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Agri-nutrition research: Revisiting the contribution of maize and wheat to human nutrition and health

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ABSTRACT

Research linking agriculture and nutrition has evolved since the mid-20th century. The current focus is on child-stunting, dietary diversity and 'nutrient-rich' foods in recognition of the growing burdens of malnutrition and non-communicable diseases. This article concerns the global dietary and health contribution of major cereals, specifically maize and wheat, which are often considered not to be 'nutrient-rich' foods. Nevertheless, these cereals are major sources of dietary energy, of essential proteins and micronutrients, and diverse non-nutrient bioactive food components. Research on bioactives, and dietary fibre in particular, is somewhat 'siloed', with little attention paid by the agri-nutrition research community to the role of cereal bioactives in healthy diets, and the adverse health effects often arising through processing and manufacturing of cereals-based food products.

We argue that the research agenda should embrace the whole nutritional contribution of the multiple dietary components of cereals towards addressing the triple burden of undernutrition, micronutrient malnutrition, overweight/obesity and non-communicable diseases. Agri-nutrition and development communities need to adopt a multidisciplinary and food systems research approach from farm to metabolism. Agriculture researchers should collaborate with other food systems stakeholders on nutrition-related challenges in cereal production, processing and manufacturing, and food waste and losses. Cereal and food scientists should also collaborate with social scientists to better understand the impacts on diets of the political economy of the food industry, and the diverse factors which influence local and global dietary transitions, consumer behavioural choices, dietary change, and the assessment and acceptance of novel and nutritious cereal-based products.

1. Introduction

The Sustainable Development Goals (SDGs) define the international development agenda to 2030 (United Nations General Assembly 2015). Designing effective policies, strategies and programmes for achieving the 17 SDGs is a complex and multidisciplinary process, requiring specialists to escape the substantive sectoral silos which characterise global development (Waage et al. 2015). Because of multiple entry points to the agenda, agriculture should recover its place as the central driver for food and nutrition security, for achieving inclusive and sustainable economic growth, reversing environmental damage, and boosting the resilience and welfare of the most disadvantaged populations (Omilola and Robele 2017). However, there has yet to emerge a cross-sectoral vision on the form that engagement between agriculture and nutrition should take. For the second half of the last century, the agriculture-nutrition interface was concerned, in broad terms, with the availability of and access to calories and protein. Now, many countries are increasingly facing the 'triple burden' of malnutrition: i) undernutrition (hunger) and ii) micronutrient deficiencies on the one hand, and iii) overnutrition (overweight and obesity) on the other.

The SDGs include the ambitious SDG2 'Zero Hunger' by 2030—which appears unachievable. In *The State of Food Security and Nutrition in the World 2020* (FAO et al. 2020) FAO *et al.* estimate that almost 690 million people were still hungry in 2019. The data confirm that the trend in the number of people affected by hunger globally has been rising since 2014. Preliminary assessments suggest that the current COVID-19 health pandemic may add 82–133 million hungry people in 2020 (FAO et al. 2020). These trends imply that the number of hungry people will likely exceed 840 million by 2030, almost 10 percent of the global population. The prevalence of child stunting has been declining and in 2019 was 21.3 percent, or 144 million children, but will still fail to meet the SDG target.

While we continue to combat undernutrition and micronutrient deficiencies, overnutrition is increasing globally. 'If the prevalence

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continues to increase by 2.6 percent per year, adult obesity will increase by 40 percent by 2025, compared to the 2012 level' (FAO et al. 2020:27). Obesity is an important element of the triple burden *per se*, with great significance as a contributory factor to a range of non-communicable diseases (NCDs), which are targeted not in SDG2 but in SDG3 'Health and Wellbeing'.[1] It is unfortunate that diet-related interlinkages with ill-health are not explicit in SDG3, and that NCD targets are separated from SDG2, given conclusive evidence from Global Burden of Diseases studies of the interconnections between undernutrition and overnutrition. Policies should simultaneously address both dimensions to be effective (The Lancet 2020).

Traditionally the agricultural sector has responded to food insecurity by increasing the production of cheap, high calorie staple foods. Recently, some have argued against 'staple grain fundamentalism' and advocated for more research, *inter alia*, on 'micronutrient-rich' foods such as fruits and vegetables to achieve food and nutrition security (Pingali 2015; Krishna Bahadur et al. 2018; Pingali and Abraham 2019; Sanchez 2020). Sanchez (2020) recommended a major shift in research priorities 'from non-nutrient-rich' foods, including cereals, to 'nutrient-rich foods' (p.3). Considering the global extent of micronutrient malnutrition, renewed efforts to combat micronutrient deficiency diseases is necessary. However, such efforts should be in addition and not instead of a continued focus on cereal foods. So far, only some have argued for a balance in research to meet increasing demand for both staple crops and for nutrient-rich foods (Zhou and Staatz 2016).

This Viewpoint signals the need to nudge the agri-food and nutrition policy paradigm. It aims to add missing dimensions to the efforts of the agri-nutrition community of national and international researchers, funders and implementing organizations who are working towards and beyond the SDGs to tackle the 'triple burden' of malnutrition and also the pandemic of diet-related NCDs. We reflect on the shifting nature of concepts and priorities for agriculture and nutrition research and development programming. We suggest that faster progress towards nutrition, food security and diet-related health targets hinges, in part, on embracing a set of challenges beyond micronutrient malnutrition and SDG2 'Zero Hunger' (Byerlee and Fanzo 2019; Fanzo 2019). In particular, there are unexploited opportunities through increasing availability of, and access to, healthy foods derived from cereals, specifically maize and wheat, and through enhanced crop qualities. Benefits would include reductions in diet-related NCDs[2] such as cardiovascular diseases, cancers, diabetes and chronic respiratory diseases, through assuring intakes of bioactive food components (Section 3.2), in particular dietary fibre (Section 3.3), of which cereals are a rich source. Other cereals are important in global diets, including rice and so-called 'minor' grains and 'speciality' grains, but are beyond the scope of this Viewpoint. We also suggest further analysis of the interrelationships between public and private food policies and strategies, food processing, and consumer behaviour and preferences that will lead to better manufactured products, and more precise public interventions and health outcomes. These are proper concerns of the national and international agri-nutrition communities.

2. Shifting agri-nutrition priorities

2.1. Paradigms past and present

Research in agriculture and nutrition has changed over the decades. Reviews of agricultural development, food security and nutrition reveal several shifts since the middle of the 20th century (Levinson and McLachlan 2013; The World Bank 2014; Nomura et al. 2015; Gillespie and Harris 2016; Harris 2019). Since the 1950s, agricultural development has maintained a strong orientation towards increasing the supply of staple food crops, reflecting concerns over global population increase and the ability of food production to keep pace (Byerlee and Fanzo 2019). The aim was to expand and secure production of cheap, energy-dense foods which were acceptable to consumers—as an input for food—and farmers—in terms of their willingness to produce. Food research interests and commercial investments have diversified over the years to include sustainable development and climate change adaptation, but the overall public policy orientation has continued to focus on agricultural production as a supply of food to urban areas and a generator of income and export revenues. While investments in staple crop production are generally considered to have been a success, only recently has research addressed nutrition, health and the transformation of food systems. Reviewing experience from the 1960s, a report for the World Bank (2014:1) commented that 'both the fields of agriculture and nutrition have lacked unified zeal for addressing nutrition problems explicitly through food over the past several decades' (p.1). On the disciplinary disjuncture between agriculture and nutrition, hitherto, '… ownership of nutrition issues has been limited in agriculture, and emphasis on food has been low among nutritionists' (The World Bank 2014:29).

Fan et al. (2019) have suggested that in the development of agri-nutrition thinking, 'The early 2010s seemed to signal a turning point' (p.5). Micronutrient deficiencies are now widely recognised to be as important, if not more important than undernutrition. Jonsson (2010), who traced the 'paradigm shifts' in public health nutrition from 1950, noted that the 'micronutrient paradigm' prevailing at the time of writing began in 2005. Ridgway et al. (2019) have referred to the nutrition science, guidance and policy changes since the early 20th century as 'paradigm shifts' in public health. Similarly, Rifkin (2020) has critiqued the thinking about primary health care, and highlighted the undue attention given to 'microcosms' (meaning 'a narrow and siloed focus' on health) 'that block the critical importance of viewing improvements in health in the much wider environment of social, political and economic contexts' (p.1). Both Ridgway *et al.* and Rifkin frame their paradigmatic arguments within Kuhn's 'The Nature of Scientific Revolutions' (1962).

Over the last two decades, discussions at the intersection of agriculture and human nutrition and health have gathered momentum. In 2003, HarvestPlus was established within the CGIAR to advance research and deployment of biofortification, and work intensified on staple food crops to address common forms of micronutrient malnutrition (Nestel et al. 2006). The more recent shift towards sustainable food systems acknowledges changing patterns of consumption, variously towards animal-source foods, and towards vegetarianism and veganism, waste reduction, a circular food economy and reducing the environmental footprint. These factors and others are implicated in the search for 'sustainable and healthy diets' (Fanzo 2019; FAO and WHO 2019).

The 'food systems' paradigm recognises that food and health are fundamental in all ecosystems (A4NH 2020). The definition of desired food system outcomes has been broadened and sharpened: 'Nutritional security has now emerged as the central issue in world food production as well as the key link between food security and human health. Nutrition security occurs when availability, access and stability not only refer to calories, but also to proteins, fats, fibers and micronutrients' (Sanchez 2020:1). The High Level Panel of Experts on Food Security

[1] Target 3.4 is to 'reduce by one third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being', with a specific indicator 3.4.1 'Mortality rate attributed to cardiovascular disease, cancer, diabetes or chronic respiratory disease'.

[2] See SDG3 indicator 3.4.1 targeting reductions in 'Mortality rate attributed to cardiovascular disease, cancer, diabetes or chronic respiratory disease' (https://sustainabledevelopment.un.org/sdg3).

and Nutrition of the Committee on World Food Security (HLPE 2020) advocates adding two additional elements to the four pillars of food security (availability, access, utilization and stability), being 'agency' (individual and group), and 'sustainability' (economic, social and environmental). Researchers have also advocated incorporating 'nutrition-sensitive' elements—specific nutrition goals and targeted interventions—into agricultural development programming (Jaenicke and Virchow 2013), into agrifood policies (Gillespie et al. 2019) and into value chain development (Allen and de Brauw 2018; Gelli et al. 2020). These discussions have downplayed the contribution of cereals in alleviating food and nutrition insecurity among the most vulnerable population groups.

2.2. The triple burden and beyond

The causes of malnutrition are complex, involving multiple disease conditions, inadequate water, sanitation, hygiene, and care practices, and a range of basic causes at the societal level (UNICEF 1998). Agri-nutrition research on improving diets targets adequate intakes of vitamins and minerals (Gillespie and Harris 2016), and the 'triple burden' of hunger, micronutrient malnutrition and overweight/obesity. According to the 2020 Global Nutrition Report (Development Initiatives 2020), 'Among children under 5 years of age, 149.0 million are stunted, 49.5 million are wasted and 40.1 million are overweight. There are 677.6 million obese adults' (p.33). Obesity is a global problem, a 'ticking time bomb' with major current and future adverse health and economic impacts, coexisting with hunger/undernutrition and hidden hunger/micronutrient deficiency (Popkin et al. 2020). Based on 2016 data in Shekar and Popkin (2020), at the time of writing it can be said that probably half the world's adults are overweight or obese, three-quarters of whom live in low- and middle-income countries. Shekar and Popkin outline the range of public health interventions that, based on diverse country experiences, have significant potential for addressing obesity: fiscal and regulatory controls of industry conduct; food system-wide interventions through agricultural research and food production and manufacturing, subsidies, infrastructure and logistics; and education and early child-hood interventions.

The Global Nutrition Report also referred to diet-related NCDs, but the siloed nature of some agri-nutrition thinking exhibits limited interest beyond energy provision and fortification programmes in the dietary and health contribution of the cereals. Nevertheless, cereals form the major part of the actual diets of the urban and rural poor. This implies an incomplete agenda for steadfast advancement towards development goals.

The 'triple burden' itself has come under scrutiny by Scrinis (2020) who argues that the concept abstracts from a complex phenomenon that has social as well as biological dimensions. It is a fragmented framing of the problems, and results in fragmented research and policy proposals. Arguably, the triple burden focuses attention on proximal indicators or objectives (underweight, stunting, wasting, and overweight/obesity). The ultimate objective of good nutrition should be healthy lives and wellbeing, including freedom from physical and mental disease—of which there are multiple and complex causes—and specifically from diet-related NCDs—which also have non-diet-related causes.

2.3. The prominence of micronutrient malnutrition

Child stunting is a principal indicator of nutrition insecurity and micronutrient malnutrition, attributable to deficient maternal and infant diets, and affecting the poor disproportionately (Arimond and Ruel 2004; UNICEF 2013; Smith and Haddad 2015). Since Black et al. (2008) it has been clear that maternal and child malnutrition, evidenced in childhood stunting, contribute significantly to the global disease burden. Stunting incurs huge intergenerational health, economic and social costs. Many international organisations recognize stunting as the major challenge: the World Bank highlights stunting (2018); prominent indicators for the child nutrition programme of USAID are stunting and wasting of under-fives (USAID 2020); the Gates Foundation strategy on nutrition acknowledges the importance of 'hidden hunger', or micronutrient malnutrition (BMGF 2020); the European Union Action Plan on Nutrition directly targets stunting (European Commission 2019); the UK Global Challenges Research Fund (GCRF) addresses global issues faced by developing countries, among which stunting is a major theme (UKRI 2020). Interventions now commonly advocated are micronutrient focused, malnutrition-preventative food-based approaches rather than clinical, curative 'therapeutic' interventions still favoured by some ministries of health (Thompson and Amoroso 2011; FAO and FCRN 2016; Poole et al. 2018; Gelli et al. 2020).

The dependence in nutrition metrics on stunting as an indicator is indisputably important, but it is one measure of overall food and nutrition security. For children suffering severe acute malnutrition, other childhood conditions often attributable to (maternal) malnutrition, such as low birthweight, also have long-term consequences for the chronic disease burden (Briend and Berkley 2016; Lelijveld et al. 2016). Leroy and Frongillo (2019) have acknowledged that stunting—or 'linear growth retardation'—has become a widely-used and useful tool. They argued that stunting is associated with, but does not cause, the health correlates of linear growth retardation, except for a causal relationship with difficult births and poor birth outcomes. Brown et al. (2020) reviewed 90 empirical studies which examined factors associated with child malnutrition, focusing on the three major indicators of malnutrition, being wasting, stunting and underweight. They noted that stunting was the common indicator, and that wasting was relatively understudied.

A danger of emphasising a single indicator such as stunting, and associated targets, is the tendency to reduce the multiple dimensions of complex or 'wicked' problems, like poor nutrition and health, to simple solutions, like more micronutrients. Just as the conditions for food security and good health cannot be reduced to good nutrition, good nutrition in turn cannot be reduced to an adequate micronutrient intake. FAO *et al.* (FAO et al. 2020) take a comprehensive view of the nutrition challenges, noting that 'Diets of poor quality are a principal contributor to the multiple burdens of malnutrition—stunting, wasting, micronutrient deficiencies, overweight and obesity and both undernutrition early in life and overweight and obesity are significant risk factors for NCDs. Unhealthy diets are also the leading risk factor for deaths from NCDs. In addition, increasing healthcare costs linked to increasing obesity rates are a trend across the world' (FAO et al. 2020:xxiii). However, this misses a potential benefit from clear communication to a concerned wider audience, by referring to SDG3 only in terms of health costs, and not the critical targeted reductions in NCDs.

2.4. The significance of dietary diversity

There is an abundant literature which links diverse diets to provision of the vitamins and minerals that prevent 'hidden hunger' and micronutrient deficiency diseases (Jones et al. 2014; Pellegrini and Tasciotti 2014; Baudron et al. 2017; Dulal et al. 2017; Nithya and Bhavani 2017; Komatsu et al. 2018; Rosenberg et al. 2018). Dietary diversity is a proxy for nutrient adequacy (FAO 2010) and is inferred from estimates of the nutrient content and frequency of consumption of foods from different food groups, elicited through individual and household surveys (Zezza et al., 2017; Ruel, 2003a; WFP, 2008). We are learning more of the gaps in rural and urban populations in terms of access to more diverse diets, i.e., those richer in fruits and vegetables, and about less-nutritious patterns of consumption of processed foods and beverages (Penny et al. 2017; Law et al. 2019; Bren d'Amour et al. 2020), and the differential distributional impacts of temporal, spatial and socioeconomic dimensions of local food environments (Duran et al. 2016; Flores-Martínez et al. 2016; Sibhatu and Qaim 2017; Bakker et al. 2018; Poole et al. 2019; Zanello et al. 2019).

For vulnerable populations, increasing consumption of 'nutrient-rich foods' can be achieved through multiple strategies, including own-food production among the rural poor, better incomes, and enhanced market availability and access for all consumers. Nevertheless, we are also learning more about specific barriers to adoption of better diets, for example, the complexity of linkages between agroecological, economic and social systems and education, and cultural barriers including food taboos on maternal behaviour patterns and infant and young child feeding practices (Klassen et al. 2019; Chegere and Stage 2020).

The outcome of dietary diversity assessments is often the Food Consumption Score (FCS) (Wiesmann et al. 2009; Arimond et al. 2010; Kennedy et al. 2010). The FCS is constructed by using weightings based on estimated nutrient content at the food category level. The weightings are crude estimates of the nutritional value of different food groups. Revision of the Food Consumption Score Nutritional Quality Analysis Guidelines (FCS-N) (WFP 2015) has introduced a more disaggregated food list which discriminates nutrient-rich foods from other less nutrient-rich items belonging to the same food group. Dietary diversity scores have been found to be sensitive, robust, valid and cheap-to-measure indicators of micronutrient intake adequacy in many contexts (Headey and Ecker, 2013; Nithya and Bhavani, 2017; Ruel, 2003; Zhao et al., 2017; Wiesmann et al., 2009). Sensitive to the choice of indicators of dietary diversity, Smart et al. (2020) recently used several measures covering both the nutritional content of the diet and the diversity of food intake for their study of consumption patterns in Mozambique. However, Fongar et al. (2019) have recently identified positive associations between both individual and household measures of dietary diversity and diet quality in rural households in Kenya, but no clear association between dietary indicators and anthropometric indicators of nutritional status.

Loose application of protocols may be partly responsible for varying results of studies investigating the association between indicators of dietary diversity and nutritional status. A systematic review of the use and interpretation of dietary diversity association in 46 studies between 2006 and 2017 by Verger et al. (2019) found wide variation among the study characteristics in respect of the unit of analysis, the location, study design, sample size, choice of indicators and analysis of the dietary diversity data. The results showed inconsistent use of protocols and misleading data interpretation within the sample. They also criticised the lack of comprehensiveness of the food items included in food groups across datasets.

Overall, we need to revise the conceptualisation of food types in dietary diversity studies for various reasons. Two areas are raised here for wider discussion: mis-categorisation and missing nutrients.

2.4.1. Mis-categorisation

An aggregation problem is that heterogeneous foods are included within a single category. For example, different meats and other foods based on animal-source products have varying nutritional qualities; vegetables and fruits differ considerably in the micronutrient content; fortified (orange) sweet potatoes are categorised with orange vegetables rich in vitamin A, whereas fortified (yellow rice) is not so distinguished; nor are other bio- or industrially-fortified products so distinguished[3].

In particular the single 'staples' category of cereals and tubers includes numerous diverse foods. They are derived from a wide range of crops which exhibit inherent between-species differences. They also often exhibit different within-varietal nutritional qualities attributable to plant breeding and varying production systems and conditions. From these staples many foods are derived through processing and manufacturing that alter nutritional quality for better—by improving acceptability and digestibility—and for worse—by stripping out valuable nutrients and adding noxious components. Through ultra-processing into other forms—such as products high in saturated fats, sugar and salt—they can be nutritionally harmful, obesogenic and contribute to NCDs (WHO, 2020b).

2.4.2. Missing 'nutrients'

Another issue with measures of dietary diversity is the categorisation of the macronutrients (fats, carbohydrates and proteins) and micronutrients. The measures do not differentiate among, or include all, essential vitamins and minerals which are epidemiologically significant; nor essential fats—or more precisely, fatty acids; nor essential amino acid content and hence protein types. The FCS-N ignores some nutritional deficiencies including those that are context-specific to national, regional (within country) and even local levels (WHO, 2020a). Zinc, iodine, folic acid and vitamin D deficiencies would be examples.

Moreover, there is a significant omission of the many components of foods that are 'bioactive substances' and contribute to health (Weaver 2014; Perez-Gregorio and Simal-Gandara 2017; Sanchez 2020). The health-promoting bioactive food components ('BIOFOCS') are not included in the dietary diversity discourse and are largely absent from the agri-nutrition literature, but their significance is recognised in biomedical research, food sciences and within the food industry (Section 3.2).

2.4.3. Beyond dietary diversity

Dietary diversity as conceived is an essential but partial approach to combatting food insecurity. There is a particular dilemma when overt hunger due to insufficient food calories is an immediate population and policy concern, and where energy needs are paramount (Harris 2019).

More comprehensive dimensions of food insecurity such as the Integrated Food Security Phase Classification (IPC) are used in humanitarian contexts. In their deconstruction of the meaning of 'famine', Maxwell et al. (2020) critique the IPC which assesses famine in five phases, the indicators for which use data on food consumption (or hunger), changes in livelihoods, prevalence of acute malnutrition, and mortality. They argue, *inter alia,* that the IPC gives a 'mono-dimensional view' of a phenomenon that is multifactorial. Even so, the set of IPC indicators captures a wider range of health drivers and outcomes than does the focus on dietary diversity and stunting. It also links to SDG3 and targets for reductions in infant and child mortality and NCDs (United Nations, 2020b).

The argument thus far is for agri-nutrition research to open up to a broader perspective on the nexus of agriculture, food, nutrition and health. At the heart of this complexity is acknowledgement that foods contain more than the conventional macro- and micronutrients, and that agri-nutrition research should address the nutrition and health requirements for all the essential BIOFOCS.

3. The dietary contributions of cereal foods

3.1. Nutrient components

Only relative to other 'nutrient-rich' foodstuffs are cereals 'nutrient-poor'. This terminology reflects the emphasis on micronutrient malnutrition. Most cereals provide varying amounts of proteins, fats, minerals and vitamins, in addition to being important sources of dietary energy. Wheat contributes some 20% of the total dietary calories and proteins globally (Shiferaw et al. 2013), rice contributes 20% of global calories and contains important minerals, vitamins and bioactive phytochemicals with other essential food components found in rice bran (Fukagawa and Ziska 2019); maize is a staple of over 1 billion people for whom the grain energy contribution to the diet can exceed 50%. Whole maize grain is rich in anthocyanins with many nutritive properties which can be enhanced by the traditional process of 'nixtamalization' (Rosales et al. 2016; Bañuelos-Pineda et al. 2018). Nutritional

[3] Footnotes explain some of these issues in WFP (2015). *Food Consumption Score Nutritional Quality Analysis Guidelines (FCS-N). Technical Guidance Note.* Rome, United Nations World Food Programme (WFP). Retrieved 02 September 2020, from https://www.wfp.org/publications/food-consumption-score-nutritional-quality-analysis-fcs-n-technical-guidance-note.

qualities of cereals are amenable to improvement through traditional plant breeding, genomic selection, bio- and industrial fortification (Mattei et al., 2015; Palacios-Rojas et al., 2020; Shewry and Hey, 2015; Velu et al., 2016; Yu and Tian, 2018; Zhao et al., 2020). However, the micronutrient content of cereals-based foods is also often reduced through processing methods (Suri and Tanumihardjo 2016).

Cereals are the dominant source of carbohydrates in the global diet, providing essential food energy. Energy matters universally, but has particular importance when minimal energy needs are not being met. Persistent humanitarian situations come to mind due to natural disasters such as famines and floods, and anthropogenic disasters such as conflict. Across the rural South and under seasonal conditions of hardship and hunger, cereals provide necessary bulk and energy for the poor and those involved in physical work.

Carbohydrates are a complex and contested nutrient. Several classification systems are used currently (Ludwig et al. 2018). Some adverse health reactions to carbohydrates in cereals are well-documented: for example, specific components of wheat affect people with coeliac disease and wheat allergy (Brouns et al. 2019). Regarding starch, a high glycaemic response is known to have adverse effects on diabetes and obesity. However, a higher amylose content compared with amylopectin decreases digestibility, postprandial glycaemia and insulinaemia, and hence can reduce the glycaemic index of carbohydrate foods.

A series of systematic reviews and meta-analyses of prospective studies conducted on carbohydrate quality and human health by Reynolds et al. (2019) concluded that higher intakes of DF or whole grains were likely causally associated with reductions in the risk of mortality and in the incidence of a wide range of NCDs and risk factors. In light of the popular concerns about starchy food intakes, they found less evidence for the potential benefit of a low glycaemic index or low glycaemic load diets. Nevertheless, processed 'whole grain foods' may not have the same health benefits as unprocessed whole grains, and some 'whole grain foods' which contain added 'free' sugars probably have adverse implications for health (Ludwig et al. 2018). In addition, there is a popular and simplistic misconception that avoidance of cereals, particularly wheat, reflects a healthy lifestyle (Igbinedion et al. 2017).

It is often difficult to disentangle food science and policy from food populism and marketing, whose concerns 'have generally not been substantiated by detailed scientific review' (Shewry 2018:470). According to the UK SACN (2015: 2), 'total carbohydrate intake appears to be neither detrimental nor beneficial to cardio-metabolic health, colorectal health and oral health… there are specific components or sources of carbohydrates which are associated with other beneficial or detrimental health effects'. Thus, it may be the balance of carbohydrate qualities as well as overall energy intake that determines effects on chronic disease and health outcomes (Ludwig et al. 2018; Reynolds et al. 2019), although this view is contested.

3.2. Bioactive 'non-nutrient' food components (BIOFOCS)

There are other components of foods that, puzzlingly, are not invariably considered to be 'true' nutrients but yet are essential for healthy diets: 'Other components of food that are not technically "nutrients" also contribute to nutrition and health, such as fiber, probiotic bacteria, and phytonutrients' (The World Bank 2014:3). These collectively are 'bioactive food components' (BIOFOCS): dietary fibre and other BIOFOCS that are not energy, protein, fats, minerals, vitamins and water are handled in many different ways by different authors and authorities: 'non-nutritional, but biologically-active substances [include] toxins and contaminants, such as alkaloids and aflatoxins, which are detrimental to health, as well as constituents, such as phytochemicals, that may be health-promoting' (Webster-Gandy, 2020).

In 2004, the US Offices of Disease Prevention and Health Promotion, Public Health and Science, and Health and Human Services solicited comments on a proposed definition of BIOFOCS because:

> 'Foods provide numerous chemical constituents that may influence health and disease prevention, in addition to those usually characterized as essential nutrients. The physiological implications of these food components have been the subject of recent scientific inquiries and publications. Widespread scientific, governmental, and consumer attention to these components, referred to here as "bioactive food components," has sparked an interest about how they should be defined and how best to evaluate their significance in promoting health and disease prevention. Bioactive food components exist not only in commonly consumed foods but also as ingredients in fortified foods and dietary supplements' (Federal Register 2004:55822).

Examples of bioactive compounds include carotenoids, flavonoids, phytosterols, glucosinolates, and polyphenols. Since vitamins and minerals elicit pharmacological effects, according to Gökmen (2016) they also can be categorized as bioactive compounds.

Bioactive compounds are found naturally in various foods, and have beneficial antioxidant, anticarcinogenic, anti-inflammatory, and antimicrobial properties. Some naturally occurring substances and others introduced during food manufacturing, such as acrylamide in bakery products, may also have adverse effects (Gökmen 2016). Most of the beneficial effects of the consumption of wholegrain cereals on NCDs are currently attributed to the bioactive components of dietary fibre and a wide variety of phytochemicals (Bach Knudsen et al. 2017). There is much research into the bioavailability and bioaccessibility of such active compounds and nutrients, as well as macronutrients such as carbohydrates, by the food processing industry as well as academic researchers, not least the use of nanoemulsions as vehicles for bioactive compounds to improve the sensory, nutritional and health properties of processed foods (Mahfoudhi et al. 2016; Leong et al. 2019; Santos et al. 2019).

Our interest here concerns the mainly naturally-occurring substances in foods that are beneficial or essential to nutrition and health.[4] These BIOFOCS are known to prevent and combat health conditions comprehended by SDG3, target 3.4 'to reduce premature mortality from non-communicable diseases' (United Nations, 2020b). Because BIOFOCS such as fibre and phytochemicals, like proteins, minerals and vitamins, are also found in cereal foods, it is a mistake to classify cereals automatically and universally as 'nutrient-poor'. Research on BIOFOCS seems to be largely siloed in biomedical and food science disciplines and discussions of functional foods, in the same way that, it is argued, nutrition is siloed from agri-food sustainability (El Bilali 2019). BIOFOCS are, however, present in popular health media (Brouns et al. 2017; Duyff 2017).

The literature on BIOFOCS is abundant, the science is complex, and this viewpoint can only summarise the field. Here we acknowledge cereal carbohydrates not only as important source of energy, but also as a source of diverse BIOFOCS and in particular, of dietary fibre (DF).

3.3. Dietary fibre (DF)

The dietary and health impacts of carbohydrates are summarised in Fig. 1.[5] Simply put, carbohydrates provide energy through digestion of sugars, starch and oligosaccharides in the small intestine. Some carbohydrates also create a glycaemic response with adverse effects on, for

[4] We thereby differ from the US Office of Dietary Supplements' view which defined bioactive compounds as 'constituents in foods or dietary supplements, other than those needed to meet basic human nutritional needs, which are responsible for changes in health status' Weaver, C.M. (2014). Bioactive foods and ingredients for health. *Advances in Nutrition* **5**(3): 306S-311S DOI: https://doi.org//10.3945/an.113.005124.

[5] The presentation is necessarily simplified, and elements may be contested by different schools and through ongoing research.

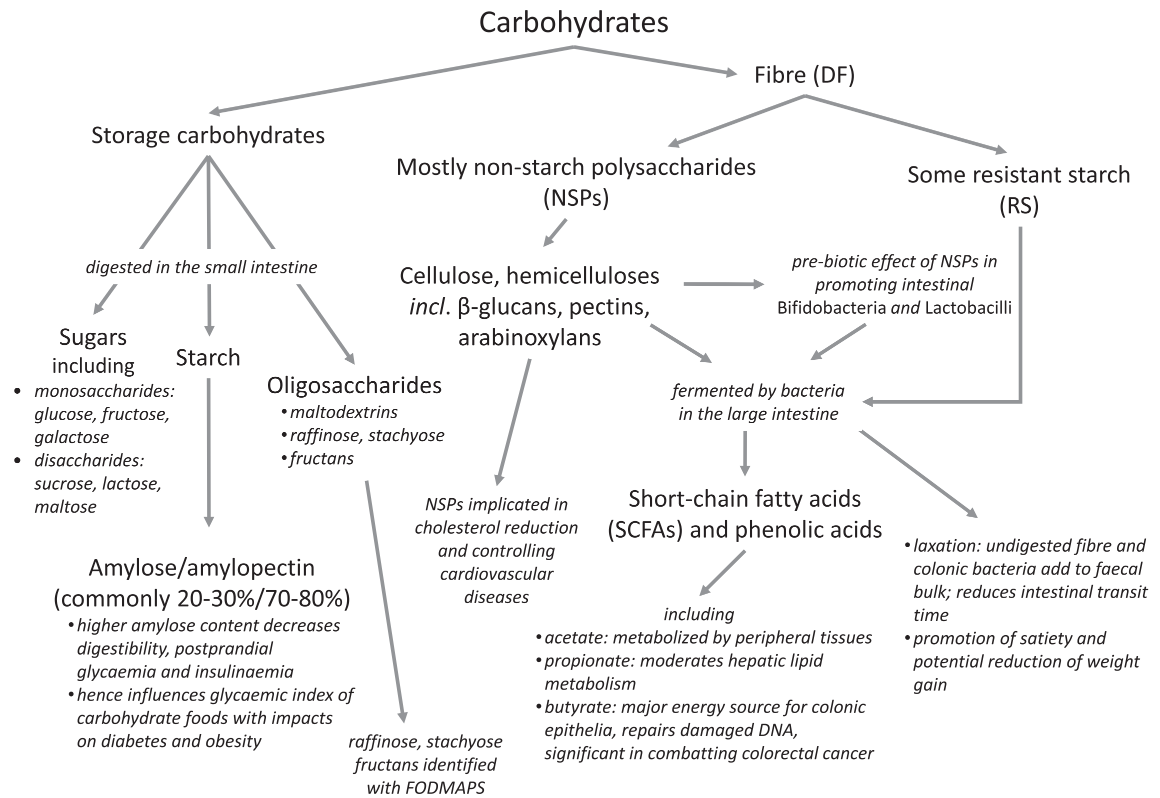

Fig. 1. Dietary and health effects of carbohydrates. Source: authors' elaboration from diverse sources.

example, diabetes and obesity, and possibly other negative effects associated with 'fermentable oligo-, di-, mono-saccharides and polyols' or so-called FODMAPS. DF comprises carbohydrates which are fermented by bacteria in the large intestine, with diverse, complex and largely positive metabolic and health effects.

There is now a good understanding of the physiology, biochemistry, and metabolism of most carbohydrates (Reynolds et al. 2019), and of the importance of DF in disease prevention (Cummings and Engineer 2018). Stephen et al. (2017:150) give an account of DF intake, types and dietary sources, and the relationships with numerous NCD risks. These include improvements in all-cause mortality, cardiometabolic health and risk factors including hypertension, hyperlipidaemias, type 2 diabetes, obesity in terms of both energy intake and appetite effects, gastrointestinal health including faecal weight and constipation, diverticular disease, oesophageal disease and a range of cancers.

Broad guidelines for DF intakes exist in national and international nutrition policies but dietary guidance still focuses on topics other than fibre (Stephen et al. 2017), with the level of detail lagging that for vitamins and minerals (see Section 3.4 below). In fact there is little in the WHO Fact Sheet on the role of DF: only '… many people do not eat enough fruit, vegetables and other dietary fibre such as whole grains… Eating at least 400 g, or five portions, of fruit and vegetables per day reduces the risk of NCDs and helps to ensure an adequate daily intake of dietary fibre' (WHO 2018).

In a review of European countries, we learn about diversity in DF sources, consumption and recommendations: 'Grain products provide the largest proportion of fibre in the diet for all countries studied, with bread by far the largest grain source, with smaller contributions from breakfast cereals, pasta and biscuits and pastries. Vegetables, potatoes and fruits also contribute substantially, but these vary more widely from country to country, depending on climate and cultural norms. Recommendations about types of fibre to consume are therefore difficult as "not one size fits all"' (Stephen et al. 2017:182). Processing also affects the nutritional quality of grains, and differences have been identified between the quality of processed grains and of fibre added to manufactured foods compared to naturally occurring DF within whole grain foods (Slavin 2003; Reynolds et al. 2019).

3.4. Dietary guidelines

3.4.1. BIOFOCs

Dietary guidelines are political tools for promoting healthy consumption patterns 'and can also serve as the basis for developing food and agriculture policies' (Muka et al. 2015; FAO and FCRN 2016:v). New research reported by Herforth and Masters (2020) reviews methodologies, approaches and metrics for estimating the affordability of nutritious diets around the world. A proposal to harmonise nutrient reference values could introduce new rigour to dietary guidelines (Allen et al. 2020), and new analytical tools for estimating human nutrient requirements are becoming available (e.g., Schneider and Herforth (2020)). Dietary advice about the consumption foods such as of whole grains rich in DF is not uncommon, but quantitative guidelines are unavailable for many countries, and details are often incomplete (Herforth et al. 2019). In particular, gaps persist on the quality of DF essential to meet dietary recommendations (Stephen et al. 2017). The relative inattention given to DF and other BIOFOCS is significant for agricultural sciences research. Weaver (2014) has commented that because bioactives are of increasing interest, more research is needed to understand the complex relationships between individual food components, foods, and the biological effects, thus providing better evidence to inform dietary guidelines. A balanced, comprehensive and more thorough understanding of the contribution of carbohydrate-rich cereals to diets in respect of under-nutrition, overnutrition and NCDs will likely alter dietary research and guidelines.

All evidence hitherto points towards consumption of more fibre and more whole foods, including cereal grains. Springmann et al. (2020) found that in all FAO-defined geographical regions, with the exception of North America, current intakes of whole grain foods should at least double compared with national dietary guidelines, and in the cases of WHO and EAT-Lancet guidelines, increase by 241% and 362%

respectively. Adoption of dietary guidelines would lead to major reductions in the global burden of diet-related NCDs through increasing consumption both of cereals rich in DF, and necessarily of fruits, vegetables, pulses, nuts and seeds rich in both micronutrients and DF.

New knowledge is needed specifically of DF: '[The UK Scientific Advisory Committee on Nutrition] SACN would welcome research to improve the functional categorisation of specific dietary fibres and relevant extracts: building structure-function understanding to link and predict from defined, measurable physical and chemical properties to specific physiological effects. This should include defining physiologically meaningful effect ranges for colonic and faecal pH, short chain fatty acids, and bacterial populations' (SACN 2015:199).

3.4.2. Model diets

Concern about the sustainability of agriculture and diets is not new (Reynolds et al. 2014; Tilman and Clark 2014), and has received new impetus. The EAT-Lancet Commission reference diet was 'based on the best evidence available for healthy diets and sustainable food production' (Willett et al. 2019:447), using food groups plus added fats, sugar, salt, and other dietary constituents. Grains were recognised therein as the principal source of energy in global diets, with whole grains and fibre from grains associated with reduced risk of coronary heart disease, type 2 diabetes, and overall mortality.

The formulation of model sustainable diets that are affordable by the global poor in different food cultures is still pending (Hirvonen et al. 2019; Willett et al. 2019; Drewnowski 2020). Using 2017 data, a least-cost EAT-Lancet Commission healthy diet formulated according to local food preferences and availability has been found to be unaffordable by 3 billion people globally (FAO et al. 2020). For India, Sharma et al. (2020a) have illustrated how diets across local and national geographical dimensions and socio-economic levels deviate significantly from the EAT-Lancet reference diet.

Economic modelling suggests that increasing the supply of fruit and vegetables to meet the WHO's dietary recommendation of 400 g/person per day is for many countries unlikely by the year 2050 (Mason-D'Croz et al. 2019). Therefore, assuring diverse diets incorporating nutrient-rich foods is not a trivial matter. This suggests the need for more research into how, in diverse food cultures and seasons, intakes of cereals and other fibre-rich foods such as pulses, can complement 'nutrient-rich' foods to meet revised dietary recommendations. FAO and WHO (2019) and the HLPE (2020) have recommended moving towards context-specific 'territorial diets' based on locally available, economically accessible, and culturally acceptable foods, delivered through sustainable systems. Cereals, for energy and much more, will be the foundation of such diets.

3.5. Cereal challenges

Understanding the nutritional requirements for DF and other bioactives adds a new dimension to the continuing agenda for optimising plant breeding and production conditions for best nutritional outcomes in uncertain and changing climates.

3.5.1. Production

Increases in crop productivity are necessary in many countries and challenging contexts. Bloom et al. (2020) offer various explanations for their estimation that research productivity generally has fallen during the past 15 years. For agricultural research, they have calculated a negative annual growth rate in agricultural productivity both for the United States and globally. But in summary, the finding is robust that 'ideas are getting harder and harder to find' (p.1138) and that considerable increases in research investment are needed to maintain GDP growth rates. A major task is to redress the significant yield gaps in crop productivity between many African countries and other regions. Investment by the international community in local capacities to address local conditions is essential. A recent report critical of the AGRA programme shows that there is no consensus on the merits of a "Green Revolution" approach to agricultural intensification, and that the evidence of poor impact impels exploration of alternative models of sustainable crop production for food and nutrition security among the poor in Africa (Bassermann and Urhahn 2020). Moreover, greater collaboration among international and national cereals researchers is necessary, in order for wheat and maize scientists to share lessons learned with the other major cereal sector, rice, and with 'minor' cereals which are also very important regional food crops, with many advantages of local adaptation, resilience and nutritional quality.

Soil characteristics and production systems affect crop macro- and micronutritional qualities for human consumption (Herencia et al., 2011; Kihara et al., 2020; Lovegrove et al., 2020; Shewry, 2018; Shewry and Hey, 2015). More local knowledge is needed. There is also considerable potential for plant breeding strategies to improve grain composition through exploiting natural variation, genomic selection, mutagenesis and transgenesis, improving cereal cell wall polysaccharides, and specifically improving the starch composition and structure through natural and induced mutations: 'In recent years the manipulation of the amylose-amylopectin ratio in cereals [maize, rice, wheat and barley] has been identified as a major target for the production of starches with novel functional properties and improved health benefits' (Lafiandra et al. 2014:318).

Programmes of biofortification of seed varieties and industrial fortification of processed products are proven and should be continued, accompanied by efforts to integrate biofortification into public and private policies, programmes, and investments, and to evaluate and enhance consumer uptake (Bouis and Saltzman 2017; Bouis 2018). Similarly, programmes of industrial fortification of cereal products should be expanded, considering how to overcome the obstacles to fortification programmes where flour is derived from local milling rather than industrial-scale processing (Ansari et al. 2018; Poole et al. 2020).

3.5.2. Processing and manufacturing

The loss of nutritional quality through processing is a major challenge. Public sector food policy still allows the food industry to mill away much of the nutritional content of cereals and to create ultra-processed foods (UPFs). These often contain noxious qualities and components, and contribute directly to the huge and increasing global health and economic costs of NCDs (Monteiro et al. 2018; Vandevijvere et al. 2019).

Agricultural scientists and socioeconomists should collaborate with food scientists in order to enhance the nutritional quality of inputs to the food industry and to assess health claims and assure consumer acceptance of novel or reformulated products. Collaboration between cereal scientists and industry food scientists are also needed to improve processing and develop innovative technical approaches to overcome the spoilage of fats in whole grain foods, and achieve the effective substitution of 'free' or added sugars that have adverse health effects. Overall, we need a reorientation of food manufacturing towards processes and products that enhance the nutritional contribution of cereal foods rather than over-processing which strips out the nutritional content, adding instead the noxious components.

In plant breeding and metabolic studies together, as well as cereal processing and manufacturing, further research is needed to elucidate the relationship between dietary components of cereals and cereal foods, and glycaemia/insulinaemia that underlies some of the critical increase in NCDs. New metrics have been proposed to assess the dietary quality of carbohydrate-rich foods in respect of calories and other macro- and micronutrients which should generate enhanced dietary guidelines, promote novel and healthy foods, increase the accuracy of product labelling, and reduce consumer confusion about nutritional qualities (Liu et al. 2020).

3.5.3. Food safety

Food safety is one dimension that spans the whole food system and demands diverse but coherent technical, commercial and policy responses. As an example of the food safety challenges to nutrition and health from cereals, mycotoxins are an important agent. For cereal systems, aflatoxicosis is a common health hazard in Africa, first identified in the 1960s. Aflatoxins in maize can develop in the field, causing ear-rot, and in the absence of field contamination, during post-harvest grain processing and storage (Council for Agricultural Science and Technology 2003). A systems approach to food safety in the maize sector was recently designed and implemented in Kenya, funded by the CGIAR Research Program on Agriculture for Nutrition and Health (AN4H) (PACA, no date). Results suggested that testing procedures throughout the maize value chain could enhance food safety from aflatoxin poisoning for 10 million Kenyans (Hoffmann 2020). Recommendations included 'the adoption of coregulation that is a governance option that uses government-backed standards adopted by industry, leading to shared responsibility to manage aflatoxin risk in Kenya and elsewhere in the region' (Herrman et al. 2019:146). Hence the importance of collaboration with farmers and with private sector firms such as maize millers (Fisher et al. 2019; Pretari et al. 2019).

3.5.4. Food waste

Post-harvest losses are known to account for a major part of global food production. Food waste is a serious threat to narrowing the gap between supply and demand (Mason-D'Croz et al. 2019). The causes of losses persist throughout the food system and in low-income countries are mainly connected to financial, managerial and technical limitations in harvesting techniques, storage and cooling facilities in difficult climatic conditions, infrastructure, packaging and marketing systems. Given that many smallholder farmers in developing countries live on the margins of food insecurity, a reduction in food losses could have an immediate and significant impact on their livelihoods.

Food systems improvements may not necessarily be costly or technologically advanced. Recent research on combatting losses in Tanzania, mainly for maize, found that the use of inexpensive 100 kg hermetic storage bags could reduce infestation by, and losses through, insects and other pests and mitigate food insecurity by 38% in the lean season for smallholder farmers (Brander et al. 2020). In this case, disentangling the effects of the technology itself from the effects of training on adoption of new storage technology needs further work, and illustrates the multisectorality of the food systems challenges which constrain good nutrition and health.

3.5.5. Political economy of the food industry

Progress in addressing the nutritional drivers of NCDs is largely held up by the twin obstacles of commercial interests and lack of political will (Horton 2018). Current nutritional challenges have much to do with the political economy of food through lobbying of the food industry, with advocacy of civil society, and the need for public regulation of and policies for research and investment, sectoral taxation, prices, subsidies and incentives, and food trade and security policies. The cereal industry is centre-stage in food trade, manufacturing and processing as well as consumption. Balarajan and Reich (2016) have identified six themes in the political economy of nutrition that highlight current challenges: leadership, intersectoral coordination, accountability, issue framing, hierarchy and demonstrating effectiveness of nutrition actions. Agri-nutrition scientists and socioeconomists should participate in this agenda and adopt multidisciplinary approaches, particularly through joint ownership of issues, shared prioritisation, industry engagement, and above all by deploying food systems thinking (Gillespie and van den Bold 2017; Gillespie et al. 2019).

The Global Alliance for Improved Nutrition (GAIN) is one collaborative vehicle which aims to increase the availability, affordability and consumption of nutritious and safe foods, and change market incentives, rules and regulations to promote nutritious diets. Based on experience in South Asia, and the growing literature on public-private sector food, nutrition and health linkages, Poole et al. (2020) have identified various ways for researchers to engage in enhancing the delivery of nutrient-rich foods, and limiting the consumption of harmful foods.

3.5.6. Consumer behaviour and health challenges

The prevalence of adult obesity has superseded underweight, both globally and in all regions except parts of sub-Saharan Africa and Asia (Development Initiatives 2020). Two recent research examples among many illustrate the importance of understanding consumer behaviour in the varying contexts of economic and nutrition transition. In India, like many other countries, the nutrition transition towards obesity is marked by increased sales of processed and packaged foods (Law et al. 2019). Analysing data from a representative sample of take-home purchases of packaged food and beverages by urban Indian households between 2013 and 2017, they found that purchased quantities per capita lagged those in Western economies which have advanced further along the transition except for high levels of consumption of foods such as packaged milk, processed wheat or edible oils. Income was not a simple determinant of purchasing patterns.

Similar health and research challenges have been reported by Smart et al. (2020) in Sub-Saharan Africa, where undernutrition and increasing overnutrition are prevalent. Investigating the changes in food demand in Mozambique, they found that urbanization impels consumption of more nutritious foods and more processed foods at the same time, with both positive and negative impacts on diet quality and implications for health. Urbanization and increased consumption of processed foods were significantly and strongly associated with deterioration in diet quality. They conclude that 'As urbanization continues and incomes rise, African cities need to consider what mix of policies and programs might counteract the negative effects we see from both these factors on diet quality' (p.16).

Such findings imply more social science analysis of consumer education and behaviour change, not least in favour of whole grain foods, and more political economy analysis which might reduce the production, distribution and consumption of UPFs of which cereals, as noted, are often an ingredient (Mattei et al. 2015). Such analysis should cast a light on why knowledge and dietary guidelines have often had limited influence on public nutrition policy and less on actual public health and consumer education and behaviour change (Poole et al. 2020).

3.5.7. Cereals and the livestock industry

Cereal grains such as maize and wheat are used as an input to livestock feed as well as food, offering an indirect route to better (human) nutrition outcomes. Maize grain is an important feed source for monogastric livestock, and poultry in particular—and may imply different feed quality needs as compared to food (Krishna et al. 2014). Cereal crops are also grown for forage and crop residues and are an important by-product widely used as feed in the Global South (Blümmel et al. 2013; Valbuena et al. 2015). As Sanchez (2020) notes in response to the EAT Lancet Commission, animal-source foods (specifically red meat, poultry and eggs) are a nutritional necessity for hundreds of millions, '…if not billions, of fertile women and children in low- and middle-income countries who in all likelihood need more that the 14 g/day indicated in the EAT-Lancet diet' (p.3). Here we avoid contention concerning the sustainability of livestock production in general (Adesogan et al. 2020), and limit ourselves to reiterating the ongoing importance of cereals as an input to livestock production, in order to meet the nutritional needs of vulnerable populations.

4. Policy implications: Revisiting the agriculture, food and nutrition security research agenda to 2030

It has been argued that agricultural research, by concentrating on staple cereals, has not responded adequately to persistent micronutrient malnutrition and child stunting, and increasing overweight and obesity (Pingali 2015; Pingali and Abraham 2019). Sanchez (2020) supports work on nutrition-sensitive food systems and nutrition security in terms of availability, access and stability of calories, proteins, fats, fibre and micronutrients. Now is also the time to reiterate the contribution of cereals beyond energy, particularly whole grains, to nutrition and health. The challenges enumerated in the previous (Section 3.5) are by no means exhaustive and will require comprehensive and collaborative approaches to maximise the dietary contributions of cereal foods.

4.1. Bridging and bonding disciplines

Admittedly, a comprehensive approach and multidisciplinarity exacerbate the operational challenges for many policy and research organisations, national and international, which have struggled hitherto to integrate thinking about nutrition security, rather than just food energy security, into agricultural research. This suggests new research partnerships between agricultural scientists, nutritionists, biomedical and food science researchers and socio-economists, and more support from the international community directed towards under-resourced national agricultural and nutrition research communities. Understanding of carbohydrate components of foods from field to plate, and on to digestion, fermentation and metabolism is needed. Ludwig et al. (2018) identify a number of 'carbohydrate controversies' that need further research, including those related to the contribution of whole grains and DF to diets, health and wellbeing.

4.2. Expanding the nutrition 'microcosm'

A focus on stunting and the 'micronutrient malnutrition paradigm' is unduly narrow and siloed. Micronutrient malnutrition is, to use Rifkin's term, a 'microcosm' (2020), rooted in a constrained definition of 'nutrient' that does not take into account the many other essential food components. It blocks 'the critical importance of viewing improvements in health in the much wider environment of social, political and economic contexts' (p.1). Wells et al. (2020) embrace a wider biological approach to nutrition: ''The concept of malnutrition should also incorporate the gut microbiome, representing millions of genes from microorganisms. The microbiome generates a collective metabolic activity that affects and responds to the human host' (p.76). Moreover, the 'triple burden' concept implies addressing not just SDG2 but also the NCDs cited in SDG3, and it is important to communicate this concern to a wider readership.

4.3. Redefining 'nutrient'

Use of the term 'non-nutrient components of foods' (The World Bank 2014) is a misnomer: should not DF be classed as a nutrient? Just as there is a case for modernising the definition of protein quality (Katz et al. 2019), so may there be also a case for redefining nutrients in terms of DF and other naturally-occurring food components that takes into account the nuanced and net effects on health of a wide range of bioactive compounds. Meanwhile, 'BIOFOCS' will serve the purpose for those substances that are essential to nutrition and health. And that implies new research on cereal foods, carbohydrates and DF. We need to build knowledge about production factors affecting DF, phytochemicals and other BIOFOCS in major and minor cereals (Gołębiewska et al. 2018). Distinction should be made among naturally-occurring substances and contaminants, industrial supplements and additives, and those which are beneficial or harmful (Yasmeen et al. (2017). To do so is beyond the scope of this Viewpoint.

4.4. Rethinking agri-food cereal systems

Agri-food systems thinking provides a robust platform for reshaping the agri-nutrition research agenda and to incorporate multi-disciplinary partnerships. There are ongoing wheat and maize systems research needs, which are to:

i) accelerate plant breeding for nutritional quality and biofortified crop varieties, and scale up industrial fortification, both being proven strategies for enhancing the nutrient-intensity of major cereals among other crops (HarvestPlus 2020);
ii) persist in crop productivity and sustainability research in diverse soil and production conditions and in the context of climate change, especially under the resource-constrained conditions of smallholder farmers (Ritzema et al. 2017; Kihara et al. 2020);
iii) enhance practices for processing, manufacturing, storage and distribution of natural, bio- and industrially enriched cereal foods to reduce losses and nutritional harm in terms of both quality and quantity (Sharma et al., 2020b);
iv) understand consumer behaviour at a disaggregated level: livelihood patterns and access to different foods among vulnerable groups, in different cultures, and in different production and marketing systems (Haddad 2020);
v) identify the inherent contradictions and resolve the trade-offs within cereal food systems concerning environmental sustainability, poverty reduction, profitability for actors and firms throughout the value chain, and improved nutrition and health of vulnerable populations.

5. Concluding comments

Agri-nutrition and development communities need to embrace a multidisciplinary research agenda that integrates disciplines, goes beyond the nutrition 'microcosm', redefines nutrients and rethinks agri-food cereal systems. This calls for collaboration with other food systems stakeholders to broaden understanding of the nutritional and health-promoting value of cereals, including preserving and enhancing the nutritional qualities of processed foods, and with consumers, assessing and assuring acceptance of novel and nutritious cereal-based products.

Research funds are increasingly with foundations and industry rather than traditional publicly-funded bilateral and multilateral donors and development organisations. It is not only because the problems are multidisciplinary and multisectoral that researchers must look for new collaborations: the required level of resources is held by the private sector. Hence SDG17.

It would be pretentious to claim to have identified a Kuhnian paradigm shift in agri-food systems for food security, nutrition and health, but we do need a broader and more nuanced understanding of the nutritional and health-promoting value of diverse foods, including cereals. We do not want to question here the merit of researchers and organizations engaged with cereals versus 'nutrient-rich foods'. Micronutrients matter but so also do many other food components that contribute to health and wellbeing. We do want future research reprioritization, and the community of researchers, research funders and implementing organizations in agriculture, nutrition and international development to rethink strategies that go beyond vitamins and minerals, specifically to integrate the contribution of dietary carbohydrates and other macronutrients to health and wellbeing. Cereals and 'nutrient-rich foods' are complementary in agri-nutrition and require additional research and resources, and increased attention for one should not replace the other. While concentrating on maize and wheat, we acknowledge that many of these considerations apply to rice, the other major cereal crop, and also to so-called 'minor' grains and 'speciality' grains—but detailed discussion is beyond the scope of this Viewpoint.

In Rifkin's words, 'Paradigm change depends on people accepting a new interpretation of events and putting in place policies to accommodate this new interpretation' (2020:2). As long as the SDGs remain, and beyond, and while food systems drivers are evolving and acute, food security and nutrition research cannot be 'either/or' any of the elements of a comprehensive agri-nutrition agenda.

6. Postscript

In 2020 the COVID-19 pandemic exposes the fragility of global food systems and adds urgency to reshaping the agri-nutrition agenda (Development Development Initiatives, 2020; Global Panel 2020; United Nations, 2020a). Among the likely outcomes of the pandemic will be increases in poverty, hunger and malnutrition among the world's most vulnerable populations through reductions in dietary quality, incomes and healthcare provision. The Lancet Global Health considers increasing food insecurity as a result of COVID-19 to be 'an impending natural disaster' (Editorial 2020: e737). With the likelihood that reduced national and international resources will imperil the work of national governments and organisations and the development community, the chances of achieving at least some of the SDGs are retreating beyond 2030. The commitment to food security expressed in the G20 Ministerial Statement on COVID-19 highlights the importance of cooperation, efficiency, appropriate support mechanisms and functioning markets 'to help ensure that sufficient, safe, affordable, and nutritious food continues to be available and accessible to all people, including the poorest, the most vulnerable, and displaced people in a timely, safe, and organised manner, consistent with national requirements' (G20 Extraordinary Agriculture Ministers Meeting 2020: no page numbers).

7. Disclaimer

The views expressed in this paper are those of the authors and do not necessarily reflect those of any institution. The usual disclaimer applies.

Declaration of interest

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