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University of Reading, Agricultural & Food Economics; School of Agriculture, Policy & Development, Whiteknights, PO Box 237, Reading, RG6 6AR, United Kingdom

astrail@reading.ac.uk



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Would Functional Agricultural Foods Improve Human Health? ¹

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*University of Reading, Agricultural & Food Economics; School of Agriculture, Policy & Development, Whiteknights, PO Box 237, Reading, RG6 6AR, United Kingdom
aestrail@reading.ac.uk*

Concern over diet-health relationships has moved to the forefront of public health concerns in the UK and much of the developed world. It has been estimated, for example, that obesity costs the UK National Health Service up to £6b per year (Rayner and Scarborough, 2005), but if all consumers were to follow recommended healthy eating guidelines there would be major implications for food consumption, land use and international trade (Srinivasan et al, 2006). This is unlikely to happen, at least in the short term, but it is realistic to anticipate some dietary adjustment toward the recommendations, resulting in an improvement in diet quality (Mazzocchi et al, 2007). Although consumers are reluctant to make major changes to their diets, they may be prepared to substitute existing foods for healthier alternatives.

Three of the most prominent nutritional recommendations are to consume more fruit and vegetables, which contain phytochemicals beneficial to health, reduce consumption of saturated fatty acids (SFA) and increase intake of long-chain *n*-3 fatty acids (FA). In the first case, consumption of fruit and vegetables has been stable at around three 80 g portions per person per day according to the Health Survey for England. It is estimated that 42,200 deaths per year could be avoided in England and 411,000 Quality Adjusted Life Years (QALYs) could be saved if fruit and vegetable consumption were increased to the recommended 5 portions per day (Ofcom 2006). As well as continuing to encourage people to eat more, it could be desirable to ‘intensify’ the beneficial phytochemical content of existing fruit and vegetables.

In the case of long chain *n*-3 FA, daily intake in UK adults is only about 25% of the recommended value of 450 mg (Givens et. al. 2006). It is estimated that 3,300 deaths per year in England could be avoided and 30,000 Quality Adjusted Life Years (QALYs) could be saved if saturated fat intake were reduced by 2.3% of energy intake (Ofcom, 2006). Therefore, as well as seeking to change diets away from meat and dairy, which may not always be appropriate for other nutritional reasons, it could also be desirable to improve the fatty acid profile of existing livestock products. These possible changes in fruit and vegetable and livestock products would bring them into the category of functional food, which Diplock et al. (1999) define as food that improves health or wellbeing, or reduces disease risk, through beneficially targeting the body’s functions. It is likely that efforts to improve the functionality of food would be more acceptable to consumers if pursued through alterations in husbandry rather than genetic modification or novel processing methods. Selective breeding of crops and livestock has emphasized yield, appearance and shelf-life at the expense of other attributes like taste and health. Alternative

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varieties and breeds may also have superior health properties.

The UK Government's Strategy for Sustainable Farming and Food (Defra, 2002a) identified healthy eating as a key principle, with a major objective to produce safe, healthy products in response to market demands and to ensure that everyone has access to nutritious food. The strategy aims to secure a profitable and internationally competitive food and farming sector that respects the environment and improves nutrition and public health. The strategy builds on the recommendations of the Independent Policy Commission on the Future of Food and Farming (the Curry Commission), and in its response to the Commission's Report (Defra, 2002b), the Government made the commitment that its stance on reform of the Common Agricultural Policy (CAP) would be informed by analysis of the health impacts, as well as the environmental effects.

This paper draws from the research project *Implications of a Nutrition Driven Food Policy for the Countryside* which draws together natural and social scientists at the University of Reading to examine some of these issues. Specifically the answer to the question in the title of the paper depends on three sub-questions: (i) is it scientifically feasible to produce 'enhanced' agricultural products?; (ii) if so, would it raise farmers' costs of production? (iii) if so, would consumers be willing to pay a premium sufficient to cover the extra cost? If the answers to all these questions is yes, supplementary questions from a public policy perspective are: would the health benefits be significant?; and would the outcome be desirable from the perspective of land use and the rural environment?

Case studies are soft fruit and lettuce, grown in polytunnels in the UK, and lamb, traditionally reared in the lowlands on ryegrass pastures. With respect to lettuce and strawberries, both important sources of healthy phytochemicals, a new generation of UV-transparent plastic was expected to enhance phytochemical levels. In lowland fat lamb, biodiverse pastures are expected to have higher levels of long chain n-3 fatty acids and the hypothesis was that the meat from animals grazed on these pastures would also have an improved fatty acid profile.

1. Phytochemical enhancement in fruit and vegetables

Polyphenols are widespread in plant materials, and they have been the subject of an increasing number of studies to investigate their beneficial effects as dietary components. Polyphenols in food include flavonoids, with classes of particular interest as dietary components being anthocyanins, procyanidins, flavonols, isoflavones, as well as phenolic acids. Polyphenols, particularly flavonoids, are believed to make an important contribution to the beneficial effect of fruit and vegetables (Prior and Cao, 2000). It must be noted that there is uncertainty about how the polyphenols might exert their benefits physiologically, about the significance of their antioxidant properties, about the relative importance of the various classes of polyphenols, and about the extent to which dietary polyphenols might be absorbed (Scalbert and Williamson, 2000). Against this background of uncertainty, there is nevertheless a general agreement that a diet rich in a variety of polyphenols does have a protective effect against a wide variety of degenerative disease states.

Although polyphenols are widely distributed in fruits and vegetables, not all foods are equally good sources, and soft fruits such as strawberries, raspberries and blueberries are now recognised as especially rich sources (Beattie et al, 2005). For example, in a systematic screening of total antioxidants in commonly consumed plants, Halvorsen et al (2002) found that there was a 1000-fold difference between different plant materials (on a fresh weight basis), with the high-

est values being given by berries, which were in general 10-fold higher than the values obtained with other fresh fruits.

A particular polyphenolic constituent of strawberries, raspberries and blackberries that commands attention on account of its potential health benefit is ellagic acid, which is an anti-mutagen and anti-carcinogen present in these berries in much greater amounts than in other foods.

The most visually striking feature of berry fruits are their colours. These are due to the accumulation of anthocyanins, which, despite doubts over the extent of their absorption and bioavailability (Scalbert and Williamson, 2000), are believed to be important polyphenols present in the fruit that are beneficial for health. There is an enormous, genetically based variation in anthocyanin content in soft fruit. This is apparent, for example, in strawberry, where there are varieties that ripen as white fruit, with virtually no anthocyanin; while others will ripen to an intense redness. In raspberry intensely dark fruit can appear almost black. Anthocyanin content, and the related antioxidant capacity, of blueberry are also markedly enhanced by increasing the maturity (or ripeness) of the fruit when it is harvested (Prior et al, 1998).

The most important UK-grown berry crop, the strawberry, is now grown increasingly in plastic tunnels (approx. 80%). This enables the productive season to be extended by months either side of the traditional mid-summer period, thus greatly enlarging the market for UK grown strawberries. In addition, the polytunnels protect the crop from the worst of the UK weather, enhancing crop quality, and making harvesting easier and more economical. However, standard commercially used plastic films block much of the UV radiation, and there is evidence (Gould, 2004) to suggest that the flavonoids and other polyphenols have an important function in absorbing otherwise damaging UV radiation, and thus plants may respond to a low UV regime during growth by reducing their production of polyphenols. Research at the University of Reading is comparing the phytochemical content of crops grown on a semi-commercial scale under plastic films with different UV transparencies, including novel films that are fully transparent to UV radiation.

We are also including red-leafed lettuce (cv. Lollo Rosso) in our study, as this is a crop that is again being increasingly grown under plastic, and makes a growing and useful contribution of polyphenols to the diet. Lettuce is a widely available crop whose production worldwide increased by 17% between 2000 and 2004 and, since it is largely eaten raw, no loss of nutrients due to processing occurs. In temperate countries, lettuce is increasingly being grown in polytunnels in order to extend the seasonal availability, and enhance crop quality.

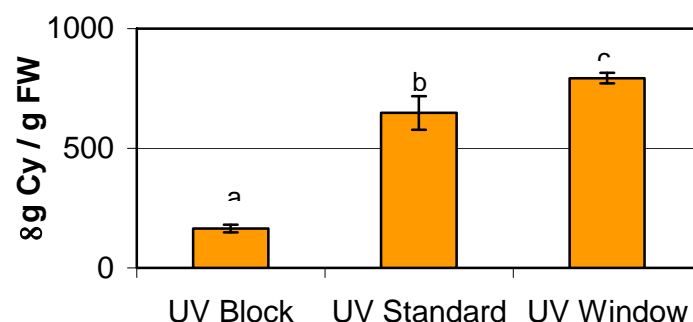


Figure 1. Lettuce Lollo Rosso Anthocyanin Content

Results of the Reading research are not as impressive as was hoped. Figures 1 and 2 are illustrative, indicating that anthocyanin content under UV transparent plastic is somewhat higher than under standard plastic and yield is somewhat lower, but differences are not dramatic. Similar results were obtained for berries. Preliminary studies suggest variety is a more important contributor than growing conditions.

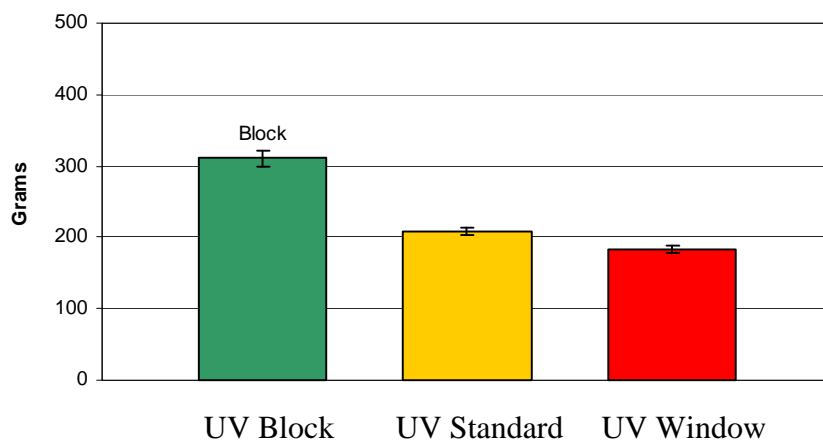


Figure 2. Lettuce—Lollo Rosso yield

2. The role of biodiverse pastures for enhancing fatty acid profiles of ruminant products

While ruminant meat often has a low total fat content and can be an important source of certain beneficial fatty acids (FA) (e.g. conjugated linoleic acid (CLA)), a large proportion of the FA are saturated. This is despite the fact that ruminant diets (especially those of grazing ruminants) are high in polyunsaturated fatty acids (PUFA). However, these are extensively biohydrogenated by rumen bacteria and protozoa (Harfoot and Hazlewood, 1988). Recent research has focused on reducing SFAs and increasing monounsaturates and *n*-3 long chain PUFAs in ruminant products. The most effective method of manipulating FA composition of ruminant meat is by dietary means with the strategic use of lipids (e.g. linseed oil) and forages, often with the aim of bypassing rumen biohydrogenation.

For forages, which contain a high proportion of their total FA as α -linolenic acid (~0.5 to 0.75; Harfoot and Hazlewood, 1988), there is now strong evidence (Chilliard et al, 2000) that diets based on fresh forage(s) are likely to lead to an improved FA profile in milk and meat, in particular a reduction in SFA and an increase in α -linolenic acid (C18:3 *n*-3) and conjugated linoleic acid. The scope to further exploit fresh forages depends on the ability to optimise the α -linolenic acid concentration in the plant material through herbage management and/or by reducing the extent of its biohydrogenation in the rumen.

Recently, there has been increased interest in alternative forage sources as a means of manipulating the FA profile of ruminant products. Certain biodiverse species have been positively correlated with increased polyunsaturated fatty acids in milk (Collomb et al, 2002) and cheeses produced in Alpine regions have been shown to have higher α -linolenic acid contents (Hauswirth et al, 2004). Following conservation of herbage of increasing species diversity, Lourenço et al. (2005) showed that the silage with most species diversity was associated with milk with the

highest content of conjugated linoleic acid and other biohydrogenation intermediates.

The effects of biodiverse pastures on the FA profile of ruminant meat is now emerging and is an area of growing research interest across many countries. Determining the effect of grazing lambs on three unimproved grazing systems (salt marsh, heather and moorland) with increasing biodiversity, Whittington et al. (2006) found no significant differences in muscle -linolenic acid content but total and *n*-6 polyunsaturated fatty acids increased with the level of biodiversity. Lourenço et al. (2007) measured the effects of four silages of increasing plant-diversity on lamb meat FA profile. Both subcutaneous and intramuscular fat of animals fed biodiverse and non-biodiverse silages had similar -linolenic acid contents, but the longer chain *n*-3 FAs were higher for the biodiverse diet, suggesting a possible enhancement of elongation and desaturation at the tissue level. The mechanisms behind this are as yet unknown but it is possible that secondary plant compounds contained in certain biodiverse species may be involved.

While there is growing interest in low-input grasslands and use of pastures with enhanced plant diversity, to-date little work has focussed on the role of individual plants present in biodiverse pastures, their FA content and profile, and how they may modify the process of rumen biohydrogenation. Together with the need for a greater understanding of the nutritional value of biodiverse forages and their effects *in vivo*, further research is also required to ensure plant species persistence through appropriate management (e.g. grazing) and to identify differences in plant foraging selection between animals and breeds.

This latter work is ongoing at Reading. Six plants species were selected; *Trifolium pratense* (red clover), *Lotus corniculatus* (birdsfoot trefoil), *Achillea millefolium* (yarrow), *Centaurea nigra* (knapweed), *Plantago lanceolata* (plantain) and *Prunella vulgaris* (selfheal). The overall objective was to achieve at least a 10% contribution from the biodiverse plants within the pastures which is similar to that achieved within the 'Entry Level Stewardship' (environmental management) schemes. Further work is on-going to complete the assessment of the overall contribution of the biodiverse species within the plots and to determine the amount of biomass within both the biodiverse and conventional plots. Future work will involve allocation of the lambs to the plots for grazing from mid-May until a target weight of ~45 kg is achieved. Analysis of the FA content and profile of specific tissues will be used to determine if botanically diverse pastures can be used to beneficially alter sheep meat composition.

On the down-side there is lost productivity and additional costs associated with lamb produced more extensively. This would reduce the margin by £0.69/kg (wholesale) or £0.11/kg if compensated under an English Stewardship High Level Stewardship scheme.

3. Consumer attitudes and willingness to pay

Literature on consumer acceptance of functional foods has been increasing in recent years. Both qualitative and quantitative approaches have been employed. Qualitative approaches are mainly through focus groups which have the advantage of allowing specific issues to evolve and be given detailed attention in the course of the research. They are also a valuable precursor in designing quantitative studies. Quantitative research includes surveys on attitudes to functional foods and evaluation of consumers' willingness to pay increased prices for functional foods. Recent studies have employed choice experiments to achieve this objective by replicating the types of choices that consumers are confronted with in everyday life. Thus they are offered a number of products characterised in terms of key attributes and asked to select their preferred product. Because they have to make trade-offs it is possible to infer statistically the values pla-

ced by consumers on the separate attributes which are used to define the choices available.

Results of the focus groups and attitudinal surveys indicate that the majority of people are unsure of the benefits of functional foods, preferring to buy conventional food; however, there has been a rise in the number of people reporting that they buy functional foods (Schmidt, 2000).

Functional foods include both plant and animal products, and the type of product appears to have an impact on consumer willingness to accept these foods. Bech-Larsen and Grunert (2003) found that a positive or negative perception of a functional food product is based strongly on the nutrient content of the base product and less so on its health claim. This is consistent with other studies which found that enhancement of plant products is more acceptable than the enhancement of animal products (Larue et al, 2004). Taste is also a major factor in determining consumer acceptance of functional foods, with consumers unwilling to sacrifice taste for potential health benefits (Verbeke, 2005; Urala and Lähteenmäki, 2007).

Evidence suggests that women have a more positive view of functional food, as well as towards natural and organic food (Verbeke, 2005). There are differences between men and women in the type of health claims they react positively to. For example, women prefer claims that are aimed at increasing a healthy digestive system, such as probiotic drinks; however, men generally prefer products with added vitamins and minerals, such as milk with added calcium to increase bone strength (Urala et al, 2003). In addition, evidence suggests that men and young people have less trust and are more skeptical of the claims that are made of different functional foods (Pelletier et al, 2002). Middle aged and older people are more accepting, believing that functional foods are beneficial to health (Poulsen, 1999). Other demographic groups that appear to be more enthusiastic about, and buy more, functional foods include those with a higher income and married couples (Katan and de Roos, 2004). However, recent research suggests that demographic differences in acceptance levels may be decreasing, with gender, age and education levels less important than they once were (Urala and Lähteenmäki, 2007).

Of the more quantitative approaches, Burton and Pearse (2002) assessed the willingness-to-pay by Australian consumers for beer which has increased antioxidants and consequent health benefits. These increases were assumed to be achieved through genetic modification. Their results indicated that consumers who stated that they considered their cholesterol level “to be important” were prepared to pay an additional A\$0.83 per bottle of beer. Kaye-Blake et al. (2005) conducted a similar experiment on apples and found that consumers would be willing to pay an additional NZ\$0.87 per kilo but this falls to NZ\$0.13 if the functionality is to be achieved by genetic modification. West et al. (2002) investigate consumers’ preferences for three products with functional attributes. They find that consumers are prepared to pay 67% more for tomato sauce which has an “anti-cancer” attribute, 63% more for potato crisps which have a “heart healthy” functional attribute and 24% extra for “heart healthy” boneless chicken breasts.

Two focus groups (total n=18) were conducted at The University of Reading during July 2006. The aim of these was to examine consumers’ attitudes to, and willingness to pay for, functional foods, particularly those of agricultural origin. Although naturally occurring functional foods, such as fruit and vegetables were purchased often, few participants reported buying enhanced functional foods each week. The main reasons for this were that participants felt they were an unnecessary addition to an already healthy diet (*“I tend to think if you’re having a balanced diet you shouldn’t need added stuff like that”*). However, there was some enthusiasm for them from people with deficiencies in their diet. Also, most participants said they would rather eat functional foods than take dietary supplements, though some reported

they felt they had better control over appropriate intake levels with a supplement (in foods it was often impossible to tell how much food would need to be consumed to affect health). Much of the scepticism towards functional foods was due to uncertainty over the validity of various health claims and the feeling that consumers were being exploited by firms wanting to market higher priced products (*"I would have thought it's just another way of trying to sell their product"*). Whilst participants were wary of government involvement in issues of food choice, they felt that regulation would be a positive way of encouraging higher levels of consumption.

With specific reference to enhanced strawberries and lamb, there was more enthusiasm for the lamb. People thought of strawberries as healthy and indulgence foods (*"But I buy strawberries to enjoy a strawberry in summer. I don't think about antioxidants"*); in contrast, lamb was considered pleasurable but potentially unhealthy, so a healthier version was positively perceived (*"I'm generally a sceptic, but I probably would be swayed by that because I'm a heavy meat eater, but I don't eat a lot of oily fish"*¹ and *"Well I would rather have lamb less often and have decent meat"*). With lamb there was the added bonus that people perceived the extensive grazing on bio-diverse pastures to be more natural than modern intensive practices (*"So you are basically going back to producing things like they used to be produced, letting animals eat naturally"*). It is clear that characteristics of the product and the nature of the health benefit are important and there are no easy generalisations to be made.

From these qualitative findings, a choice experiment questionnaire was developed looking at willingness to pay (WTP) for enhanced lamb, strawberries and lettuce. Analysis of choice experiments conducted using a face to face survey carried out in Autumn 2006 (n= 200) suggests positive willingness to pay with a mean premium of £1.50/kg for strawberries, 48 pence per lettuce and over £2/kg for lamb. We are concerned that the WTP is unrealistically large (as it is in other studies mentioned above), perhaps indicating that consumers view choice experiments as too hypothetical (a criticism of other methods of value elicitation choice experiments are supposed to overcome by forcing people to consider trade-offs among product attributes); we are further examining the data to try to shed light on this issue. Even if inflated, the WTP is much more than enough to pay for any reduction in yield associated with the production process.

4. Conclusions

Plants and animals have been bred and produced in intensive systems that emphasise yield, shelf-life and appearance. It is probable that alternative varieties/breeds and production methods of many products could enhance health properties of foods. In some cases the change would imply a less intensive production system with benefits to the rural environment—landscape and biodiversity. The studies carried out in Reading are not conclusive in this respect, but generally supportive of the notion. This appears to be a fruitful area of investigation and we expect the future will see much more scientific research on the subject, especially as consumer research suggests considerable willingness to pay for such products. Consumers will, however, need to be convinced they are not being exploited to enhance companies' profits.

1. Oily fish is the main natural source of n-3 fatty acids

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