (and costs) to introduce this product in China (see section 6.5), the cost figures are estimates.

We assume that each micronutrient trait is developed independently and then combined with the other traits through conventional backcrossing. While the research initiatives for each micronutrient started at different points in time, for better comparison we use the same time frame for each of the calculations, namely 2002-2032. The costs for more basic research components, which occur at the international level, are included only partially in this study. The reason is that the basic research components will not only be used in China, but may also lead to benefits in several other countries. The more adaptive development costs are country specific. They include the costs of adaptive breeding and variety development in a magnitude of US$ 1.5 million per trait (Stein et al., 2007; Stein et al., 2008a). Moreover, the costs for the regulatory process of transgenic events are covered here. Table 51 also shows projected costs for social marketing of the new varieties. This will be required especially for the folate and provitamin A traits, as these are transgenic and also associated with color changes. Especially for provitamin A (Golden Rice), this color change will be very notable. Hence, without specific awareness campaigns, widespread acceptance cannot be expected (Stein et al., 2006, 2008b). Regarding FBR as a single GM biofortified strategy, social marketing costs are expected to be halved, as we assume that no other rice attributes, except for the folate content, will be altered. Finally, after technology release and adoption, only some maintenance breeding will be necessary to preserve the purity of the biofortified varieties and seeds.

For some components, the cost for multi-biofortification is simply the sum of the costs for individual trait development. A case in point is the basic research cost. For other components, additional costs will occur, such as backcrossing all four traits into the same rice varieties. And yet for other components, multi-biofortification may allow significant cost savings. For instance, social marketing for the combined product will render marketing for individual traits unnecessary. As shown in Table 51, we expect the total cost of developing and implementing FBR and MBR in China to be in a magnitude of US$ 31.6 and US$ 85.4 million, respectively.

Saving one folate deficiency related DALY in China would cost between US$ 64.2 and US$ 21.4. In the case of MBR, the scenario where the two transgenic traits are backcrossed results in a cost-effectiveness between US$ 9.6 and US$ 2.3 per saved DALY (Using single insertion through genetic modification would lower these figures due to lower R&D and regulatory costs; see section 5.4.5.2). As the cost-effectiveness is a relative measure, the results need to be benchmarked. The World Bank (1993) cut-off levels for a highly cost-effective strategy should vary between US$ 86.04 and US$ 258.12 per gained DALY (in 2011; BLS, 2011). Both folate and multi-biofortification of rice achieve the upper limit of this threshold and can be considered as potential highly cost-effective health interventions. The high, aggregated benefits of tackling the main micronutrient deficiencies in China outweigh the relatively high intervention costs, even when the transgenic traits need to be separately backcrossed through conventional breeding. The low one-time R&D investments of folate biofortification show that the DALYs that could be saved with single biofortification are also worth to consider.

For the CEA, we juxtapose the cost stream over time with the benefit stream (the number of DALYs saved). We assume that multi-biofortified varieties may be released starting in 2014. After that, technology adoption and coverage will increase gradually. We assume a linear diffusion profile, with maximum coverage rates to be achieved 15 years after the first release, i.e. in 2029. The last two columns in Table 51 show the CEA results expressed in the cost per DALY saved. While we assume equal costs in the two scenarios, the benefits differ according to the more pessimistic and optimistic assumptions, as discussed above. The upper part of the Table shows the potential cost-effectiveness for the single trait technologies. While these results are interesting, they should be interpreted with some caution, because when four separate rice technologies were released, there would be competition in terms of achieving high coverage rates. This competition is avoided when rice varieties simultaneously carry all four traits, which is one of the major advantages of multi-biofortification.

Table 51 Costs and cost-effectiveness of multi-biofortified rice in China, per trait

| | **Costs** *(million US$)* | | | | | **Cost-effectiveness**[j] *(US$ per DALY saved)* | |
|---|---|---|---|---|---|---|---|
| | Basic R&D[f] (8 years) | Country-specific[g] (6 years) | Social marketing (Until end) | Maintenance breeding (Until end) | Total (30 years) | Pessimistic scenario | Optimistic scenario |
| **Single biofortification** | | | | | | | |
| **Folate** | 5.7[a] | 9.5[a] | 15.0[a] | 2.1[a] | 31.6 | 64.2 | 21.4 |
| Vitamin A | 7.6[b] | 9.5[b] | 30.7[b] | 2.1[b] | 48.9 | 18.1 | 5.0 |
| Zinc | 8.7[c] | 1.5[c] | /[h] | 2.6[c] | 16.9 | 4.8 | 1.2 |
| Iron | 6.0[c] | 1.5[c] | /[h] | 2.6[c] | 13.7 | 3.8 | 0.8 |
| Sum | 28.1 | 22.0 | 45.7 | 9.5 | 105.3 | /[k] | /[k] |
| **Multi-biofortification** | **28.1** | **24.0**[d] | **30.7**[i] | **2.6**[i] | **85.4** | **9.6** | **2.3** |

[a]Based on estimates from experts of the Chinese Academy of Agricultural Sciences and the scientists involved in folate biofortification; [b]Based on Stein et al. (2006, 2008b) study on Golden Rice; [c] Estimates based on previous health impact analyses on rice biofortified with zinc (Stein et al., 2007) or iron (Stein et al., 2008a); [d]For multi-biofortified varieties, in addition to the country-specific research costs for each single micronutrient, a total cost of US$ 2.0 million is added to account for the backcrossing of all four traits into the same varieties. We assume that 10 multi-biofortified rice varieties will be developed, each involving a backcrossing cost of US$ 200 000; [f]The basic R&D cost is only partially attributed to China, using China's share in total rice production of China, India, Bangladesh and the Philippines, which are all potential target countries for rice biofortification. China's share is 48% (FAOSTAT Database, 2008); [g]While for conventional traits only adaptive breeding costs are taken into account, the transgenic traits additionally have to comply with Chinese biosafety regulations. Regulatory costs are assumed to be US$ 8 million per event, using a recent analysis for the US by Kalaitzandonakes et al. (2007); [h]As zinc and iron are traits that are invisible to consumers and included through conventional breeding, no significant marketing efforts will be necessary to achieve widespread coverage; [i]Regarding the social marketing and maintenance breeding costs of multi-biofortification, the highest cost of the single biofortified traits was selected; [j]The pessimistic and optimistic scenario differ in terms of the health impact, as shown in Table 50; [k]Because the cost-effectiveness of introducing four independent biofortified rice products would influence the coverage rates, due to the presence of four products, no estimates are given for four single biofortified crops as a combined health intervention. Moreover, the advantage of multi-biofortified rice is its ability to tackle four micronutrient deficiencies simultaneously, without creating a differentiated market for biofortified products.

## 5.4.4. Putting the results in perspective

Another way to evaluate the cost-effectiveness of FBR and MBR is to look at health interventions that use the same approach (e.g. biofortification) or other alternative health interventions that aim to address the same health problem, i.e. reducing folate deficiency and NTDs (Laxminarayan et al., 2006; Musgrove and Fox-Rushby, 2006). These issues are discussed in section 5.4.4.1 and 5.4.4.2, respectively. Furthermore, FBR is evaluated in two of the most important high-risk regions, the Chinese Shanxi Province and the Indian Balrampur District (see section 5.4.4.3).

*5.4.4.1. A comparison with other cost-effectiveness studies on biofortification*

One of the key advantages of CEA is that it provides straightforward information which can be compared in different settings and different interventions (Stein, 2006). By expressing the number of DALYs gained per 10 000 persons, the potential health impact of FBR and MBR in China can be compared with findings from other, similar health impact studies that applied the DALY approach.

Table 52 presents the estimated potential health impacts of different transgenic and non-transgenic biofortified staple crops in several developing countries. For ease of comparison, costs are presented in US$, i.e. the international standard in CEA (Tan-Torres Edejer et al., 2003; Chisholm, 2006).

In comparison with the burden of micronutrient deficiencies in other health impact studies, the relative burden of folate deficiency and micronutrient malnutrition in China is the lowest and one of the highest, respectively. However, as only NTDs caused by folate deficiency are included as functional outcomes, only a part of the folate burden is calculated. If other functional outcomes would be included, such as heart diseases, the investigated target group could be extended to the total population. Given the estimated total number of folate deficient people in China, 258 million, the actual burden of folate deficiency would be much higher.

With respect to the health impact, most of the DALYs can be saved through the introduction of Vitamin A biofortification in Uganda (sweet potato) and Congo (cassava roots). The relative impact of iron or zinc biofortification on public health is the highest in India and Pakistan, and North-East Brazil (iron) and Bangladesh (zinc). While the burden of FBR in China is relatively low, this intervention could be one of the most effective strategies to save DALYs. This is mainly due to the high folate intake levels after biofortification and the assumption that these intake levels prevent maternal folate deficiency and the risk of having a baby with an NTD (see section 5.2.2.1).

According to the pessimistic and optimistic impact scenario, FBR is ranked, respectively 15$^{th}$ and 20$^{th}$ out of 27 cost-effectiveness analyses. MBR holds the fifth (pessimistic) and seventh position (optimistic). The cost-effectiveness of the latter, for instance, is in line with other biofortified rice products, wheat and sweet potatoes, except for the less cost-effective iron biofortified rice study in the Philippines, and are substantially lower than biofortified maize, beans and cassava roots, regardless of the deficiency that is addressed.

Although this comparison is useful to put folate and multi-biofortification in the context of policy interventions to tackle micronutrient deficiencies in developing countries, these findings should be interpreted with caution. First, the parameters of the DALY framework and the characteristics of the impact scenarios differ from one study to another. As a consequence, the cost-effectiveness figures are scale-dependent, by which small-scale projects might be highly cost-effective in the long term, but less desirable to further increase the coverage rate (Laxminarayan et al., 2006). Second, as there is currently no transgenic biofortified staple crop commercialized, and most of the figures are derived from ex-ante evaluation studies, the expected micronutrient content after biofortification is mostly based on estimates from plant breeders. This is, for instance, the case in the HarvestPlus health impact analyses of conventionally enriched staple crops (Meenakshi et al., 2007).

Evans et al. (2005, p. 1140) express their concerns about the comparison of CE studies as follows: *"[…] it is not possible to recommend that an intervention shown to cost $45 per DALY averted is more efficient than one costing $60, given the nature of the uncertainties. For the broad comparison across goals we, therefore, interpret cost effectiveness figures in broad order of magnitude ranges".* Therefore, the cost-effectiveness figures are also compared with the lower and upper thresholds of cost-effective health interventions (Table 52). The results show that most of the biofortified crops are highly cost-effective. Only 7 out of 27 CEAs do not achieve the lower limit of cost-effectiveness, of which only one study (zinc enriched beans in North-East Brazil) is considered cost-ineffective in the pessimistic and the optimistic impact scenario.

Table 52 Comparison of the burden of micronutrient deficiencies (DALYs lost), the potential benefits (DALYs saved) and the cost-effectiveness (US$/DALY saved) of biofortified staple crops, per crop, nutrient, and target country, in relative numbers (per 10 000 persons), in the reduction of the burden or compared to the World Bank thresholds.

| | | | | **Burden of Deficiencies (DALYs lost)** | **Health impact (DALYs saved)** | | | | **Cost-effectiveness (US$/DALY saved)** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Pessimistic** | | **Optimistic** | | **Pessimistic** | | **Optimistic** | |
| **Crop** | **Nutrient** | **Technique** | **Target country** | **Relative** | **Relative** | **%** | **Relative** | **%** | **Total** | **Threshold[i]** | **Total** | **Threshold[i]** |
| Rice | Vitamin A | TB | India[b] | 20.52 | 1.80 | 8.8 | 12.19 | 59.4 | 19.4 | <WB High | 3.1 | <WB High |
| | | | Philippines[c] | 32.06 | 1.82 | 5.7 | 10.11 | 31.5 | / | / | / | / |
| | Iron | CB | Bangladesh[a] | 34.36 | 2.75 | 8.0 | 0.91 | 2.6 | 17.9 | <WB High | 4.8 | <WB High |
| | | | India[a] | 35.27 | 1.76 | 5.0 | 7.22 | 20.5 | 16.7 | <WB High | 3.4 | <WB High |
| | | | India[e] | 35.27 | 4.41 | 12.5 | 5.29 | 15.0 | 3.9 | <WB High | 0.3 | <WB High |
| | | | Philippines[a] | 8.31 | 0.33 | 4.0 | 1.22 | 14.7 | 234.4 | <WB Low | 54.5 | <WB High |
| | Zinc | CB | Bangladesh[a] | 30.86 | 5.25 | 17.0 | 10.18 | 33.0 | 6.8 | <WB High | 1.5 | <WB High |
| | | | India[a] | 24.96 | 4.99 | 20.0 | 13.98 | 56.0 | 5.7 | <WB High | 1.3 | <WB High |
| | | | Philippines[a] | 9.50 | 1.23 | 12.9 | 4.08 | 42.9 | 55.0 | <WB High | 12.2 | <WB High |
| | **Folate** | **TB** | **China[f]** | **2.38** | **0.48** | **20.0** | **1.43** | **60.0** | **64.2** | <WB High | **21.4** | <WB High |
| | **Multi** | **TB** | **China[g]** | **80.59** | **8.99** | **11.1** | **37.19** | **46.2** | **9.6** | <WB High | **2.3** | <WB High |
| Wheat | Iron | CB | India[e] | 35.27 | 2.65 | 7.5 | 13.76 | 39.0 | 9.8 | <WB High | 1.1 | <WB High |
| | | CB | India[a] | 35.27 | 2.47 | 7.0 | 13.23 | 37.5 | 8.7 | <WB High | 0.6 | <WB High |
| | | | Pakistan[a] | 57.65 | 3.46 | 6.0 | 8.82 | 15.3 | 13.0 | <WB High | 3.1 | <WB High |
| | Zinc | CB | India[a] | 24.96 | 2.25 | 9.0 | 11.98 | 48.0 | 10.6 | <WB High | 1.3 | <WB High |
| | | | Pakistan[a] | 40.11 | 2.01 | 5.0 | 13.24 | 33.0 | 18.4 | <WB High | 2.4 | <WB High |
| Maize | Vitamin A | CB | Ethiopia[a] | 52.76 | 0.53 | 1.0 | 8.97 | 17.0 | 289.0 | Above | 10.7 | <WB High |
| | | | Kenya[a] | 32.27 | 2.58 | 8.0 | 10.33 | 32.0 | 112.7 | <WB Low | 18.4 | <WB High |
| Cassava roots | Vitamin A | CB | Congo[a] | 1206.93 | 36.21 | 3.0 | 386.22 | 32.0 | 123.8 | <WB Low | 7.6 | <WB High |
| | | | Nigeria[d] | 100.26 | 7.05 | 7.0 | 21.11 | 21.1 | / | / | / | / |
| | | | Nigeria[a] | 57.14 | 1.71 | 3.0 | 16.00 | 28.0 | 137.4 | <WB Low | 7.9 | <WB High |
| | | | North-East Brazil[a] | 10.00 | 0.40 | 4.0 | 1.90 | 19.0 | 1006.5 | Above | 126.5 | <WB Low |
| Beans | Iron | CB | Honduras[a] | 57.65 | 1.06 | 1.8 | 16.14 | 28.0 | 401.6 | Above | 65.5 | <WB High |
| | | | Nicaragua[a] | 53.61 | 1.61 | 3.0 | 5.84 | 10.9 | 439.2 | Above | 64.5 | <WB High |
| | | | North-East Brazil[a] | 40.00 | 3.60 | 9.0 | 8.58 | 21.5 | 133.9 | <WB Low | 20.0 | <WB High |
| | Zinc | CB | Honduras[ah] | 13.27 | 0.40 | 3.0 | 1.99 | 15.0 | 1494.3 | Above | 160.2 | <WB Low |
| | | | Nicaragua[a] | 17.87 | 0.36 | 2.0 | 1.97 | 11.0 | 5939.6 | Above | 576.4 | Above |
| | | | North-East Brazil[a] | 20.00 | 1.00 | 5.0 | 4.00 | 20.0 | 1899.7 | Above | 152.6 | <WB Low |
| Sweet potato | Vitamin A | CB | Uganda[a] | 56.64 | 21.52 | 38.0 | 36.25 | 64.0 | 29.5 | <WB High | 8.6 | <WB High |

DALYs, Disability-Adjusted Life Years; TB, biofortification using transgenic methods; CB, biofortification using conventional methods; WB, World Bank

*Note:* Bold refers to the findings of the CEA in this PhD dissertation.

[a]Own calculations, based on Meenakshi et al. (2007); [b]Own calculations, based on Stein et al. (2006); [c]Own calculations, based on Zimmermann & Qaim (2004); [d]Own calculations, based on Manyong (2004); [e]Own calculations, based on Stein et al. (2008a); [f]Based on Table 50 (burden, impact) and Table 51 (costs); [h]According to Suarez (2010), the cost-effectiveness is even more positive, with a range between US$ 96-379. [i]World Bank thresholds are expressed in 2011. WB Low = lower World Bank threshold (US$ 258.12 per gained DALY); WB High = upper World Bank threshold (US$ 86.04 per DALY saved).

#### 5.4.4.2. A comparison with other folate interventions

Due the different characteristics of folate interventions, e.g. fortifying staple crops versus distributing supplements, which imply a different cost structure, gathering evidence on - or data to measure - the cost-effectiveness of supplementation and food fortification activities is a difficult challenge (Fiedler et al., 2007). Another important factor which complicates a comparison of micronutrient intervention evaluations, is the use of different cost measures. Depending on the investigated intervention, previously published CEA or CBA measures are, for example, the cost per dose or cost per averted death (supplementation) and the cost per metric ton (MT) of the food vehicle or the increased retail price (fortification)(Fiedler et al., 2008). Given the lack of reliable country-specific information about the potential folate program characteristics and the affiliated costs, the cost-effectiveness of other folate interventions in China is not included in this PhD dissertation. However, this section attempts to shed a light on the potential costs of the two currently most important folate interventions, i.e. supplementation versus food fortification, by reviewing the literature on the costs and cost-effectiveness of folate and other micronutritional interventions. The general characteristics, success factors and bottlenecks of all folate strategies are discussed in section 2.4.

When juxtaposing supplementation and food fortification programs to reduce micronutrient malnutrition, whether it is iron, iodine or vitamin A deficiency, the cost per DALY is often below the World Bank threshold (World Bank, 1994; IOM, 1998b; Hunt, 2001; Laxminarayan et al., 2006). Although targeted supplementation generates the largest impact on the short term, population-wide fortification appears to be 2 to 10 times more cost-effective given its lower costs (Hunt, 2005; Horton, 2006). Therefore, supplementation is still considered a valuable, cost-effective strategy when there is no appropriate food vehicle or convenient staple crop available (Baltussen et al., 2004). Similar conclusions were drawn in the only Chinese study that roughly estimated the cost-effectiveness of iron and zinc interventions (Ma et al., 2007). In terms of the cost per capita, tackling both deficiencies could be highly cost-effective when choosing biofortification (US$ 0.01) or food fortification (US$ 0.01 - 0.06). Supplementation is a better option when aiming to increase zinc (US$ 0.05) instead of iron intake (US$ 11.4). When aiming to minimize the costs, dietary diversification is the least recommended option, with a cost of US$ 1148 per capita.

*Folic acid supplementation*

CEA studies of folic acid supplementation programs are rarely existing (Grosse et al., 2007). Another difficulty is that folic acid is often promoted in combination with iron, i.e. iron-folic acid supplements (Klemm et al., 2009; Horton et al., 2010). It is widely acknowledged that such multiple micronutrient interventions are effective (Sanghvi et al., 2010). When targeting the high-risk group, the costs are estimated at US$13 per DALY averted (Durkin et al., 2006) or US$ 2.0 per pregnancy (Horton et al., 2008). Such cost measures do not address periconceptional intake and, therefore, do not take into account the negative impact of unplanned pregnancies, which mainly occur in high-risk groups (Cornel and De Smit, 2010). The cost-effectiveness to promote the use of periconceptional, single micronutrient supplements with folic acid is generally low. In the Netherlands, for instance, the costs to reach a 50 % coverage rate was estimated at around 2 545 US$ per DALY saved (Postma et al.,

2002). However, cost estimates differ between and within countries and across different types of programs and their characteristics (Fiedler et al., 2007).
Based on the cost structure of vitamin A and iron supplementation programs in developing countries, Fielder et al. (2007) showed that the costs of the supplements only accounts for 6 % of the total program costs. The personnel costs, including health workers, are considered to have the largest contribution (65 %). Training and promotion constitute 5 and 10 %, respectively. In other words, the cost to deliver the doses outweigh the costs of these doses. According to Horton et al. (2010), the delivery costs of iron-folic acid supplementation programs constitutes roughly 90 % of the total cost. Regarding the cost structure, there is still a lot of variation across regions (Baltussen et al., 2004) and between supplementation programs (Fiedler et al., 2008). First of all, compared to iron (daily or weekly) and vitamin A (every 4 to 6 months), folic acid supplements need to be taken each day, which will increase the cost per dose per person. Also the country-specific characteristics of the targeted micronutrient deficiency (e.g. high-risk regions in poor rural risk regions) influences the costs to adequately deliver the supplements to those in need. Programs differ according to the type of intervention: in-facility versus field-based delivery programs (Fiedler et al., 2008); long-term routine service-based programs (e.g. the Chinese premarital folic acid supplementation program; Hesketh 2003; Li and Hao, 2008), versus campaign-based interventions (e.g. the Chinese free folic acid supplement campaign in 2009; see below).

*Folic acid supplementation in China*

Regarding the aforementioned Chinese free folic acid supplement campaign (Juan, 2009)(thoroughly described in section 2.4.1.2), only the costs of the supplements could be retrieved through interviews with two of the scientific program coordinators (Lu Ciyong and Aiguo Ren; personal communication, respectively, 08-01-2011 and 03-03-2010). The aim of this program is to provide 12 million rural women of childbearing age with free folic acid pills during 6 months (or more, if a participant became pregnant). Based on the targeted population per province and the price per dose (¥ 24 per person), the total estimated cost of the pills amounts ¥ 284 million or US$ 42.9 mi, of which, on average 56 % is funded by the central government. These costs only refer to the dose and given the high share of delivery costs in supplementation programs, underestimate the overall program costs. Based on the review of the cost structure of Vitamin A (Fiedler et al., 2007) or folic acid supplementation (Horton et al., 2010), the total costs of this large-scale intervention may range from 428.8 mi. and 714.6 mi. US dollars, regardless of the number of DALYs that will be saved. Although the cost data does not allow measuring a full economic evaluation, the high costs might make such a program less cost-effective than biofortification, especially if it would be implemented on a 30-year time scale.

*Folic acid fortification*

Folic acid fortification have shown its high potential as a cost-effectiveness strategy for different food vehicles (CDC, 2010), including grains in the US (Bentley et al., 2009), wheat flour in Chili (Hertrampf and Cortes, 2008) and the Netherlands (Jentink et al., 2008), and wheat flour and maize meal in South Africa (Sayed et al., 2008). In Chili and the United States, for instance, each invested dollar in folic acid fortification saves US$ 11 (Llanos et al., 2007) and US$ 100 (Grosse et al., 2005), respectively. However, folic acid fortification is in most cases combined with other micronutrients, like iron, zinc, and niacin (Durkin et al., 2006). The total costs to add folic acid in staple foods are estimated at US$ 0.01 per person, per year (Mason et al., 1999; Mannar, 2001; Horton et al., 2008), while the annual cost of iron-folic acid fortification varies between US$ 0.12 (Horton and Ross, 2003), US$ 0.20 (Horton et al., 2010) and US$ 0.54 per person (Fiedler et al., 2008)[54]. Expressed in volumes, the estimated average cost of folic acid and iron-folic acid fortification amounts US$ 0.16 (Durkin et al., 2006; Llanos et al., 2007; Hertrampf and Cortes, 2008) and US$ 0.4 per metric ton of grain (Fiedler et al., 2008), respectively.

*Folic acid fortification in China*

In their Country Investment Plans (CIPs), the Asian Development Bank (ADB, 2004a) proposed and evaluated the potential of the 10-year implementation plans of two fortification programs in China, which included folic acid among other micronutrients (iron, zinc) in their fortification mix: a large-scale wheat flour program in Western China (250 million consumers) and a country-wide soy sauce intervention (500 million consumers). The ten-year costs amount, respectively, US$ 184 mi. and US$ 240 mi., of which 55 % and 82 % are attributable to the costs of the fortification mix. These two folic acid fortification strategies also differ in terms of the start-up costs (US$ 54.5 mi. versus US$ 5.6 mi.) and the costs of a marketing and education campaign (US$ 26.4 mi. versus US$ 15.9 mi.). The monitoring and food control costs account for less than 1 % of the total costs. Except for the lower share of the latter, these cost-structures are in line with estimates from vitamin A and iron fortification (Mason et al., 1999; Mannar, 2001; Fiedler et al., 2008). Although both fortification strategies are considered cost-beneficial, especially in rice consuming populations (ADB, 2004a; Durkin et al., 2006), the high start-up costs pose difficulties to wheat fortification in China. As in other fortification programs, the structure of the food vehicle industry plays a crucial role in the success of the fortification program (Fiedler et al., 2007). Contrary to the concentrated soy sauce industry, wheat milling is a segmented sector with about 100 000 small-scale mills in Western China, which hampers communication and (food) quality assurance (ADB, 2004a).

As the Chinese PNDC mainly supports research on wheat flour and soy sauce fortification, there is little information on folic acid fortification of rice in China (PNDC, 2011). Rice fortification is generally more expensive than adding folic acid to soy sauce or wheat (Susan Horton, Wilfrid Laurier University, personal communication, 15-12-2010). The use of the traditional fortification technology to lay a micronutrient coat is not a sustainable option because consumers typically wash rice before cooking (Shrestha et al., 2003). Nevertheless, there are two strategies of rice fortification being explored: the market-driven approach of DSM-Buhler and the socially-supported approach of PATH (Wailes and Lee, 2008). While the first approach is represented by leading rice milling equipment manufacturers, the latter is advocated by an international non-profit organization, who seeks to introduce fortification in governmental feeding programs. Therefore, the former aims at the high-income users, e.g. in Jiangsu Province, while the undernourished populations are the primary target group of the latter.

[54] In general, adding micronutrients to staple crops costs U$ 0.40-0.50 per person, per year (Hunt, 2001; Durkin et al., 2006), with Vitamin A and Vitamin E considered as the most expensive fortificants (Mason et al., 1999; Mannar, 2001).

Regardless of the selected strategy/technology, a company-based cost analysis reveals that fortified rice in china would raise the price of rice up to 3.5 to 4.0 %, which reflects an annual cost of US$ 1.60 per consumer and a significantly higher cost per MT (US$ 139 per MT) compared to other fortification food vehicles (Wailes and Lee, 2008). It is important to notice that these cost estimates are built upon the assumption of an industry that is based on a few large rice milling companies. At present, the Chinese rice milling industry consists of more than 300 000 companies, of which no more than 10 millers are capable of producing more than 80 tons per hour (Wailes and Lee, 2008). Fortification in small mills is technically feasible, but the associated monitoring costs will be extremely high (Bertebos Foundation, 2008). Furthermore, many families in rural areas are milling rice themselves or rely on small, local millers, which limits their access to fortified food. The decentralized, segmented rice milling sector is considered one of the major constraints of future rice fortification in China. Choosing for rice as the fortification vehicle will likely negatively affect the cost-effectiveness of the intervention, as more efforts are needed to guarantee quality control and technical barriers imply a more expensive technology (Susan Horton, personal communication, 15-12-2010).

##### *5.4.4.3. A comparison with other high-risk regions – the case of the Balrampur District (India)*

This section explores the impact of folate biofortification in Shanxi Province (see section 5.4.1) and another major high-risk region, namely the Balrampur District in India.
Historically, the average folate consumption in India are substantially below the recommended nutrient intake levels (Krishnaswamy and Madhavan Nair, 2001; Chakravarty and Sinha, 2002; Mallikharjuna Rao et al., 2010), leading to a high number of NTDs (see Figure 10 in section 2.3.3), especially in the sugar cane milling Balrampur District. Situated in the Uttar Pradesh State of Northern India, this rural district is considered as one of the least developed and poorest regions of the country. What Shanxi Province is to China in terms of NTD prevalence and folate intake levels, Balrampur District is supposed to be for India. Yearly, between 65.7 and 82.1 per 10 000 births are affected with an NTD (Cherian et al., 2005). Notwithstanding the lack of (recent) evidence of NTD prevalence in India, it can be expected that this high NTD risk region can be expanded to the whole Uttar Pradesh State (Sharma et al., 1994; Krishnaswamy and Madhavan Nair, 2001) or even neighboring States (Mahadevan and Vishnu Bhat, 2005).

Table 53 presents the health gap of folate deficiency in the current situation and after the implementation of FBR. The methodology is similar as in the main analysis of this chapter, but here the results are expressed in relative numbers. Because this section focuses on two high-risk regions, the high coverage rates as derived from the Shanxi consumer survey were selected: 36.95 % and 81.91 % (section 5.2.2.1.). As a consequence, the health impact figures are slightly higher than in the main study (see Table 49).
Given the NTD prevalence rates and the NTD attribution levels to folate deficiency, the relative burden of folate deficiency in Balrampur varies between 22.83 and 39.93 DALYs lost per 10 000 persons. As these figures do not take into account the large difference in birth rate between Balrampur (29.5) and

Shanxi (11.3)[55], the burden is also expressed per 1 000 births. By doing so, both the burden and the potential health benefits in Shanxi Province approximate the high impact scenario of Balrampur, which supports the high NTD risk status in these regions.

Folate deficiency is increasingly acknowledged by the Indian government. For example, they integrated a large iron-folic acid supplementation program for young, pregnant and lactating women (79.82 mi. US$ per year) in their Micronutrient National Investment Plan (IMNIP)(Micronutrient Initiative, 2006). Unfortunately, micronutritional programs in India are often characterized by poor fund allocation, poor community involvement, ineffective distribution strategies, a lack of monitoring and build-in evaluation, and the absence of a social marketing strategy, including nutritional education, which lead to an unsatisfactory coverage rate (Vijayaraghavan, 2002). Together with the governmental support, the large production of GM crops (especially Bt cotton, see section 2.5, Figure 11), the involvement in the Golden Rice projects (e.g. recently started field trials, (ISAAA, 2009), the positive reactions of Indian consumers towards Golden Rice (Deodhar et al., 2008), the high rice production rates (FAOSTAT Database, 2008) and the effectiveness of enriching rice with folate (see section 5.2.2.1), FBR might be considered a valuable intervention to reduce folate deficiency in both risk regions.

[55] China has one of the lowest birth rates in Asia, together with Singapore, South-Korea and Japan (ESCAP, 2009). This is mainly due to its 'one-child family policy', which started in 1979, and aims to curtail the population growth (Kane and Choi, 1999). Despite its success, one of the most important pitfalls of this policy is the sex discrimination, by which girls are significantly more a victim of abortions and orphans. For an overview of the Chinese birth rates per administrative region, see Table 40.

Table 53 Demographic profile of Uttar Pradesh, the current burden and health impact of FBR, and a comparison between Balrampur and Shanxi Province, in relative numbers.

| | **Numbers for Balrampur**[a] | | **Current burden** | | | **Folate intake levels** | | | | **Potential health impact** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total population | 1 682 350[b] | | **Balrampur** | | **Shanxi**[a] | **Balrampur** | | **Shanxi**[a] | | **Balrampur** | | **Shanxi**[a] | |
| Birth rate | 29.5[c] | | ***Low*** | ***High*** | | ***Befor*** | ***After*** | ***Befor*** | ***after*** | ***Low*** | ***High*** | ***Low*** | ***High*** |
| Births | 49 629 | | *DALYs lost per 10 000 persons* | | | *μg /day/cba* | | | | *DALYs saved per 10 000 persons* | | | |
| Life expectancy at birth | 64 years[d] | | | | | | | | | | | | |
| **Scenario** | ***Low*** | ***High*** | | | | | | | | | | | |
| NTD prevalence rate[e] | 65.7 | 82.1 | 22.83 | 39.93 | 14.31 | 249.3[j] | 1290.8[k] | 190.9 | 508.6 | 8.43 | 32.71 | 5.29 | 11.72 |
| NTD attribution level[f] | 50 | 70 | *DALYs lost per 1 000 births* | | | | | | | *DALYs saved per 1 000 births* | | | |
| Coverage rate[g] | 36.95 % | 81.91 % | | | | | | | | | | | |
| Total NTDs | 163 | 284 | | | | | | | | | | | |
| NTD Morbidity | 65 | 114 | 77.38 | 135.37 | 126.70 | | | | | 28.59 | 110.8 | 46.8 | 103.89 |
| a. Spina bifida[e] | 45 | 80 | | | | | | | | | | | |
| b. Encephalocele[e] | 20 | 34 | | | | | | | | | | | |
| NTD Mortality | 98 | 170 | | | | | | | | | | | |
| 2. NTD Stillbirths[h] | 47 | 82 | | | | | | | | | | | |
| 3. NTD Abortions[h] | 51 | 88 | | | | | | | | | | | |
| Rice consumption[i] | 356.67 g/day/person | | | | | | | | | | | | |

cba, women of childbearing age; NTD, neural tube defects
*Note*: unless otherwise mentioned, the parameters of the DALY framework to measure the health impact of China are used, e.g. discount rate of 3 % (Table 42).
[a]Numbers for Shanxi Province are presented in section 5.2.1.1 (population data) and section 5.2.2.1 (health impact); [b]Figures derived from the 2001 census for India; [c]The birth rate is expressed per 1 000 births, in 2007 (Govt. of India, 2008); [d]Based on WHO life tables for India, in 2008 (WHO, 2008b); [e]Both the NTD prevalence rates and the composition of the two non-fatal NTDs, i.e. 70 % (a) and 30 % (b), are derived from the NTD study in Balrampur District (Cherian et al., 2005); [f]Due to the lack of region-specific evidence, the attribution level of NTDs to folate deficiency is based on the global percentages, i.e. 50 % and 70 % (see section 2.3.3); [g]The coverage rate in both provinces are derived from the Shanxi consumer study in 2008 (see section 5.2.2.1); [h]Due to the lack of region-specific evidence, the figures are derived from the data assumptions for Shanxi Province (see section 5.2.1.1); [i]Rice consumption in Balrampur refers to purchases through the Public Distribution System (P.D.S.) and other channels (Govt. of India, 2001); [j]The current daily folate intake level is based on a folate study in Lucknow, the capital of Balrampur (Misra et al., 2010). When maternal figures for rural areas would be available and included, the mean folate intake levels are expected to be lower; [k]The calculation method is similar as in section 5.2.2.1.

## 5.4.5. Sensitivity analysis

### *5.4.5.1. Impact of NTD prevalence rates and NTD attribution levels in Shanxi Province*

Although a sensitivity analysis cannot justify the use of specific parameters in the DALY framework (WHO, 2000), it provides the reader with information about their impact on the results. For example, using different NTD prevalence rates could influence the potential health impact of folate enriched rice. This is explored for Shanxi Province because this region was subject of several folate and NTD research publications.

Table 54 lists published evidence on studies that measured the prevalence of NTDs in Shanxi Province (Moore et al., 1997; Li et al., 2006; Gu et al., 2007), Northern China (Moore et al., 1997) or in different regions of China (Xiao, 1989; Dai et al., 2002). All NTD prevalence rates differ in terms of the time of the research (i.e. 1987 until 2004), the method of data collection (hospital-based, population-based or combined approaches), and the research location (rural versus urban populations).

The selection of the NTD rate directly influences the total number of DALYs that are lost or saved due to folate deficiency and FBR, respectively. If the lowest prevalence rate of NTDs would be used, the burden of folate deficiency and the health benefits of biofortification would be 43.89 % lower than the NTD rate of Li et al. (2006). However, this percentage refers to the absolute reduction of the burden and the health benefits. Although the total number of DALYs saved will change, the reduction of the burden of folate deficiency through the introduction of folate biofortification remains the same, whether a low or high NTD prevalence rate is selected. This is because the health impact is determined by the coverage rate. If the coverage rate would increase, for instance, this would have a direct positive effect on the reduction of the folate deficiency burden, regardless of the selected NTD prevalence rate. Thus, while the NTD prevalence rate affects the absolute figures of the current burden and health benefits, the coverage rate determines the health gap, i.e. the discrepancy between these numbers.

Table 54 Comparison of the impact of using different NTD prevalence rates to measure the health impact of folate biofortified rice in Shanxi Province

| **NTD prevalence rate in Shanxi Province**[a] | **Study characteristics** | | | | **Change in burden (%)** |
|---|---|---|---|---|---|
| | **Period** | **Method** | **Research location** | **Source** | |
| 60.88[b] | 1996-2000 | HB | 31 provinces[c] | Dai et al., 2002 | -56.11 |
| 105.50 | 1987 | HB | 29 provinces[c] | Xiao, 1989 | -23.14 |
| 138.70 | 2003 | PB | Shanxi Province | Li et al., 2006 | 0.00[f] |
| 149.00 | 1997 | PB | 4 provinces[d] | Moore C et al., 1997 | +7.43 |
| 199.38 | 2002-2004 | HB + PB | Shanxi Province[e] | Gu et al., 2007 | +43.75 |

HB, hospital-based; PB, population-based
[a]Expressed per 10 000 births; [b]NTD prevalence rate used in the health impact study of chapter 5; [c]Including Shanxi Province; [d]Hebei and Shanxi in Northern China, and Jiangsu and Zhejiang in Southern China; [e]Only Jiaokou and Zhongyang, i.e. two counties in the Lvliang mountain area of Shanxi Province, are included; [f]Reference rate in this sensitivity analysis.

Using other attribution rates of folate deficiency to NTDs also has direct implications. If the 85 % attribution level of Berry et al. (1999)(see section 5.2.1.1) would be replaced by the 80 % level found in the Chinese study of Chen et al. (2008) or the world attribution rates (50-70 %, see section 2.3.3), the size of the burden of folate deficiency would be directly influenced. For example, the burden and health impact would be 41.18 % and 17.66 % lower when an attribution level of 50 % or 70 % would have been used.

Another commonly addressed issue in sensitivity analyses of health impact studies is the effect of discount rates (Murray, 1996). The current study confirms the conclusions of the sensitivity analysis of the GBD study: a zero discount rate increases the burden before and after the intervention, and, thus, its absolute impact.

##### *5.4.5.2. Potential cost-effectiveness of the single-insertion approach in MBR*

So far, we assumed that the four micronutrient traits would be developed independently and combined later on through backcrossing to obtain multi-biofortified rice varieties with all four traits. Hence, two transgenic single trait events, one for provitamin A and the other for folate, need to be deregulated, while the other two (iron and zinc) are conventionally bred. As argued above, for the concrete example of multi-biofortified rice in China, this is the most realistic avenue, given that the four traits are being developed by different research organizations. However, multi-biofortified rice may also be used in a number of other countries. Moreover, the individual technology components may be further improved over time, or new biofortification technologies in rice and other crops may be developed. Hence, it is also instructive to analyze how the cost-effectiveness might change if a single-insertation approach were used in future.

In our example of multi-biofortified rice we assume that the two transgenic traits would be stacked in one gene construct, while iron and zinc as conventional traits would be added through backcrossing. This would reduce the country-specific costs, as only one transgenic event would need to be deregulated. In particular, US$ 8.0 million could be saved, lowering the country-specific costs by 33 % from US$ 24.0 million to US$ 16.0 million (compare with Table 51). We further assume that such a stacking approach would help reduce the basic R&D costs by 20%, as this research would be carried out in one single organization with resulting synergies. For social marketing and maintenance breeding, no cost advantages are expected. Thus, the total cost would drop by 16 % from US$ 85.4 million to US$ 71.8 million, with all cost savings occurring in the first half of the 30 year time horizon. With these new cost assumptions, the cost per DALY saved would be US$ 7.91 and US$ 1.91 in the pessimistic and optimistic scenario, respectively. This is significantly lower than the values calculated above, demonstrating that the cost-effectiveness of multi-biofortification can be further increased by improving the efficiency of technology development. A single-insertion approach is of particular interest when multiple transgenic traits are involved.

## 5.5. Conclusions

This chapter evaluates the potential health benefits and cost-effectiveness of introducing GM folate enriched rice in China, both as a single and multi-biofortified staple crop. Application of the DALY method reveals that the current burden of folate deficiency amounts up to an annual loss of 314 180 DALYs. The introduction of GM rice with a folate content of 1 200 µg per 100 g rice in China would save 62 863 DALYs in the low impact scenario and 188 508 DALYs in the high impact scenario. The burden and the health impact are the highest in Northern China, in absolute (northeast) as well as relative numbers (northwest). The region with the highest NTD prevalence rate, Shanxi Province, will benefit the most from folate biofortification. The regional health benefits in China are based on average daily folate intakes between 433 µg and 1 411 µg per woman of childbearing age, which are significantly higher than the recommended folate intake of 400 µg. Although these numbers refer to averages, the high folate intake level in China demonstrates that FBR can be a valuable means to reduce folate deficiency and NTDs, especially in poor, rural regions where other folate interventions are less feasible. Even in the northern regions, where wheat is more popular than rice, folate biofortification of rice could contribute to achieve the recommended folate dose.

According to the target group, newborns or their mothers, the health impact of FBR can be interpreted in two ways. First, the health benefits can be expressed in terms of DALYs saved, based on the reduced number of births affected with an NTD, which is due to their mothers biofortified diet. Second, based on the coverage rate of FBR, the health impact can also be understood as the number of women of childbearing age, including mothers, recovering from folate deficiency. This “double” health impact is an important argument to underpin future communication strategies in order to tackle folate deficiency and its adverse health outcomes.

The results on MBR show that out of the 10.64 million DALYs that are yearly lost due to micronutrient malnutrition in China, between 1.19 million and 4.91 million DALYs could be saved when multi-biofortified rice would be introduced. Despite its favorable cost-effectiveness, the biggest contribution of multi-biofortification refers to its large health benefits, rather than to reduce the costs of single biofortification initiatives. The cost implications of the backcrossing approach are mainly reflected in the basic R&D costs, where the costs of developing each trait are aggregated, next to the backcrossing costs. This means that the costs to develop multi-biofortification are likely to be higher than the sum of developing each single biofortified crop. But the same goes for the coverage and, thus, health benefits of a multi-biofortified crop, which is likely to outweigh the simultaneous commercialization of four biofortified crops. Still, a first glance at the costs of introducing FBR in China reveals that even single-nutrient policy interventions can be a cost-effective method to reduce folate deficiency and its negative outcomes.

Although the application of the DALY approach in CEA analyses of health interventions is generally acknowledged, several limitations need to be taken into consideration. The analysis is highly dependent on the availability of data, such as the DALY parameters associated with the functional outcomes of micronutrient deficiencies, but also rice consumption and nutritional data. Not all functional outcomes could be entered, due to unknown prevalence rates (e.g. nightblindness of

Chinese lactating women; multiple NTD malformations; non-reported births) or the uncertainty of the attribution level (e.g. attribution of anemia to folate deficiency), which underestimates the total burden of micronutrient malnutrition in China.

With respect to the impact of consuming biofortified rice, the analysis relies on average nutrient and rice intake levels. To cope with this aggregated data level, the dose-response relationship compares the average micronutritional dose after (multi-)biofortification with the Recommended Nutrient Intake (RNI). These nutritional thresholds differ from the Estimated Average Requirements (EAR), which are often recommended in health impact analyses based on individual household data (Stein et al., 2006). While an EAR defines the average daily nutrient intake level to meet the requirements for half of the individuals of a given gender and age category, the RNI is a higher reference standard which meets the daily requirements of nearly all these individuals (97-98 %)(FAO/WHO, 2004). As some micronutrient intake levels in the optimistic impact scenario significantly exceed the RNI level, achieving the tolerable upper level (UL) might become an issue. Very high intakes of folic acid (>1 000 µg/day), for instance, could mask Vitamin $B_{12}$ deficiency (Scott et al., 2000; Bailey, 2004; Bekaert et al., 2008) and lead to a higher risk for colorectal cancer (Smith et al., 2008)(see also section 2.3.1). However, FBR and MBR increase the natural folate levels in rice, instead of inserting folic acid, which is assumed to be less problematic (Storozhenko et al., 2007)[56] and makes an early diagnosis of Vitamin $B_{12}$ deficiency possible (Tam et al., 2009). In regions with folate intake levels higher than 1 000 µg after folate biofortification, such as in most of Southeast China, a transgenic line with a lower folate content could be deployed to avoid potential negative side effects associated with high folate intake levels. As the uptake of Vitamin A and iron increases through biofortified rice is homeostatically controlled, toxicity issues and associated adverse health effects are also less likely to occur (Stein et al., 2005b). Regarding zinc, its UL is too high to be achieved through conventional biofortification techniques (IOM, 2002). On the other hand, not all administrative areas have high folate intake levels after biofortification. In Shandong and Xinjiang, for instance, the average folate intake levels are slightly above the RNI. This could be tackled by implementing a transgenic line with higher folate content, such as 1 700 µg per 100 g of raw polished grains.

This is the first attempt to measure the cost-effectiveness of folate and multi-biofortification. Some recommendations can be made to further improve the research results.

First, collecting primary or fine tune secondary data would significantly benefit this health impact study. While some parameters of the DALY framework have to be further explored (e.g. a stable folate content of folate enriched rice and the exact degree of bioavailability), others need to be adapted according to the study location (e.g. the current folate intake and the attribution level of folate deficiency to NTDs, per administrative area). Since several parameters are based on different years (i.e. NTD prevalence rate in 2004, rice consumption in 2007, FBR coverage rate in 2008), the health impact has to be perceived as a theoretical number, rather than a real figure.

[56] Vitamin $B_{12}$ deficiency is characterized by macrocytic anemia and neurological impairment. The diagnosis of Vitamin $B_{12}$ may be delayed by folic acid (reduction to H4folate), as the latter can correct the macrocytosis (Gutstein et al., 1973). Because (natural) folate biofortified rice contains 5-methyl-tetrahydrofolate (MTHF), the synthesis of H4folate from 5-MTHF is catalyzed by a Vitamin $B_{12}$ dependent enzyme, which eliminates the effect of masking Vitamin $B_{12}$ deficiency (Storozhenko et al., 2007; Tam et al., 2009).

Furthermore, the DALY is a disease burden measure that is related to health outcomes, just as morbidity, mortality, life expectancy, DALE (disability-adjusted life expectancy) and QALY. The focus could also have been put on or extended to the costs of the burden, e.g. using a cost-of illness analysis (COI) to calculate both direct and indirect costs attributable to the disease, such as the (non-) medical costs and the costs related to productivity losses, respectively. Although such an analysis could have provided additional arguments regarding the importance of the burden of folate deficiency, as the Dutch study of Jentink et al. (2008) shows, data constraints hamper the measurement of such costs.

Second, to be able to calculate all health benefits of FBR, additional research is required to define the attribution of folate deficiency to each of its functional outcomes or, when the focus of the intervention is on reducing NTDs, explore the impact of other micronutrient deficiencies. NTDs, for instance, have also been associated with zinc deficiency (Sandstead, 1994). In this respect, the effect of micronutrient interactions in the case of MBR should deserve more attention. Some interactions could generate additional health benefits. For example, improving the Vitamin A status might enhance iron absorption (Schultink and Gross, 1996), while tackling zinc deficiency could increase folate bioavailability (Sandstrom, 2001) and folic acid supplementation could alter zinc absorption (Sandstead, 1994). On the other hand, combining traits may also impair micronutrient absorption and reduce its health effects. Iron supplementation, for instance, could negatively influence zinc absorption and vice versa (Winichagoon, 2008). Nevertheless, evidence of the effect of micronutrient interactions between zinc, iron, folate and vitamin A is mixed and it still remains unclear how these interactions will be affected through multi-biofortification. This study assumes that the health impact of four traits is equal to the aggregated impact of each individual trait.

Third, when the regional data in the FBR health impact study would be available (or collected) at individual level, the burden could be further refined and the characteristics of high-risk regions and individuals could be more precisely mapped and, thus, better addressed.

Fourth, in-depth analysis and verification of the different cost estimates are needed to further underpin the introduction of FBR or MBR in China. Therefore, policy issues regarding the price of folate enriched rice, promotion campaigns, the selected variety, and so on, need to be explored and incorporated into the analysis (see also section 6.5). Also the availability of, and access to the product, and the final product attributes (see section 3.3.4) will define whether women will actually be able (and willing) to switch to FBR.

# 6 General conclusions

## 6.1. Answering the research questions

This PhD dissertation addresses eight research questions concerning the market potential of FBR in China, and Shanxi Province in particular (see section 1.4). Hereunder, I provide an answer to each of the research questions and their sub-questions, based on the results presented in the different research chapters.

| | |
|---|---|
| ***RQ1.*** | ***Is consumer acceptance of FBR determined by socio-demographic indicators, knowledge and consumer perceptions related to GM food?*** |
| *RQ1A.* | *How do consumer perceptions of GM food affect FBR acceptance?* |
| *RQ1B.* | *Does objective GM knowledge determine FBR acceptance?* |
| *RQ1C.* | *How do socio-demographic variables influence FBR acceptance?* |

As expected, socio-demographic indicators, GM knowledge and consumer perceptions influence FBR acceptance (see section 3.3.2). By using four multi-item scales of GM food perceptions, the study found a positive association between risk and benefit perceptions of GM food and a favorable opinion of FBR, which is in accordance with the general literature findings (Baker and Burnham, 2001; Li et al., 2002). The appropriateness to use these perception categories is also shown in the cluster analysis (see RQ2).

Compared to previous research that found a one-sided, positive effect of objective knowledge (and education level)(Hoban, 1998; Koivisto Hursti and Magnusson, 2003; Traill et al., 2004; Chen and Li, 2007; Costa-Font et al., 2008), or no effect at all (Hamstra, 1995; House et al., 2004), high objective GM knowledge increases the likelihood of being either reluctant or favorable. People who are indifferent to FBR are more likely to be those without any understanding of the GM concept. This provides evidence to use a categorical acceptance construct that distinguishes acceptance from indifference.

Due to the low explained variance of the model, one could argue that socio-demographic variables are not powerful factors of FBR acceptance, in line with several GM studies (Bredahl et al., 1998; Li et al., 2002; Kontoleon and Yabe, 2006; Anand et al., 2007). The lack of significant family-related indicators in our study further underpins this. On the contrary, FBR acceptance is determined by four socio-demographic factors (gender, age, education and farmer status), which advocates to take into account the socio-demographic profile of consumers in GM food research. Somewhat surprising, men are more likely to accept this GM food product. Nevertheless, the majority of the Shanxi rice consumers and farmers are favorable to FBR.

***RQ2. What kind of segments of Shanxi rice consumers can be distinguished based on GM food knowledge, consumer perceptions and trust in information sources/channels?***

The consumer study in a Chinese Province with a high risk of folate deficiency provides further insight in the existence of three market segments for FBR as a GM food product, denoted as cautious (44.6 %), opposing (41.2 %) and enthusiastic consumers (14.2 %)(see section 3.3.3).

Objective knowledge, trust in information sources and channels, and FBR acceptance is the highest in the group of enthusiasts, followed by the cautious segment. The former also have generally the most positive view on the GM food consumer perception categories, whereas the opponents and cautious cluster are more concerned about the primary (safety, risks) and secondary conditions (benefits, price impact) of GM food, respectively. Regarding the acquisition of GM food information, opponents rely less on audio-visual information channels and more on anti-GM sources, while having less trust in typically pro-GM sources, such as the government and the biotech industry.

The small size of the enthusiastic segment is due to its general positive values on nearly all examined variables, such as knowledge, acceptance, trust in information sources and channels. This means that consumers, whose high objective knowledge and positive consumer perceptions led to higher acceptance, are clustered in a homogenous group of (extremely) favorable consumers. As a consequence, the cautious are considered less enthusiastic, rather than being averse.

***RQ3. Which negative changes in rice attributes would deter FBR acceptance?***

Depending on which attributes are negatively altered, different segments of the favorable consumers may become resistant, which will hamper the coverage rate and the success of FBR (see section 3.3.4). In general, the relatively high acceptance rate of FBR in Shanxi Province (62.2 %) would be drastically reduced when the final product generates a negative taste (-34.1 %) or environmental effect (-33.3 %). The reduction is substantially smaller when the cultivation potential, the external appearance, the availability or price impact would be negatively affected. When selecting the rice varieties to insert the folate trait, sensory aspects and environmental impacts should be taken into account. Regarding multi-biofortification of rice, developers and health planners should anticipate the potential negative reactions associated with color changes due to vitamin A enrichment.

Cluster analysis identified four different consumer segments on the acceptance of negative rice attributes in Shanxi Province, namely “Traditional attribute buyers”, “Market consciousness”, “Intrinsic attribute buyers”, and “Health seekers”, which demonstrates the heterogeneity of those holding a favorable position towards FBR.

***RQ4. How much are consumers willing to pay for FBR in a high-risk region?***

*RQ4A. What determines consumers' valuation of FBR?*

*RQ4B. How does information about the applied GM technology affects WTP for FBR?*

*RQ4C. What is the effect of providing information about the regional situation on WTP for FBR?*

*RQ4D. Is there a difference between non-student and student samples in experimental auctions?*

*RQ4E. Does the provision of a non-GM substitute influence WTP for FBR?*

*RQ4F. Do design characteristics (time, day, size) matter in auctions?*

Here, WTP for FBR correspondents with the WTP values in the third auction round, i.e. where no specific GM information was given, except for the application of the technology. In general, Shanxi female rice consumers are willing to pay 1.73 ¥ or 33.7 % more for the improved folate content in a 1 kg regular rice bag (see section 4.4.2). This average premium is in line with research on other biofortified crops (Li et al., 2002; Deodhar et al., 2008; Depositario et al., 2009a; De Groote et al., 2011) and represents an increase in the perceived quality of a regular rice bag to the next (higher) quality level. Given the low income levels in the sample, the results show that even poor consumers are prepared to pay for quality, a finding that has been confirmed in other food auction studies in developing countries (Gonzalez et al., 2009; Wayua et al., 2009; Demont et al., 2011; Rutsaert et al., 2011).

Dependent on the applied technology, different determinants are at stake in the valuation of biofortified crops. Whereas knowledge of folate benefits is the main determinant to pay more for conventional folate enriched rice, WTP for FBR is largely determined by objective GM knowledge and consumers' acceptance of GM food. The former shows that a higher value is linked to information that confirms prior knowledge of folate benefits, which indicates the presence of confirmation or congeniality bias. Furthermore, both sWTP and WTP values contradict previous research (Lusk et al., 2001a; Umberger and Feuz, 2004) by demonstrating the importance of socio-demographic indicators.

The experimental auctions also showed that the valuations of the folate benefits are high enough to compensate potential negative valuations of awareness of the applied GM technology. This supports the potential of FBR, especially in the non-student sample, where the information about the GM nature of FBR did not significantly alter consumers' valuations. When looking at zero bidding behavior, however, awareness of the GM technology increased the share of zero bidders by 12.7 %.

Provision of relevant information about the current situation in the high-risk region led to increased WTP values and substantially reduced zero bidding behavior. As the last information round, this information treatment even reduced the negative effects of the previous GM related information rounds.

The WTP valuations clearly differ between the student and non-student sample of rice consuming women of childbearing age, both in their amount of WTP, as well as in the probability to bid. Whereas students are less supportive of FBR, the general target group reacts more positively towards this GM rice variant with consumer benefits. This contradicts previous literature that found no significant differences in GM food auctions between student and non-student samples (Lusk et al., 2005; Depositario et al., 2009b). The inter-group variations are likely to be the result of differences in the degree of involvement, i.e. less concerned about pregnancy, the socio-demographic profile and GM food acceptance.

Offering rice with free folic acid supplements alongside the auctioned FBR bag was not as successful as might have been expected. Even when the GM technology in FBR is mentioned, having the option to bid on a GM-free folate alternative did not lower the FBR bids. Especially in the non-student sample of the auctions, FAR was considered an unattractive folate product.

Regarding the other design characteristics, no significant difference in bidding behavior could be found when auctions were held on a different time, during the weekend, or in larger groups.

***RQ5. Is there a difference between stated willingness-to-pay (sWTP) and auction-based values (WTP)?***

*RQ5A. Do the WTP values reveal a hypothetical bias in the stated valuation method?*

*RQ5B. Are the auction-based values subject to a social desirability bias?*

In general, the stated values are about ¥ 0.7 (40.5 %) higher than the auction-based values (WTP), which might indicate the presence of a (small) hypothetical bias in the latter (see section 4.4.3). In the student sample, for example, zero bidding behavior is significantly higher when monetary consequences are attached to the stated preferences. However, as the values of the two value elicitation methods differ according to the target group, i.e. student versus non-student sample, with only a small discrepancy in the latter, one could argue that the differences between the hypothetical versus non-hypothetical bids are not large enough to underpin a general hypothetical bias of this open-ended contingent valuation, as other authors have postulated (Brown et al., 1996; Balistreri et al., 2001). But the risk of a hypothetical bias might be masked by the relatively high auction values. This could be due to the separate, comprehensive information rounds about a relevant product, gender biased bidding behavior by which women bid higher in auctions (Lusk et al., 2004a), the inclusion of extensive trial sessions (Drichoutis et al., 2010), the political climate (see also section 6.5), the bidding procedures, the data constraints to compare target groups, auction fever and social desirability.

The presence of the latter two were investigated by comparing the auction-based (WTP) and indirect values (iWTP) for FBR. The difference between the two valuation methods is below ¥ 1, and a discrepancy is found between both target groups, by which it is hard to support high bidding behavior as an act of SDB (and auction fever). Also the false consensus effect (Ross and House, 1977), which could offer an alternative explanation for SDB when people consider their value as the ‘normal’ value, but is less likely to occur. For example, indirect bidding behavior deviates from the individual bids in 41 % of the cases.

Thus, although methodological and sample characteristics between the three valuation methods could account for value differences and mask biases, a general hypothetical and social desirable bias are expected to be less likely to occur.

***RQ6.*** ***To which GM information are consumers most susceptible when valuing FBR?***

*RQ6A.* *What information dominates in conflicting GM information?*

*RQ6B.* *Is there a primacy or recency effect in the evaluation of conflicting GM information?*

*RQ6C.* *Does the GM information effect differ according to consumer acceptance of GM food?*

Unlike WTP for FAR, the FBR valuations in the fourth auction round differ according to the GM information treatment, i.e. one of six randomly distributed GM information sheets. Evidence from the experimental auctions show that Shanxi rice consumers are most susceptible to one-sided positive or negative GM information. The largest WTP reduction occurs in the latter, followed by objective information. Contrary to other GM information studies (Tegene et al., 2003), the impact of objective information appears to be more negatively evaluated than conflicting information. As a consequence, the combined treatment (all = positive + negative + objective) is slightly lower valued than negative + positive information.

Conflicting information results in a significant downward adjustment of WTP values, which supports the alarmist hypothesis that is found in previous auction literature (Fox et al., 2002; Tegene et al., 2003; Parkhurst et al., 2004; Hu et al., 2006). However, the WTP reduction is smaller when positive precedes negative information, indicating the potential presence of a primacy effect. The absence of a similar information order effect in the ‘all’ information treatment might be attributed to the negative perception of the objective statements, by which an alarmist reaction appears to dominate this effect. Thus, when consumers have to deal with conflicting information, they seem to be subject to an alarmist reaction and a small primacy effect, so that negative information prevails, but appears to be less effective when positive information is presented prior to the negative statements.

GM food acceptance is associated with higher WTP values for FBR. Favorable consumers are found to be more susceptible to information that does not align with their approval of GM food. On the contrary, opponents are significantly more reinforcing their reluctance when learning about negative statements of GM. Thus, consumer’s acceptance of GM food is likely to be triggered when receiving GM food information, as stated by Fazio (1990), but it appears not capable of mitigating the effect of deviating information treatments (Frewer et al., 2000; Colson and Huffman, 2009). The presence of confirmation bias might be an explanation for this tendency (see RQ4).

***RQ7.*** ***What is the current burden of folate deficiency in China and Shanxi Province?***

*RQ7A.* *What is the relative importance of folate deficiency in micronutrient malnutrition in China?*

*RQ7B.* *How large is the burden of folate deficiency in two of the most important high-risk regions, Shanxi Province (China) and Balrampur District (India)?*

Application of the DALY framework in chapter 5 shows that an annual number of 314 180 DALYs are lost due to folate deficiency in China, of which 82.8 % in Northern China and 15.7 % in Shanxi Province. About 72.2 % of this burden is attributed to fatal outcomes of folate deficiency, namely abortions and stillbirths related to an NTD that is caused by a low maternal folate intake. Compared to the burden of other micronutrient deficiencies (vitamin A, zinc and iron) in China and other developing countries, this burden is substantially smaller but, as NTDs are the only measurable functional outcomes of folate deficiency and women of childbearing age are the only included target population, presumably underestimated. Micronutrient malnutrition in China leads to an annual loss of 10.6 million DALYs, of which about 3 % is caused by (maternal) folate deficiency.

Due to the substantially lower birth rate and higher population size in Shanxi Province, the burden of folate deficiency per 10 000 population or per 1 000 births is, respectively, lower and higher than in the Balrampur District. Nevertheless, the findings show that both regions are highly comparable. The high NTD prevalence scenario of Balrampur (135.4 DALYs lost per 1 000 births), for instance, approximates the current situation in Shanxi Province (126.7 DALYs lost per 1 000 births).

***RQ8.*** ***How cost-effective would folate and multi-biofortified rice be when introduced in China?***

*RQ8A.* *Does the cost-effectiveness of FBR and MBR in China achieve the World Bank thresholds of highly cost-effective health interventions?*

*RQ8B.* *When compared with other biofortified crops in other developing regions, how cost-effective is FBR and MBR in China?*

*RQ8C.* *What is the health impact of FBR when introduced in the most important high-risk regions of China and India?*

Based on a 30-year time horizon, the comparison of the potential health benefits (DALYs saved) and the estimated costs to develop and introduce FBR and MBR in China demonstrates that saving a DALY would cost between US$ 21.4 and US$ 64.2 in the former, and between US$ 2.3 and US$ 9.6 in the latter (see section 5.4.3). As a consequence, both health interventions are well below the World Bank 'high cost-effectiveness' threshold (US$ 86.04 in 2011), especially in the high impact scenario.

When comparing these figures with other cost-effectiveness studies of biofortification in developing countries, the relative burden of folate deficiency and micronutrient malnutrition in China is, respectively, the lowest and one of the highest. This is mainly due to the fact that measurement of the former is only based on the main functional outcome of folate deficiency, i.e. NTDs, while the latter addresses more functional outcomes than any other health impact study. Although health impact studies differ in terms of the applied parameters of the DALY framework, the assumptions of the impact scenarios and the characteristics of the research location, the benchmarking exercise provides further evidence that FBR and MBR could be a highly cost-effective intervention to reduce the burden of the respective micronutrient deficiencies in China (see Table 52).

If FBR would be implemented in Shanxi Province and the Balrampur District, both high-risk regions could achieve an average folate intake level that is significantly higher than the recommended daily folate intake of 400 µg, respectively 1290.8 µg and 508.6 µg. Although the health impact figures differ according to the benchmark indicator, per 10 000 population or per 1 000 births, the potential number of DALYs that could be saved are in the same order of magnitude. In the optimistic scenario, for instance, between 111 and 104 DALYs could be saved per 1 000 births in Balrampur District and Shanxi Province, respectively.

## *6.2. Policy implications*

In this section, I will briefly reflect on the (potential) implications of the research on the market potential of FBR. The primary audiences for the results obtained in this study are not limited to the government and its policy makers, but are also of importance to the health sector, aid agencies, consumer organizations, NGO's (e.g. The Hunger Project), the biotechnology industry, stakeholders in folate interventions, and scientific researchers involved in the field of developing, (ex-ante) evaluating and introducing novel GM technologies and health strategies (see section 6.5). Here, the recommendations and expectations will primarily refer to the specific case of FBR in China and Shanxi Province, but might be generalizable to 2$^{nd}$ generation GM crops in other high-risk regions or developing, rice consuming countries.

*Awareness of burden of folate deficiency*

The (political) recognition of FBR as a major health problem is a crucial step to (investigate the need to) fund programs to reduce its burden (Brooks, 2010). In this respect, the results of the burden of disease study can be useful broadly in two ways. First, the health gap assessment in this thesis sheds a light on the importance of folate deficiency in China and its provinces. The regional burden analysis is useful to health policy by enhancing the awareness of this problem and through the identification of problematic regions.

Second, the results are expected to increase awareness on the need to put folate deficiency and micronutrient malnutrition on the Chinese health agenda and to generate a broader debate where public health specialists, epidemiologists, agricultural and biotechnology experts, and policy makers are involved. The relatively lower size of the burden of folate deficiency, compared to other main micronutritional deficiencies in China, shows that combating folate deficiency is to be approached as a targeted intervention, i.e. addressing birth defects through women of childbearing age. It also raises awareness about the data constraints, e.g. epidemiological relations, that partly account for an underestimation of the burden of folate deficiency. This means that current health policy should address this deficiency based on the health impact of its main functional outcome, i.e. NTDs. While priority should be given to further unlock this 'hidden hunger', by stimulating research to reveal its attribution to other functional outcomes. In other words, this first burden analysis should stimulate governments to improve and update the results, in order to evaluate the progress and impact of FBR over time.

*Economic evaluation of FBR as a health priority-setting tool*

The thesis further demonstrates that this folate intervention, whether it would be combined with other micronutrients or not, would be a highly cost-effective health strategy to alleviate the current burden of folate deficiency. The cost-effectiveness study contributes to priority-setting of micronutrient interventions and, thus, to allocate resources related to R&D and the implementation of FBR. Governments typically seek health interventions that aim to avert a large public health problem in a cost-effective way (Jamison, 2006; Laxminarayan et al., 2006).

In the case of FBR, our regional approach provides decision-makers an alternative tool to effectively reduce the burden of folate deficiency in regions where the burden is highest and current policy interventions are less successful, which is the case in Shanxi Province. Although FBR is often less (but still highly) cost-effective than other single biofortified crops, one could advocate for FBR because the expected health impact is among the highest. Moreover, as about 258 million Chinese people are assumed to be folate deficient, a national population-based approach would even be more cost-effective than our study on women of childbearing age indicated. When incorporated in a multi-micronutritional strategy, the scope of the intervention is expanded to micronutrient malnutrition as a whole, which further increases the benefits of biofortification as a cost-effective strategy.

Although policy makers will take into account several factors when deciding which (micronutrient) burden needs to be addressed, this thesis offers them a cost-effective option that could be considered when planning to develop programs to improve folate intake. Furthermore, application of the DALY approach makes it possible to go beyond the cost-effectiveness rates by providing in-depth information on the health impact of specific functional outcomes and separate cost components.

*Fostering the approval of FBR and GM biofortified crops in China*

As Hotz and Brown (2004, p. 168) concluded in their zinc risk assessment report: "*If results from scientific studies indicate that [zinc] fortification is an efficacious and effective strategy to reduce [zinc] deficiency, the government should create legislation to implement an intervention program*". One could make a similar conclusion regarding folate deficiency. However, like other more advanced GM biofortification strategies, such as Golden Rice, the high cost-effectiveness of FBR is a prerequisite, but not a guarantee for its future approval or commercialization.

As an agricultural health intervention that is based on GM technology, several issues need to be addressed before governments will finally approve the commercialization, e.g. biosafety requirements, IPR issues, involvement of seed companies, … (see section 6.5.1). However, as public (and farmer) acceptance is considered a crucial determinant of the political approval of GM crops, the general positive reactions that are found in the study on acceptance and WTP are expected to be important arguments towards future commercialization of FBR and other GM rice crops with health benefits (member of the Chinese Biosafety committee, personal communication, 18-04-2011). It might further speed up the implementation of the approved Bt rice, encourage the development and submission of similar applications and thereby facilitate the process and progress of GM crop regulation, which is currently delayed by anti-GM actions (see section 6.5).

Some experts even expect that GM biofortification will be the precursor to finally commercialize GM staple crops with agronomic traits in China (Biotechnology industry representative, personal communication, 19-04-2011). This means that biofortification can lead to create a more favorable public and political climate to advocate for 1st generation GM rice crops, such as Bt rice. Despite these potential policy implications, it is important to note that there is still no solid proof that policy makers will adopt GM rice in China. Even if China would not choose to begin the production of GM rice, the results are not considered to be useless for health policy. As Grosse et al. (2007) state, economic evaluation study results that do not influence policy makers in their resource allocation towards GM biofortified interventions could contribute by helping them to apply other, alternative interventions to tackle malnutrition.

*Providing a better understanding of the potential market (demand) for FBR as a prerequisite for future health policy interventions*

From a marketing point of view, knowing the needs and potential reactions of the population and the different target groups, contributes to a successful implementation of GM foods (Lusk and Norwood, 2006) and biofortified crops (Dubock, 2008). Musgrove and Fox-Rushby stated (2006, p. 227): *"The effectiveness of an intervention and, therefore, the degree to which it deserves priority depend on how far it is culturally appropriate or acceptable for the population it is intended to benefit".* This thesis defined the potential coverage of FBR as a GM crop with health benefits in a high-risk region, which represents the key beneficiaries of this pro-poor, pro-rural strategy, by investigating the needs (e.g. information, product attributes) and potential demand (e.g. WTP) of consumers.

While Shanxi rice consumers are generally not reluctant to FBR, policy makers, health planners, and agricultural stakeholders will have to take into account some areas of special attention when aiming to introduce and promote this intervention towards specific target groups (see also the discussion section of chapter 3). If the goal of FBR is to reduce the number of birth defects, female consumers, who are less supportive of FBR than men, but are still willing to pay for it, should be primarily targeted. The large cautious segment of women supports that there is potential to further increase the coverage rate. Broadening the objective of the intervention to the population as a whole necessitates a shift in the focus towards those at risk. Unfortunately, poor consumers mainly belong to the opposing segment, i.e. a segment with less positive views on GM food and FBR. The need to address these opponents is acknowledged by Kalaitzandonakes and Bijman (2003), who stated that the approval and market acceptance of GM food is most likely driven by the extreme, reluctant consumer instead of the average consumer. Rather than increasing objective GM knowledge as such, attention should be paid to learn opponents about the specific benefits and improve their risk perceptions in order to ensure a widespread coverage. On the supply side, farmers seem to be even more enthusiastic than consumers. Although this does not necessarily imply that they will adopt FBR when it would be available, it is a crucial first step of future farmer adoption.

From a purely economic perspective, consumers' WTP could be used, and juxtaposed with the production costs, in order to decide whether it is beneficial and commercially viable to adopt it or to set its price level, e.g. based on a premium that still achieves a sufficient market share (Breidert et al., 2006; Lusk and Norwood, 2006). Despite the importance of consumers' valuation in price-setting (Lusk and Hudson, 2004), it is certainly not the only key factor that affects pricing decision (Monroe and Cox, 2001). Even though the study revealed that poor consumers are prepared to pay for FBR, the ability-to-pay might be an important constraint of the empirical validity of consumers' WTP, as shown in valuation studies on health care options in poor populations (Donaldson, 1999). Poor Shanxi rice consumers may not be able to pay the high premium they have stated in the auctions. Therefore, the high WTP values should be interpreted as consumers' preferences of FBR over regular rice. Moreover, an agricultural commodity like FBR is developed by the public sector and has to be also considered as a health policy intervention. As such, the strong preferences for FBR in Shanxi Province, as reported in chapter 4, are useful to provide governments with information on - the direction of - consumer preferences and the potential market demand among specific target groups (e.g. women of childbearing age and rice consumers from a folate deficient region). This could be incorporated in the decision regarding the implementation of this pro-poor strategy. As Pearce and Özdemiroglu (2002, p. 22) stated: *"Economic values expressed in money terms, […], will reflect people's preferences and can thus be used as weights to inform any policy analysis or decision process"*. Gaining insight in consumer preferences through ex-ante non-hypothetical WTP studies makes it possible to determine the value for consumer benefits in GM rice, predict the impact of information on attributes, develop activities to adequately address the target population and, thus, increase its success rate in rural areas. Thereby, it will be a challenge to simultaneously attract farmers, who seek to make profits out of the added value of their products; poor consumers, who will have different rice varieties at their disposal; and other stakeholders, who will need to be involved to commercialize, distribute and promote FBR, while taking into account the costs of the developers (see section 6.5).

To further increase the health impact of FBR in China, intervention strategies should pay attention to attribute changes of the end-product and, once commercialization would be approved, the kind of information that will be disseminated. The importance of negative information from anti-GM sources on WTP for FBR confirms the current political hesitance to bring GM staple crops to the market. The experimental auctions have demonstrated that it will be hard to convince the reluctant consumer through an information campaign, if they have access to opposite information. Such a situation could discourage those that are not resistant to GM food, which may deter consumer acceptance of GM rice with health benefits. Although one-sided positive GM information was highly successful in removing the effect of prior attitudes about GM food, it is less realistic in the current Chinese debate, where positive GM information is immediately countered by leading anti-GM activist groups, like Greenpeace

China, or local NGOs, such as Utopia (Stone, 2011). In order to reduce the substantial negative impact of anti-GM campaigns, the focus should be on the (non-GM) product- and the context-specific advantages of FBR, such as nutritional knowledge and the regional burden of folate deficiency. For example, it would be valuable to organize public education actions to promote FBR at community level, as the Micronutrient Initiative (2009) recommended. The mandatory labeling issues (see section 6.5.2), which are not negatively perceived by Chinese consumers, is another opportunity to provide consumers with correct and relevant information. For example, adding a picture of NTDs is expected to reinforce the effect of folate information. Future FBR communication campaigns should also attempt to improve the low trust levels regarding GM proponents, which might be related to consumers' opposition.

Despite the market potential of FBR, through its positive consumer reactions and cost-effectiveness, it is important to note that biofortification alone will not be sufficient to completely eradicate the burden of micronutrient malnutrition. But interventions should not be evaluated in terms of their potential to eliminate diseases. As Underwood (1999) suggests, interventions should eliminate the nature of the problem, i.e. being of major public significance. A combination of different nutrition interventions, such as supplementation or fortification (Fiedler et al., 2008) and biofortification (Horton et al., 2008), is then considered the best option to achieve this level of elimination at a large scale. As such, micronutrient interventions are recently included among the best investments in global development (CC, 2011).

When FBR would be launched, activities are needed to convince opponents of FBR, to provide them an alternative solution to increase their folate intake (e.g. FAR to students), or to introduce other folate products for those who do not (frequently) consume rice. The experimental auctions, for instance, revealed that opposition towards FBR may drive a consumer towards an alternative, non-GM intervention with folic acid supplements (e.g. in the student sample; see section 4.4.2.2). However, folic acid supplementation is largely seen as an unattractive folate substitute for FBR, which is further reflected in the low usage levels of women of childbearing age (see section 4.4.2.1).

Addressing the widespread prevalence of different micronutrient deficiencies in China and the world also advocates the combination of multiple micronutrient interventions, such as the investigated, highly cost-effective multi-biofortified rice. Although such an approach might be more desirable from a public health view, additional difficulties could arise when aiming to obtain approval and commercialize additional GM biofortified traits (see section 5.4.5.2 and 6.5).

## 6.3. Limitations

This section will reflect upon the main limitations of this PhD dissertation. I will mainly focus on general, cross-chapter constraints. Chapter specific limitations are primarily tackled in the respective research oriented chapters.

First of all, the scope of this thesis as presented in section 1.2 is a limitation in itself. Although many considerations underpin the choice to focus on China and Shanxi Province, gathering data led to additional limitations, such as the limited access to and availability of nutritional data. Therefore, prudence is in order when aiming to generalize the findings from the consumer studies in Shanxi Province. Investigating consumer behavior in this poor, rural region of China implied that the surveys and the auction procedures needed to be easy to understand and culturally adapted. In the auctions, for instance, some survey questions needed to be deleted (e.g. SDB-scale), recruitment procedures had to be facilitated (e.g. illiterate persons could not participate in the auctions) and design characteristics were relaxed (e.g. fixed auction size). Besides these practical implications, the main limitation regarding the selected research location, is the level of rice consumption. Situated in Northern China, wheat consumption in Shanxi Province is typically higher than rice consumption. Although the daily rice consumption in Shanxi Province is still high enough to advocate for the implementation of folate or multi-biofortification of rice (see Table 46), the results refer to a scenario where women of childbearing age either switch to FBR or stick to their regular rice diet. Assuming a dietary mix of rice varieties instead would lead to a lower health impact of folate biofortification. Nevertheless, the coverage rate will be highly determined by the targeted rice varieties (e.g. preferably popular, pro-poor varieties; see section 6.5.2).

Second, this PhD dissertation is limited in its scope with respect to the subject of analysis, i.e. GM rice with improved folate content. Except for the study on MBR in chapter 5, the focus is solely on folate enriched rice. Therefore, I initially considered other (agronomic) rice attributes to be unchanged.

Regarding the consumer research on FBR, in the surveys or during the auctions I did not give any details about the GM technology (e.g. the transferred genes, the source of these genes, the gene transfer mechanism, …). This is an important limitation that could have masked additional negative reactions (Schnettler et al., 2008a; Colson and Huffman, 2009; Novotorova and Mazzocco, 2009). However, the low socio-education levels in the research location support our choice to focus on the comparison between a GM product and its conventional counterpart, based on consumers' awareness of the applied GM technology.

Third, the conceptual framework takes some assumptions for granted. In general, the consumer is expected to be the strong determinant of the (market potential of the) implementation of biofortified staple crops. The limitation of putting the consumer central in this thesis, directly and through the societal benefits of the impact study of FBR, is acknowledged when dealing with the stakeholder approach, as discussed in section 6.5. Further, the conceptual framework also considers the CEA study to be an important tool to influence priority-setting and resource allocation regarding biofortification as a micronutrient intervention. Although CEA is useful and recommended to demonstrate the potential of such interventions, it is likely to be only one indicator in the decision process of policy makers and program planners.

Fourth, there are some limitations attached to the way some of the concepts of the conceptual framework were measured. FBR acceptance, for instance, refers to consumers' evaluation of the product as a whole, rather than distinguishing its different characteristics (GM technology, NTD benefits, other benefits, other rice attributes, …). As a consequence, it is difficult to understand to which part of the product consumers are reacting negatively or positively. Someone largely opposed to FBR could be not interested in its health benefits or concerned about the applied GM technology.

The stated preferences as operationalized in the 2008 survey are prone to criticism (see section 1.3.2.1 and 4.2.1). I attempt to cope with the limitations of the stated valuation study in the non-hypothetical valuation study. One of the most important limitations of the latter is the fixed auction design structure to measure different (information) effects. One could argue that the whole auction process might be affected by a primacy effect, by which different information effects would be obtained when starting with the controversial GM information, followed by the folate related rounds. However, it was practically not feasible to include a control group or to examine order effects of the rounds, except for the GM information order effects. Instead, I consider the difference between subsequent WTP rounds as the information effects. This is in line with the current experimental auction literature (Roosen et al., 1998; Hobbs et al., 2006). Other limitations and potential biases of the methodological choices to measure WTP are largely discussed in section 1.3.2 and the methodology sections of chapter 4.

The DALY framework critics mainly refer to the incorporation of specific input parameters of the DALY formula, e.g. discounting (see section 5.2), and the interpretation and comparability of the DALY approach as a health measure in economic evaluation studies (see section 1.3.3). Although cost-effectiveness may be a crucial factor in priority-setting, it is certainly not the only factor that is taken into consideration (Laxminarayan et al., 2006; Musgrove and Fox-Rushby, 2006). For example, our cost-effectiveness measurement fails to directly address equity (e.g. more costly interventions might be a better investment when it aims to reach the poor, rural areas) and non-health benefits (e.g. educational progress, poverty reduction, improved productivity; see section 5.3)[57].

Fifth, the analyses regarding the Shanxi consumer survey in chapter 3 are based on specific parts of the dataset. For example, by including objective GM knowledge, only those who stated to know what GM food is, could be entered in the analysis. This limitation makes it not possible to compare the subjective and objective GM knowledge as determinants of FBR acceptance. Although some studies found more predicting power in subjective knowledge as a determinant of acceptance and WTP (Moon and Balasubramanian, 2001; House et al., 2004; Han and Harrison, 2006), this could not be verified in this thesis.

Furthermore, the research on acceptance of negative rice attributes is based on exploratory statistical techniques. There are more advanced techniques to analyze consumer preferences for different

[57] Two other indicators to decide whether health interventions should be (partly) funded or subsidized, i.e. the public attitudes and the demand for an intervention (Musgrove, 1999; WHO, 2000), are addressed in Chapter 3 and 4, respectively.

(combinations of) product attributes simultaneously (e.g. conjoint analysis), or to study the impact of sensory characteristics and appearance (e.g. taste panels).

Sixth, notwithstanding the comparison between FBR and MBR in the CEA, or between FBR and folic acid supplements in the experimental auctions, I did not include other folate interventions in both studies. The main reasons are a lack of available data (e.g. characteristics and costs of the national folic acid supplementation program or data on folate biofortification of wheat), practical feasibility to include a folate intervention (e.g. auctioning biofortification and folic acid fortification requires one to explain the difference between folate and folic acid, which is difficult in Chinese language), and the relevance of the intervention (e.g. promoting folate-rich foods in poor regions). As a consequence, I did not fully address the need to incorporate the main health interventions into a CEA (WHO, 2000; Lopez et al., 2006). Moreover, the effect of adding an improved agronomic trait in order to evaluate and compare the potential of combining 1$^{st}$ and 2$^{nd}$ generation GM crops was not investigated.

Seventh and final, the CEA is highly dependent on secondary data sources (e.g. nutritional data, functional outcomes), assumptions (e.g. dose-response relationship and coverage rates) and cost estimates, which may have influenced the results. As Schneider (2001) pointed out, the extensive data requirements related to the DALY framework makes it difficult to conduct health impact studies where they are most needed, i.e. in developing areas. Gathering cost data in developing countries, for example, is considered extremely challenging (Laxminarayan et al., 2006; Musgrove and Fox-Rushby, 2006). However, the assumptions and data constraints are more likely to result in an underestimation instead of an overestimation of the potential health benefits. With respect to FBR, this is mainly because not all folate related outcomes are included (e.g. births with multiple NTDs and non-reported births), and only women of childbearing age are considered as the target group of FBR consumption. For example, including other functional outcomes than NTDs, such as anemia, would have increased the cost-effectiveness of FBR in China. Regarding MBR, health interactions of multi-biofortification are assumed to be absent and conservative attribution levels are used (e.g. the attribution of Vitamin A to childhood mortality).

## 6.4. *Directions for future research*

In this section, I address various pathways to conduct research in order to improve, extend or go beyond the findings of this thesis. In most cases, future research is recommended to overcome the above mentioned limitations. Therefore, some research needs are already tackled in the previous section, e.g. comparison of subjective and objective GM knowledge.

Firstly, it is recommended to shift or broaden the focus in order to compare and validate the generalizability of the results that were obtained for Shanxi Province. This could be done by investigating consumer acceptance and WTP for FBR in other high-risk regions. In the health impact analysis, I compared the situation in Shanxi with the Balrampur District in India. Although our results are in line with other GM food consumer studies in China, it would be worthwhile to examine whether different consumer reactions could be observed in regions where income and rice consumption levels are higher, and folate deficiency rates are lower, such as in urban areas of Southern China. This might also help to set a regional coverage rate in the health impact study.

Secondly, economic evaluations should ideally be made by comparing the burden of diseases (Lopez et al., 2006) and the outcomes and costs of all available health interventions (WHO, 2000). Therefore, to fully evaluate the potential of FBR in China, and make optimal resource allocation decisions, information about the potential cost-effectiveness of different folate improving programs is needed. I briefly discussed the cost implications and the potential drawbacks of folic acid supplementation or fortification, but an in-depth CEA is needed to evaluate the relative cost-effectiveness of FBR among other folate interventions. For example, previous studies on vitamin A (Bertebos Foundation, 2008), zinc and iron (Ma et al., 2007) interventions have shown that the costs of biofortification are generally below other strategies, especially supplementation. Furthermore, future research should discover why folic acid supplements (in Shanxi) may not be seen as attractive product, as was shown in the experimental auctions, and how this could influence national programs on folic acid supplements.
Research is also required to analyze the cost-effectiveness of dietary diversification initiatives, as this has been rarely done (Hotz and Brown, 2004) and might be considered the most sustainable, albeit the most expensive solution. When targeting the poor consumers, however, it might be more appropriate to investigate the potential of - and incorporate - educational efforts to maintain folate concentrations when processing food products.
Another future research direction in economic evaluation is to depart from the budget that is available for micronutrient interventions or, in this case, birth defect programs, and determine the health impacts and the potential coverage that could be generated (Musgrove and Fox-Rushby, 2006). Nevertheless, comparing folate interventions would be useful to further evaluate the potential of biofortification and select the most appropriate strategy given the budgetary constraints, but cost-effectiveness should not be the only determining factor in decision-making (Lopez et al., 2006)(see also section 6.3)

Thirdly, given the future commercialization of the first GM rice crop in China (Waltz, 2010) and the first GM biofortified rice crop in the Philippines (Serapio, 2010; NCBP, 2011), future research should further explore the bottlenecks and success factors to implement FBR as an effective and efficient intervention to further alleviate the burden of folate deficiency. Therefore, it needs to be determined how FBR will be efficiently distributed, which varieties will be selected and how they will be positioned. These and other (policy) issues that need to be investigated, are tackled in section 6.5.

Regarding the evaluation of the market potential of FBR, research should go beyond the consumer by investigating the positions of other key stakeholders, such as farmers, governmental agencies and seed companies. As an agriculture-based health intervention, special attention needs to be paid to explore farmers' reaction as potential future FBR producers (Lusk and Hudson, 2004). Although the investigated farmers' acceptance in Shanxi Province has shown to be high (see chapter 3), farmers' WTP for biofortified seeds (among other seeds) needs to be assessed, e.g. through experimental auctions. Nevertheless, as many rural households in China are considered small-scale farmers, the reported consumers' WTP (e.g. valuations of female members of a farming family) might be an indication of their potential demand.

Fourthly, it would be interesting to expand the unit of analysis, i.e. GM rice with improved folate content. Given the novel character of multi-biofortification, the next step is to explore the potential acceptance of and WTP for multiple micronutritional traits. One could also determine consumer and farmer preferences of other folate biofortified staple crops, such as wheat (McIntosh et al., 2008). Other folate enriched products, such as lettuce (Nunes et al., 2009) and tomato (Diaz de la Garza et al., 2007) are less relevant to introduce in Shanxi Province and China, given the current dietary patterns of the poor.

Even more important is to combine first and second generation GM crops, such as Bt rice with high folate content, which provides an additional economic incentive to farmers through its increased yielding potential. Similar to our health impact study on MBR, the combined health and economic impacts of adding an agronomic and micronutritional trait to rice could be assessed. In China, for example, the impact of the commercialized Bt cotton (Huang et al., 2006a; Rozelle et al., 2006) and the ex-ante effects of Bt rice (Huang et al., 2005b) have been examined. Although first generation (farmer oriented) GM products are assumed to be less popular than their second generation counterparts (Frewer et al., 1997a; Lähteenmäki et al., 2002; Hossain et al., 2003; Lusk et al., 2005; O'Conner et al., 2005; Anand et al., 2007; Schnettler et al., 2008a), it needs to be determined how consumer and farmers will react to stacked GM food products, when several farmer and consumer benefits are attached.

Fifthly, regarding future consumer (and farmer) acceptance studies, it might be worthwhile to take into account additional factors, such as FBR related variables (e.g. involvement, planned pregnancy and curiosity to try), the presence of other (high quality) rice varieties, and labeling, which may further influence consumer and farmer acceptance. With respect to the study about FBR acceptance of negative rice attributes, choice modeling could be applied in order to validate and strengthen our results (see also previous section). In this respect, sensory research may be incorporated into consumer (folate) biofortification research. One could, for instance, organize a taste session as a specific round in the experimental auctions, or include it as a (hypothetical) consumption requirement. Unlike our rice auctions, other attributes, such as appearance, could have been altered and incorporated to measure their impact on consumer valuations.

Sixthly, future auction research can validate our value elicitation method by evaluating how Chinese consumers behave to other auction mechanisms. Also the impact of additional auction design characteristics could be subject of future auction research with biofortification research, such as information order effects throughout the auctions, price feedback, additional alternative folate substitutes (e.g. detaching the folic acid pills from the rice bags), various rice bag weights and different folate contents (and benefits). The way that information is provided could also be improved and further explored by using, for example, uncensored picture warnings, GM labels, a newspaper lay-out or audio-visual material, such as an informative newsflash or an interactive GM discussion round, or specific wordings (e.g. transgenic).

Seventhly, the cost-effectiveness study in chapter 5 could be improved in several ways. Primary data collection of nutrient intake and rice consumption, such as (24-hour) dietary recalls (for an example on zinc and iron, see Gibson and Ferguson, 2008), would make it possible to apply the framework to an individual household level. Some of the parameters of the DALY approach need to be included (e.g. micronutrient interactions), refined, (e.g. folate stability after processing), extended (e.g. functional outcomes), updated (e.g. NTD data), adapted to the different regions (e.g. regional coverage rates) or validated (e.g. cost estimates). But even more important is the urgent need to define the (attribution level of) functional outcomes of folate deficiency, besides NTDs.

Finally, some recommendations for future (bio)technological R&D could be formulated. Although such issues are beyond the scope of this thesis, advanced breeding efforts would allow to further evaluate the market potential by using up-to-date information of the technological characteristics of this GM crop. For instance, it is plausible that some of the investigated attributes of FBR, such as taste, folate stability and bioavailability, will be different from our expectations when crossed with certain local or stacked varieties (e.g. MBR), processed, or long-term stored. Additional laboratory tests will have to further refine and define the final product characteristics of FBR and MBR, which might influence the findings of the health impact assessment. This might open up research opportunities to examine and set up promotion activities of home processing techniques to enhance absorbable folate in food, as mentioned above. And if FBR would be approved, agricultural workshops could be then organized to increase the adoption rates of farmers and learn them how to maintain the beneficial product attributes through production and storage.

## *6.5. Issues to advance towards a successful implementation of FBR in China*

China is one of the first countries that commercially released a GM crop, namely Bt cotton (Falck-Zepeda, 2010). The widely adopted Bt cotton in China, with 7.5 million small farmers growing this insect-resistant crop, is considered one of the most important achievements in the history of GM production. The cost reductions, higher yields and lower rice prices made Bt-cotton a successful pro-farmer and pro-poor strategy (Huang et al., 2002; Raney, 2006; Rozelle et al., 2006). Despite its key role in the development and commercial introduction of transgenic plant varieties, China has not yet commercialized a transgenic food crop for consumption (Campos-Bowers and Wittenmyer, 2007). This 'commercialization slowdown' took place on a global scale (Paarlberg, 2002), by which any optimistic expectation towards a fast, successful implementation of FBR based on this PhD dissertation should take into account the broad context.

Below, I will present some key barriers and challenges that need to be taken into account when aiming to successfully introduce FBR in China. Due to the focus on the regulation and practical implementation of FBR, which is beyond the scope of this PhD dissertation, this section also refers to the experiences with Golden Rice, i.e. the most advanced biofortified rice crop (HUMBO, 2011b); Bt cotton, a success story of GM crop production in China (Raney, 2006); and the Chinese approval of Bt rice, i.e. probably the first commercialized GM rice crop (Waltz, 2010). Thereby, reference is also made to the stakeholder interviews that were held in China (see section 1.6.1). Although some commercialization bottlenecks are closely related to, or grounded in the global debate on the benefits and risks of GM food, I explicitly avoid entering this discussion[58].

### 6.5.1. Regulatory and IPR issues

Due to the GM technology in transgenic biofortified food, (political) approval necessarily implies to comply with the regulatory requirements and deals with intellectual property management.

*Regulatory process*

In China, biosafety regulations on agricultural GM products are defined and implemented by the Chinese Ministry of Agriculture (MoA) and its Office of Agricultural Genetic Engineering Biosafety Administration (OGEBA) in particular (Pray et al., 2006). The National Agricultural GMO Biosafety Committee is in charge of the risk assessment evaluation, in close consultation with its Provincial Management Offices. The Ministry of Health (MoH) is involved to ensure the food safety of biotechnology products.

In general, GM food regulators are interested in the characterization and hazard assessment of all elements that are associated with the developed GM food, including the parent crop, the donor, the delivery process, the gene products (e.g. allergenicity, toxicity) and the safety of the new GM crop

[58] The current debate on transgenic biofortification mainly focuses on Golden Rice. For a pro-GR viewpoint of the inventor, see Potrykus (2010a) or Qaim (2010). For an anti-GR viewpoint, see Greenpeace (2010).

(Barry, 2008). The Chinese regulatory process requires applicants to pay specific attention to biodiversity risks, such as cross-pollination and the preservation of locally grown crops (Campos-Bowers and Wittenmyer, 2007; Wang and Johnston, 2007a).

Apart from its financial implications, the regulation of GM food is seen as the main reason for the 10-year delay in the commercialization of Golden Rice (Powell, 2007; Potrykus, 2010b). According to Ingo Potrykus (2008), one of the founding fathers[59], GR would have been commercialized in 2002 if it was not genetically modified. The preparation of the GR regulatory dossier took seven years. In Asia alone, the annual economic loss of the delayed adoption of GR was estimated at about $15.6 billion (Anderson et al., 2005). Whether the stringent regulation procedures are justified or not (for a discussion, see Potrykus, 2010a), this further underpins the involvement of private companies in this phase of biofortification R&D (Tang et al., 2009). If one would aim to deploy a multi-biofortified crop with several transgenic traits, this regulatory process would become even more complex (Chunyi Zhang, CAAS, personal communication, 18-04-2011; see also section 5.4.3).
Despite the fact that China has one of the most advanced biosafety regulatory and monitoring systems throughout Asia, there is still a need to improve efficiency and transparency of evaluation and approval procedures (Huang et al., 2008). This could speed up and improve the adoption of GM technology (Falck-Zepeda, 2010). The weaknesses of the Chinese monitoring system became clear when the introduction of transgenic Bt cotton resulted in an enormous amount of illegal, less efficient varieties (Huang et al., 2005a). To cope with such issues, it is recommended to organize frequent interactions with the regulator (Barry, 2008).

*IPR issues*
In the case of GR, for example, about 70 patents are owned by approximately 30 private and public institutions (Brewster et al., 2005). Due to the involvement of the private sector, freedom to operate could easily be achieved without delaying the progress (Potrykus, 2008; Brooks, 2010; Potrykus, 2010a). With respect to China, a lot of progress has been made to protect Intellectual Property Rights (IPR), but its IPR framework is still criticized for a lack of coordination and enforcement (Campos-Bowers and Wittenmyer, 2007). Patent registration likely needs to be reformed and centralized in order to improve IPR-protection for biofortified crops (Campos-Bowers and Wittenmyer, 2007; Pray and Huang, 2007). This did not hold back the growing interest of companies to make this technology available in China (Paarlberg, 2002). An excellent example is the large-scale piracy of Monsanto’s Bt cotton, which demonstrates not only China’s openness towards transgenic crops, but also the IPR weaknesses due to insufficient monitoring and protection of IPRs (Campos-Bowers and Wittenmyer, 2007).

When dealing with intellectual property rights for FBR as a pro-poor, pro-rural health strategy, the introduction of humanitarian licenses for adoption in developing countries deserves attention. The inventors of GR, for example, licensed their patents through a spin-off company to Syngenta under a

[59] Together with Adrian Dubock, Gary Toenniessen and its co-inventor, Peter Beyer (Brooks, 2010). All of them are members of the GR Humanitarian Board (2011a), which is chaired by Ingo Potrykus.

license agreement with humanitarian access to innovation, also known as a Humanitarian Use Technology Transfer (HUTT)(Lybbert, 2002; Brewster et al., 2005). This institutional arrangement allows poor farmers (i.e. farmers who earn less than US$ 10 000 per year) from developing countries to use GR royalty-free. It also creates a free transfer of the rights to public research institutions in the targeted countries through (sub)licenses (Kowalski and Kryder, 2002; Dawe and Unnevehr, 2007). Currently, licenses have been granted via IRRI to research institutes in five major rice producing countries, namely Philippines, India, Vietnam, Indonesia, and China (Brooks, 2010). Syngenta can then claim their IP rights on GR in cases where farmers are above the threshold, by which the latter should pay royalties to grow GR. Private companies involved in such an arrangement will forgo substantial IP revenues, but might improve the acceptance and coverage rate where GR is needed the most. This is one of the reasons why Monsanto largely relinquished their IPRs for the freely pollinated Bt cotton in China (Paarlberg, 2002). Other strategies to retain the commercial rights include the introduction of hybrid GM varieties (Campos-Bowers and Wittenmyer, 2007), e.g. Monsanto's cotton in India. As China is the world largest hybrid rice producer, with 17 million hectares (60 %) of its rice area planted with hybrid varieties, i.e. 85 % of the global hybrid rice production (Barcley, 2010 ), introducing hybrid biofortified crops might be more successfully and quickly adopted than in other countries (Gouse et al., 2005).

The Golden Rice example demonstrates the potential to donate the technology rights for humanitarian use to stimulate research and commercialization of biofortified rice in developing countries. As a consequence, organizations or small-scale farmers can freely distribute or replant seeds (but not export) without being required to buy new seeds each year (Dawe and Unnevehr, 2007). However, the practical implementation of such biofortification licenses in agriculture is not fully explored (De Groote et al., 2008). One example of successful humanitarian sharing of IPR in developing countries is found in the pharmaceutical sector, i.e. AIDS inhibitors in Africa (Lybbert, 2002), which led to lower product prices and increased accessibility.

*Private-Public partnership*

Due to the complex regulatory and IPR process for GM products, additional financial support is likely to be gathered beyond the proof-of-concept to develop, test and refine the product according to the needs. A donor funded public-private partnership is typically set up for transgenic biofortification (Stein, 2006), such as a collaboration with Syngenta to advance the progress of Golden Rice (Potrykus, 2008, 2010b). With respect to China, the typically strong protective and anti-multinational attitudes might be an additional bottleneck when private investments are required to implement biofortified crops (Pray et al., 2006).

### 6.5.2. Implementation issues

In addition to the market potential, as investigated in this thesis, a successful commercialization of FBR will be determined by the selected varieties, how well they will be adopted by farmers, and how the stakeholders will support and be involved in the implementation.

*Variety selection*

The selection of the transgenic line and the rice variety will not only influence the regulatory process, but also consumer and farmer acceptance, and thus political support. It will be important that the selected FBR event are tailored to local varieties in order to reach the poorest consumers in the rural regions, similar to the GR events that have been backcrossed into the Indian (Indica) varieties (Virk, 2008). South-East Asia, and China in particular, is characterized by a heterogeneous, segmented market for rice varieties, grown by various substance farmers on numerous small-scale farms. Since 1960s, more than 4 000 rice varieties (inbred and hybrid) were grown in China (IRRI World Rice Statistics, 2011a). In general, the short-grained, sticky Japonica rice is the dominant rice variety in Northern China, while the long-grained, non-sticky Indica rice is mainly planted in Southern China (Alavi et al., 2008). These varieties differ in terms of whiteness, sweetness, stickiness, and hardness (Yau and Huang, 1996). As Brooks (2010, p.5) stated: *"[rice] is complicated by a contradiction: it is both the largest and smallest of cereals – large in terms of aggregate production and consumption, but small scale and highly diverse in practice*". One needs to take into account these differences and their impacts on the product characteristics of FBR when aiming to address the various regions of China.

*Stakeholder approach*

As the large-scale adoption of transgenic Bt-cotton in China shows, a well-adapted and integrated strategy is a prerequisite for success (Raney, 2006). With respect to biofortification, the involvement of stakeholders should go beyond the agricultural research community (Brooks, 2010), as it is also a nutrition and health intervention. It should address the bottlenecks of nutrition programs, by ensuring accessibility and availability (ADB, 2004b); adequately allocating resources, installing an efficient monitoring and supervising system, defining distribution strategies and a social marketing strategy (Vijayaraghavan, 2002); and integrating key stakeholders, such as the Ministry of Health (Alavi et al., 2008; Brooks, 2010).

The most important stakeholders involved in the introduction of FBR, besides the consumers, are the government and its relevant ministries, private companies, farmers, millers, vendors and seed companies (Meenakshi, 2008b). Their position towards biofortification could further influence public acceptance (Kalaitzandonakes and Bijman, 2003; Gonzalez et al., 2011). It will also be important to interact with NGOs (Aerni and Rieder, 2000); aid agencies (Laxminarayan et al., 2006); advocates of the key target groups (Dawe and Unnevehr, 2007), e.g. WHO and consumer organizations; and the media, which are largely controlled by the Chinese government. The need to involve the scientific community in the ex-ante evaluation studies, as argued by Hotz and Brown (2004), is addressed in this PhD dissertation. Future research should examine the reactions of all stakeholders in order to evaluate the success and impact of adopting biofortified food (Dawe and Unnevehr, 2007), such as FBR.

*Incentives for farmers*

Although this PhD dissertation demonstrates that farmers (and their families) might be supportive of GM rice, additional incentives could be undertaken to ensure that Chinese farmers will be motivated to produce the folate enriched variety. The aforementioned humanitarian license for poor, subsistence farmers is one example. Another option is to cross the folate trait into a variety that has a high yielding potential or is better resistant to diseases, which is done for GR in the Philippines (Barry, 2008). The combination of a nutritional and an agronomic trait in staple food crops is considered to be more than the sum of parts. Besides its potential to reduce costs through synergies, these crops improve farmer's health directly through consumption, and indirectly through increased yields, improved productivity and higher income (Juma et al., 2007). Together with the investigated multi-biofortification of rice, which could further increase consumer demand and thus attract farmers, crossing the folate trait into a 1$^{st}$ generation GM crop are considered valuable pathways of the future development of transgenic biofortified crops. Mark Chong (2003, p. 971) puts it as follows: *"[GM biofortified crops] must demonstrate yields or cost savings equivalent to (or higher than) those of the best currently grown non-transgenic varieties if it is to be successfully introduced and adopted by rice farmers […]".*
Furthermore, farmers could be convinced to produce a GM rice product when they could sell it at a higher price (Dawe and Unnevehr, 2007; Meenakshi, 2008b). In the Philippines, for instance, a premium rice variety was used to deploy GR (Brooks, 2010). The downside of such a strategy is its contradiction with the pro-poor mission of biofortification. An alternative solution to improve the adoption of poor farmers is to provide governmental subsidized credit to purchase biofortified seeds, as the case of Bt cotton in South Africa has shown (Gouse et al., 2005).

*Seed companies and seed distribution*

When biofortified seeds would be available, they should be incorporated into existing marketing and distribution systems to ensure that the crop will be produced and consumed (Bekaert et al., 2008; Dubock, 2008). Since 2000, private companies are allowed to enter the Chinese seed market and sell their seeds all over China, next to the initial state-owned seed producers (Huang et al., 2005a). This led to a complex situation of several large distribution and retail networks alongside thousands of small, local seed distributers. As a consequence, Chinese farmers are still facing difficulties to discover attractive rice varieties (Falck-Zepeda, 2010), which supports the need for a successful distribution strategy for biofortified crops. One option could be to subsidize the production and/or consumption through public distribution systems in order to facilitate farmer adoption and consumption in poor areas (Dawe and Unnevehr, 2007). With respect to iron and folic acid fortified food, which is only available in the largest cities of China, a collaboration with Carrefour China is set up to sell fortified foods in a separate section of the supermarket (Wang Bo, CDC Food Fortification Office, personal communication, 19-04-2011).

Currently, international biotech companies are only allowed to do research in China, but cannot produce or commercialize GM seeds. These restrictions reflect China's concern about food security and self-sufficiency. Before opening the market to multinationals, which is expected in the next decade at the earliest, the Chinese government aims to protect the local companies and increase their competitiveness. With respect to GM rice in particular, the MoA still needs to revise the regulations of GM cotton and formulate guidelines for GM rice seed distribution (Biotechnology industry representative, personal communication, 19-04-2011).

*Governmental support and political climate*

Of course, the support and involvement of the government and its related ministries, e.g. MoA, MoH and Ministry of Science and Technology (MOST), is a crucial success factor to introduce agricultural innovation, like GM food, as a health intervention (Hotz and Brown, 2004; Dawe and Unnevehr, 2007; Barry, 2008; Faillace et al., 2008; Potrykus, 2010a). Governments could facilitate or impede the adoption of biotechnology, and support or discourage (agricultural) health interventions, through the implementation of different policy instruments, such as R&D expenditures, taxes and subsidies, regulation and legislation, and dissemination activities (Laxminarayan et al., 2006). Whereas Chinese governmental R&D expenditures and regulation procedures in the field of GM food and biofortified crops were and will be crucial for the (facilitation of the) approval of FBR (see section 2.5), dissemination and subsidy policy will become important if this GM rice variant will actually be brought on the market.

In China, food nutrition issues are not coordinated by a specific ministry (Alavi et al., 2008). Although most governmental agencies support transgenic (biofortified) crops (Campos-Bowers and Wittenmyer, 2007), except for the State Environmental Protection Administration (SEPA)(Pray and Huang, 2007), political acceptance could be hampered by the political climate, both at national or international level.

The insect-resistant Bt rice is an illustrative example of the Chinese context. It was already approved in 2005, but needed to repeat several regulatory procedures to test the allegations of the anti-GM sources (Stone, 2011). Due to the reactions from Greenpeace and Utopia after the announcement of the safety certificates for this transgenic rice crop in 2009, the Ministry of Agriculture is currently putting the commercialization of Bt rice on-hold. According to Pray and Huang (2007), this hesitance and delay is mainly due to the importance of rice as a staple, food safety concerns, a lack of knowledge on consumer acceptance and the absence of stem borer problems, or because there is no urgent need to create rice surpluses (see for instance, Gong, 2011). If one or more of these issues would change, MoA would probably proceed the commercialization, notwithstanding the opposition (Pray and Huang, 2007). But until then, transgenic biofortified foods may be struggling to pass the biosafety regulatory process and obtain political approval. Not to mention multi-biofortified foods. More recent expert interviews stress that the anti-GM backlash after the Bt rice approval - which is reinforced by the aforementioned lack of transparency in the regulatory and approval process - is probably the most important factor that will hinder the final approval (Chunyi Zhang, CAAS; Biotechnology industry representative, personal communication, respectively 18-04-2011 and 19-04-

2011). Thus, the Chinese government appears to be influenced by the (growing) resistance, even though GM food acceptance rates are still substantially high (as shown in this thesis), a finding which is in line with Kalaitzandonakes and Bijman (2003). Nevertheless, rather than withdrawing the certificates, the Chinese MoA is currently funding initiatives to increase the transparency of GM risk evaluation (ca. ¥ 10 million or US$ 1.5 million) and to improve GM communication (ca. ¥ 2.6 million or US$ 0.4 million) (Jiao, 2011). Although GM rice received far more public opposition (Zi, 2005) than other approved GM crops, such as Bt cotton (Pray and Huang, 2007) or the imported GM soybean oil (Lin et al., 2006), experts estimate that this GM rice variant will be released within 4 (Juan and Zhu, 2010) to 10 years (Stone, 2011).

The impact of international events can be illustrated by the US Starlink™ Bt maize incident in 2000[60], after which China has put their GM crop releases temporary on-hold (Paarlberg, 2002). Other examples throughout Chinese history are extensively described by Pray and Huang (2007). Closely related, Paarlberg (2002) states that the risk of losing important export markets in the GM-reluctant developed world, such as Europe, is one of the main reasons for the delayed and postponed GM crop production in developing countries. With respect to GM rice, however, trade issues such as potential trade bans are expected to have a marginal effect on China, due to its low international rice exports (Huang et al., 2004). Compared to the largest rice exporters, Thailand (31.1 %) and Vietnam (17.9 %), China's share in the global exports is about 4.5 % (IRRI World Rice Statistics, 2011b). Thus, a period of political prudence in China might be more related to the opposition within the country, and the potential, global impact of approving the first GM staple crop. Of course, there might be also pressure from (neighboring) rice exporting countries to avoid cross-border contamination (Biotechnology industry representative, personal communication, 19-04-2011).

Although the importance of the safety approval does not need to be underestimated, Bt rice still needs to obtain 4 other licenses, including a business license, a GM variety registration, a GM seed production and a GM seed operation license (Chunyi Zhang, CAAS; Biotechnology industry representative, personal communication, respectively 18-04-2011 and 19-04-2011). Once approved, some argue that it would be a catalyst for the release of future GM staple crops (James, 2009a). As a consequence, developing countries might follow to stay competitive, while developed countries, such as US and Canada, may see China as a potential export market (Huang et al., 2004; Huang et al., 2005b).

Table 55 gives an estimation on how the main stakeholders are expected to react towards FBR as a transgenic (biofortified) crop in China. Government agencies, except for SEPA, are generally supporters, while NGOs are the main opponents of transgenic (biofortified) crops in China. As mentioned above, foreign biotechnology companies, seed producers and farmers are initially in favor, but could be further attracted by ensuring a sufficient coverage rate of FBR. When looking at farmers in particular, the lack of a mobilized political organization could further help to deploy the adoption of GM rice (Pray and Huang, 2007).

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[60] In September 2000, US Starlink™ maize was detected in the food system, although it was not approved for human consumption, leading to allergenic reactions and a recall of more than 300 products and worldwide repercussions for the trade of GM crops (Sheumack , 2003).

Table 55 The position of main stakeholders regarding FBR in China.

| Stakeholder | Position towards GM food and transgenic biofortification |
|---|---|
| **Government** | |
| MOST | Pro-GM; continues to invest in transgenic crop R&D |
| MoA | Initially in favor, but might be affected by the international political climate or public resistance. |
| SEPA | Most opposed Chinese Ministry; collaborates with Greenpeace. |
| **Foreign companies** | Interested in entering the Chinese market, especially if the IPR framework would be improved and China would further open their markets. |
| **Seed companies** | Both government-owned and private seed companies are interested, if the demand is sufficient or when the distribution to the poor would be organized by government. |
| **NGO's,** e.g. Greenpeace, Utopia | Against GM adoption, could influence political actions and consumers. |
| **Farmers** | Generally in favor (see chapter 3 and 4); could be attracted through incentives, e.g. improved agronomic traits, royalty-free production, or a price premium. |
| **Consumers** | Generally in favor (see chapter 3 and 4) |

MoA, Ministry of Agriculture; MOST, Ministry of Science and Technology; NGO, Non-Governmental Organization; SEPA, State Environmental Protection Administration
*Source*: Pray and Huang (2007), Campos-Bowers and Wittenmyer (2007) and an expert interview (Biotechnology industry representative, personal communication, 19-04-2011).

*GM food labeling*

Since 2001, China requires GM-labels for food products based on GM technology, as outlined by the Chinese State Council (Campos-Bowers and Wittenmyer, 2007). Besides MoA, MoH and MOST, all trade related ministries support transgenic food labeling (Campos-Bowers and Wittenmyer, 2007). Their mandatory labeling policy is the first to apply a 0 % level of detection, i.e. a zero tolerance approach. Others require labeling if 0.9 % (EU) to 5 % (e.g. Philippines) of the (imported) product contains GM material (Jia, 2003; Gruère and Rao, 2007). Although the Chinese threshold is officially communicated, it is less likely to be implemented in practice (Gruère and Rao, 2007). Due to the GM technology in FBR, labeling would be required in China. A GM-label for FBR could be beneficial as it could increase consumer confidence through informed food choices, i.e. the 'right-to-know' (Tegene et al., 2003). It also allows one to position a GM biofortified crop in a segmented market, especially when external rice attributes would not differ from regular rice. One of the downsides of labeling is the associated cost (market segregation, identity preservation), which is expected to increase the retail price by 10 % (Tegene et al., 2003; Gruère and Rao, 2007). This is especially valid for China, as such costs are negatively associated with the targeted detection level (Qaim, 2009).

Besides labeling, one could also consider the introduction of an attractive brand name for the biofortified crop, like 'Golden Rice' for vitamin A enriched rice, in order to favor its image and avoid its biotechnological connotation (Brooks, 2010), which is expected to negatively influence acceptance (Novotorova and Mazzocco, 2009).

# *Summary*

Despite the increasing efforts to alleviate the burden of micronutrient malnutrition in the world, over two billion people are facing a chronic lack of essential vitamins and minerals, especially children and pregnant women from less developed countries, who mainly rely on staple crops, such as rice, maize or potatoes. Biofortification, the enhancement of the micronutrient content of staple crops through conventional or transgenic technology, is more and more put forward as an alternative solution to reach poor, rural areas where the currently available micronutrient interventions, such as supplementation, industrial fortification and dietary diversification, are less successful or appropriate.
Unlike conventional biofortification, transgenic biofortified crops are currently not available at the market place. In spite of the direct health benefits associated with such 2$^{nd}$ generation genetically modified (GM) crops, the controversial nature surrounding the use of biotechnology in food remains a subject of discussion, which impedes its commercialization.

The overall objective of this thesis has been defined to contribute to a better understanding of the market potential of biofortified crops, in particular of folate biofortified rice (FBR). This GM biofortified rice crop was recently developed in order to tackle folate (or vitamin $B_9$) deficiency and its adverse health outcomes, such as an increased risk of delivering a baby with a neural-tube defect (NTD; e.g. spina bifida).
This PhD dissertation is a compilation of research papers that evaluates ex-ante the market potential of FBR in China and in particular, Shanxi Province, a poor, rural region in Northern China. Folate deficiency is an important public health problem in China, with about 258 million people being folate deficient. Especially in Shanxi Province, which is characterized by one of the highest NTD prevalence rates in the world, the need to increase folate intake levels is obvious. Given China's position as the world leader in rice production and one of the key players in GM rice research, commercialization of folate biofortification of the world's major staple crop might be considered an alternative solution to the high prevalence of NTDs and the low intake of folic acid pills.

The market potential of FBR is investigated through three lines of inquiry. While the first and second line analyze consumer acceptance and willingness-to-pay (WTP) in Shanxi Province, the third evaluates the regional health impact and the cost-effectiveness of its introduction in China. Along these three main lines of inquiry, different research questions are formulated and tackled, building upon theory, empirical evidence and/or knowledge gaps. Data is collected within the frame of the Special Research Fund – Concerted Research Action (2004 - 2009) project, entitled "*Enhancement of folate content in rice: an analytical-molecular and economic study*", based on primary and secondary sources. Insights are obtained through different exploratory and conclusive research methods. A consumer survey with 944 Shanxi rice consumers was conducted in order to examine the acceptance of FBR. The study on WTP was largely build upon fourteen experimental auctions with 252 Shanxi female rice consumers of childbearing age. And to assess the potential health impacts and cost-effectiveness of FBR, the Disability-Adjusted Life Years (DALY) framework was applied, using primary and secondary data.

The results showed that consumers in Shanxi Province are generally accepting (62.2 %) this GM rice variant with higher folate content, and provides evidence that GM products with consumer benefits are positively embraced by consumers in developing regions. Through multinomial logistic regression, objective GM knowledge, perceptions of the GM risks and benefits, and socio-demographic indicators, like gender, age, education and farmer status, are found to be important determinants of FBR acceptance. When also taking into account consumers' acquisition of GM food information, market segmentation identified an enthusiastic (14.2 %), a cautious (44.6 %) and an opposing market segment (41.2 %). An estimation of the effects of negative rice attribute changes on FBR acceptance provided insight in the critical success factors to select the rice varieties wherein the folate trait could be inserted, such as taste or environmental impacts.

Evidence from experimental auctions with women of childbearing age, split up between student and non-student auctions, lend support for the large potential of biofortified staple crops in high-risk regions. Female Shanxi rice consumers are prepared to pay a premium of ¥ 1.73 or 33.7 %, which corresponds with switching to a rice variety that is one price/quality level higher than regular rice. Offering a GM-free folate substitute did not reveal significant differences in bidding behavior. Besides a significant target group effect, by which students are less likely to buy and pay more for FBR, WTP is mainly determined by consumers' GM food acceptance and objective knowledge. Despite lower bids after providing information about the GM technology, the perceived benefits seem to be high enough to compensate for potential negative reactions to GM food. Nevertheless, when conflicting GM information is provided, negative outweighs positive information.

The health evaluation study further supports folate biofortification of rice as a valuable micronutrient intervention to drastically increase folate intake and reduce the prevalence of NTDs in China. Implementing rice with a folate content of 1 200 µg per 100 g rice in China would increase the total daily folate intake for Chinese women of childbearing age to 837 µg, which is more than two times the recommended nutrient intake level. As a consequence, between 62 863 DALYs and 188 508 DALYs could be saved by implementing biofortified rice. Although rice consumption is lower in northern areas, these regions account for the biggest health impact of biofortification in China. As expected, regions with high NTD prevalence rates, such as Shanxi Province, will benefit most from folate biofortification of rice. Moreover, FBR could be introduced as a highly cost-effective health intervention to reduce the burden of folate deficiency, with an estimated cost between US$ 21.4 and US$ 64.2 per DALY saved.

This PhD thesis provides an important basis for stakeholders in the fields of GM (biofortified) food research, development and commercialization, health prevention and intervention planning, e.g. micronutrient interventions and birth defect programs. It will stimulate the academic debate and the public awareness regarding micronutrient malnutrition, including folate deficiency and biofortification as a self-targeted means to alleviate its burden.

## *Samenvatting*

Ondanks de vele inspanningen om de globale ziektelast van micronutritionele ondervoeding aan te pakken, kampen meer dan 2 miljard mensen nog steeds met een chronisch gebrek aan essentiële vitamines en mineralen, voornamelijk kinderen en zwangere vrouwen uit minder ontwikkelde landen, wiens voedingspatroon hoofdzakelijk uit basisvoedsel zoals rijs, maïs en aardappelen bestaat. Biofortificatie, het verhogen van het natuurlijk, micronutritioneel gehalte van basisvoedsel door middel van conventionele of op genetische modificatie gebaseerde teelttechnieken wordt meer en meer naar voren geschoven als een alternatieve oplossing om arme, rurale gebieden te bereiken, waar de huidige micronutritionele interventies, zoals supplementatie, industriële fortificatie en diversificatie van het voedingspatroon, minder succesvol of haalbaar zijn. In tegenstelling tot de conventionele biofortificatie, zijn transgeen verrijkte gewassen vandaag de dag niet beschikbaar op de markt. Ondanks de directe gezondheidsvoordelen van dergelijke genetisch gemodificeerde (GM) gewassen van de 2$^{e}$ generatie, blijft de controverse omtrent het gebruik van biotechnologie in voeding ter discussie staan, die de commercialisering ervan in de weg staat.

De algemene doelstelling van deze thesis wordt gedefinieerd als het verkrijgen van een beter inzicht in het marktpotentieel van gebiofortificeerde gewassen en folaat verrijkte rijst (FBR) in het bijzonder. Dit GM rijstgewas werd recent ontwikkeld met het oog op het verminderen van negatieve gezondheidsgevolgen van een folaat- of vitamine-$B_9$-tekort, waaronder het verhoogd risico om een kind met een neurale buisafwijking (NTD; e.g. spina bidifa) op de wereld te zetten.
Deze doctoraatsthesis compileert een reeks onderzoekspapers omtrent de ex-ante evaluatie van het marktpotentieel van folaat verrijkte rijst in China en in de provincie Shanxi, een arme, rurale regio ten noorden van China in het bijzonder. Het gebrek aan folaat in China is een belangrijk gezondheidsprobleem, met ongeveer 258 miljoen mensen die onvoldoende folaat opnemen. China is de wereldleider in rijstproductie en -consumptie. Bovendien wordt de Chinese overheid beschouwd als een voorstander van GM voeding en (GM) gebiofortificeerde gewassen. Hierdoor is China een van de belangrijkste spelers in de productie van GM gewassen en kende het recent een certificaat voor bioveiligheid toe aan Bt rijst, dat in de toekomst hoogstwaarschijnlijk het eerste gecommercialiseerde GM rijstgewas zal zijn.
Voornamelijk in Shanxi Province, waar de prevalentie van NTDs tot één van de hoogste ter wereld behoort, ligt de nood om het folaatgehalte te verhogen voor de hand. Gegeven de positie van China als wereldleider in rijstproductie en als één van de hoofdspelers in GM rijst onderzoek, zou het commercialiseren van het folaat verijken van het meest geconsumeerde gewas ter wereld beschouwd kunnen worden als een alternatieve oplossing voor de hoge prevalentie van NTDs en de lage inname van foliumzuurpillen.

Het marktpotentieel van folaat verrijkte rijst wordt onderzocht volgens drie onderzoekslijnen. Terwijl de eerste en tweede lijn de acceptatie en bereidheid tot betalen van consumenten onderzoekt in Shanxi, evalueert de derde onderzoekslijn de regionale gezondheidsimpact en kosteneffectiviteit van de introductie van deze rijst in China.

In het licht van deze onderzoekslijnen werden op basis van theorieën, empirisch bewijs of bepaalde kennishiaten verschillende onderzoeksvragen opgesteld en beantwoord. De gegevens werden verzameld in het kader van het Bijzonder Onderzoeksfonds – Geconcerteerde Onderzoeksactiviteiten (2004-2009) project "*Enhancement of folate content in rice: an analytical-molecular and economic study*", op basis van primaire en secundaire data. De resultaten werden verkregen door het toepassen van verschillende beschrijvende en verklarende onderzoeksmethoden. Een consumentenonderzoek met 944 rijstconsumenten uit Shanxi werd uitgevoerd om de acceptatie van de met folaat verrijkte rijst in kaart te brengen. De studie over de bereidheid tot betalen is hoofdzakelijk gebaseerd op veertien experimentele veilingen met 252 vrouwen op vruchtbare leeftijd uit Shanxi. En om de potentiële gezondheidsvoordelen en de kosteneffectiviteit te berekenen, werd de (voor beperkingen corrigerende) levensjaren (DALY) benadering toegepast, waarbij zowel primaire als secundaire data in het model ingevoerd werd.

De resultaten tonen aan dat consumenten uit de Chinese provincie Shanxi deze GM rijstvariant met een verhoogd folaatgehalte over het algemeen aanvaarden (62.2 %), wat het bewijs vormt dat GM producten met consumentenvoordelen warm onthaald worden door consumenten uit ontwikkelingsregio's.
Door middel van multinomiale logistische regressie kwam naar voren dat zowel de objectieve kennis over GM voeding, als de percepties ten aanzien van de risico's en de voordelen verbonden aan GM, als de socio-demografische indicatoren, zoals geslacht, leeftijd, educatie en het al dan niet landbouwer zijn, in belangrijke mate de acceptatie van folaat verrijkte rijst bepalen. Wanneer ook het vergaren van informatie over GM voeding in beschouwing wordt gebracht, konden drie marktsegmenten geïdentificeerd worden: enthousiaste (14.2 %), voorzichtige (44.6 %) en weigerachtige consumenten (41.2 %). Het onderzoek naar de impact van negatief gewijzigde rijstattributen op de acceptatie van de folaatrijst bracht de kritische succesfactoren die bij het selecteren van de rijstvariëteiten waarin het folaatkenmerk kan ingebracht worden, zoals smaak of de milieu-impact, aan het licht.
De resultaten van de experimentele veilingen met vrouwen op vruchtbare leeftijd, die werden opgesplitst in veilingen met studenten en niet-studenten, ondersteunt het belangrijke potentieel van verrijkte gewassen in risicogebieden. De vrouwelijke rijstconsumenten uit Shanxi zijn bereid om een meerprijs van ¥ 1.73 of 33.7 % te betalen, wat overeenkomt met een rijstvariëteit die een prijs-kwaliteitsniveau hoger ligt dan de traditionele rijst. Het aanbieden van een niet-GM folaatsubstituut leverde geen significante verschillen op bij het veilen. Naast een significant doelgroep-effect, waarbij studenten minder geneigd zijn om (meer) te betalen voor folaat verrijkte rijst, wordt de bereidheid tot betalen voornamelijk bepaald door de acceptatie en objectieve kennis van GM voeding. Ondanks de lagere biedingen na het aanbieden van informatie over de GM-technologie, zijn de gepercipieerde voordelen hoog genoeg om de potentiële negatieve reacties ten aanzien van GM voeding op te vangen. Niettemin, wanneer zowel positieve als negatieve informatie over GM wordt aangereikt, is die laatste dominant.

De studie omtrent gezondheidsevaluatie studie biedt verder bewijs voor het potentieel van rijstbiofortificatie met folaat als een waardevolle gezondheidsinterventie. Deze interventie kan de folaatinname drastisch verhogen en de prevalentie van neurale buisafwijkingen in China verminderen. Het implementeren van rijst met een folaatgehalte van 1 200 µg per 100 g rijst in China zal de totale dagelijkse folaatinname door Chinese vrouwen op vruchtbare leeftijd doen toenemen tot 837 µg, dat is ongeveer drie keer zoveel als wat aanbevolen wordt. Als gevolg daarvan zullen er ongeveer 62 863 DALYs en 188 508 DALYs gered kunnen worden. Hoewel de rijstconsumptie in de noordelijke gebieden van China aanzienlijk lager ligt, is de gezondheidsimpact van biofortificatie er het hoogst. Zoals verwacht, zullen de regio's met de hoogste prevalentie van neurale buisafwijkingen, waaronder Shanxi, het meest baat hebben bij de folaat verrijkte rijst. Bovendien zou een dergelijke biofortificatie een zeer kosteneffectieve methode kunnen zijn om de ziektelast van folaattekorten succesvol aan te pakken, met een geschatte kost tussen US$ 21.4 en US$ 64.2 per geredde DALY.

Deze doctoraatsthesis vormt een belangrijke basis voor stakeholders in het onderzoek, de ontwikkeling en de commercialisering van GM voeding, en de planning van gezondheidsinterventies, zoals micronutritionele strategieën en programma's om geboortedefecten te verminderen. Dit alles teneinde het academisch debat te stimuleren en de publieke bekendheid van micronutritionele ondervoeding, waaronder het folaattekort, en biofortificatie als een op een doelgroep gerichte interventie om de ziektelast te verlichten.

## *Curriculum Vitae*

Hans De Steur was born in Ghent, Belgium, on June 5, 1983. He obtained a university degree in Social Sciences at the Faculty of Political and Social Sciences, Ghent University, in 2005, and an applied Master of Science degree in Complementary Studies in Economics at the Faculty of Economics and Business Administration, Ghent University, in 2006. In October 2006 he started as a doctoral researcher at the Ghent University, in Belgium. In 2007 he was involved as a scientific researcher in the promotion and research activities of the Flemish Technological Advising centre of the Vegetable Processing Industries (IWT project, VLAG). In 2008, he started working as a doctoral researcher on the socio-economic pillar of the Special Research Fund – Concerted Research Action (2004 – 2009) project, entitled "*Enhancement of folate content in rice: an analytical-molecular and economic study*" (BOF-GOA 1251204), financed by Ghent University. In April-May 2011 he took part in the IMRD (International Master in Rural Development) staff exchange program, to conduct research in Shanxi Province, with the help from Nanjing Agricultural University. He participated in many international scientific conferences and seminars with oral contributions.

**Articles in international peer-reviewed journals referenced in one of the Web of Science databanks (A1 publication)**

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# *Annex 1 Administrative areas and provinces in China, per region*


Figure 24 Administrative areas and provinces in China, per region

Source: own illustration

# Annex 2 Global burden of folate deficiency

Below the current number of DALYs lost due to folate deficiency in the world is presented (Table 56). This rough estimation is based on the number of NTD (types) that are attributable to folate deficiency, i.e. 200 000 births per year (UNICEF, 2004a, b), the global life expectancy (WHO, 2008b). Due to the lack of global estimates on the share of the different functional outcomes, these figures are derived from the composition of NTDs in different Chinese studies. China has the highest relative and absolute number of NTDs, which justifies this selection. First, based on the Chinese study of Li et al. (2006), 31.0 %, 40.1 % and 28.9 % of all NTDs are considered to be abortions, live births and stillbirths, respectively. Similar findings are found in other Chinese NTD studies (USDA, 1989; Moore et al., 1997). Second, the share of the three NTD types in the total number of NTD live births is based on findings from two country-wide Chinese (Berry et al., 1999; Liu et al., 2007) and two Shanxi studies (Li et al., 2006; Gu et al., 2007). As anencephaly is a fatal NTD type, only the average prevalence of spina bifida and encephalocele is considered, based on a share between respectively 47.5-59.3 % and 7.5-34.4 % of all NTDs. These figures are in line with studies in the United States (Feuchtbaum et al., 1999), Canada (Gucciardi et al., 2002; De Wals et al., 2007) and Ireland (FSAI, 2006). Based on the assumptions and input parameters of the DALY framework, such as the disability weights of the non-fatal NTD outcomes (Mathers et al., 1999) and the discount rate of 3 % (see section 5.2.1.1) the current, global burden of folate deficiency is assessed. The estimations indicate that worldwide, folate deficiency and folate related NTDs in particular, are responsible for an annual loss of about 4.8 million DALYs. Blencowe et al. (2010) previously estimated the burden of all NTDs at 2.3 mi DALYs, based on the global burden of congenital malformations (WHO, 2008a). Our figures demonstrate that the public health problem caused by folate deficiency could be significantly bigger than what is previously thought and show that research to improve these estimations is warranted.

Table 56 Input parameters and global burden of folate deficiency, in mi. DALYs lost per year

| Input parameters of the DALY framework | |
|---|---|
| **NTDs caused by FD** | 200 000 |
| Spina bifida | 58 644 |
| Encephalocele | 21 536 |
| Abortions | 62 000 |
| Stillbirths | 57 820 |
| **Life expectancy at birth** | 68.0 years |
| **Disability weights** | |
| Spina bifida | 0.593 |
| Encephalocele | 0.52 |
| **Discount rate** | 3 % |

| Global burden of folate deficiency | | |
|---|---|---|
| **Spina bifida** | **Encephalocele** | **YLD** |
| 1 008 462 | 324 757 | 1 333 219 |
| **Abortions** | **Stillbirths** | **YLD** |
| 1 797 941 | 1 676 725 | 3 474 665 |
| | | **TOTAL** |
| | | **4 807 884** |

DALYs, Disability-Adjusted Life Years; FD, folate deficiency; YLD, years lived in disability; YLL, years of life lost
*Note*: the different input parameters of the DALY framework are further elaborated in chapter 5.

## *Annex 3 Rice prices in China*

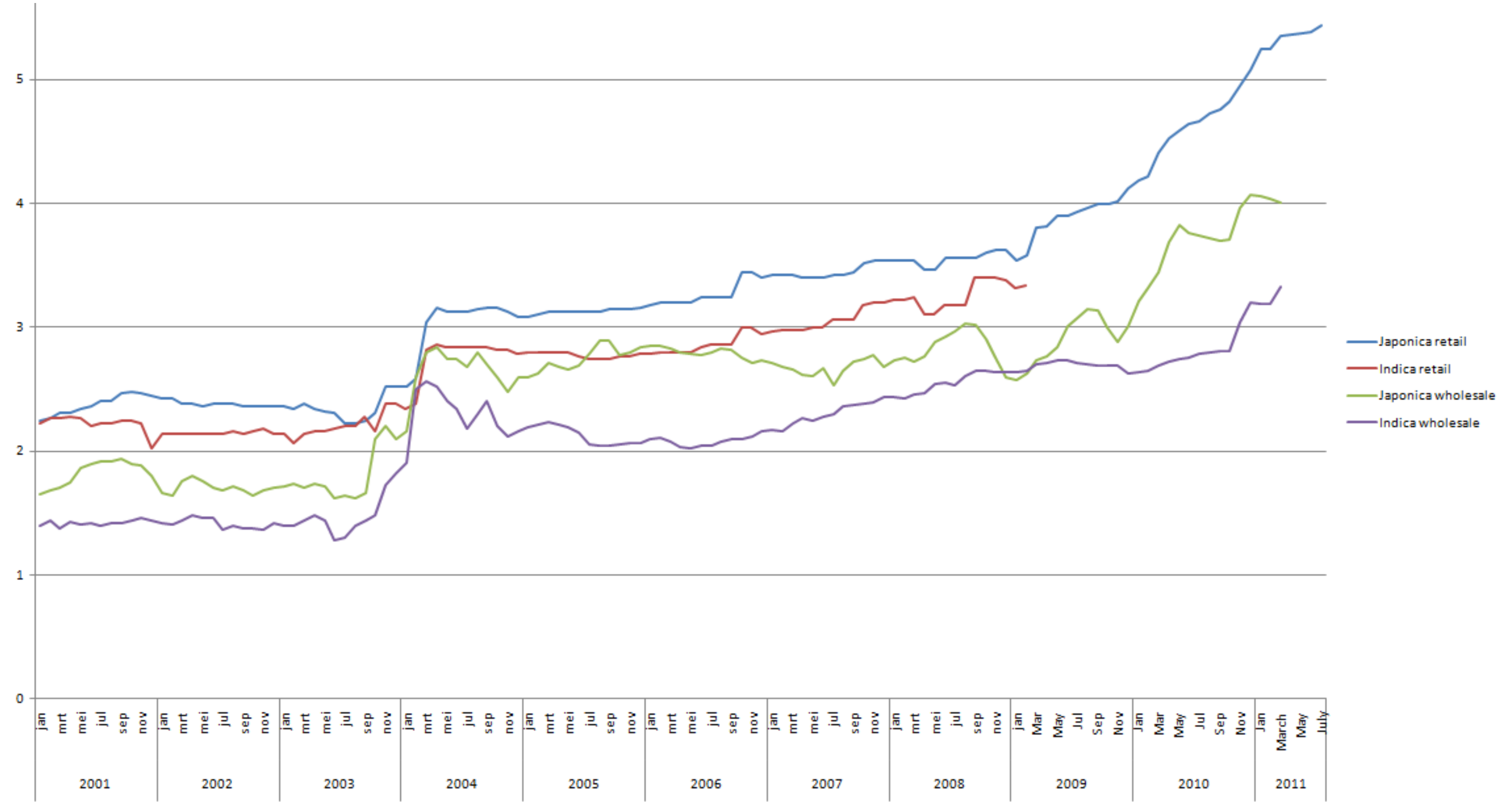


Figure 25 Wholesale and retail rice prices in China, in Yuan per kg, 2001-2011

*Source*: Own compilation, adapted from the National Bureau of Statistics of China (2011b)(Japonica retail) and data from the China National Grain and Oils Information Center (CNGOIC, 2011). Data provided by Fred Gale from the USDA Economic Research Service, Washington D.C.
*Note*: Due to data constraints, Indica retail data could not be retrieved for 2009 and later. Wholesale pricing data, initially expressed in Yuan per metric ton, refers to Jiangsu Province (Japonica) and Jiangxi Province (Indica). Shanxi Province is situated in Northern China, which mainly consumes and produces Japonica rice. The regular rice prices as mentioned in the consumer survey (see chapter 3) and the experimental auctions (see chapter 4) are based on the province specific retail prices of regular rice, but approximate the above retail figures.