A review of the dietary, health and environmental status of whole grain cereals

Lillywhite RD and Sarrouy C

Warwick Crop Centre, School of Life Sciences, University of Warwick

18 November 2014

Contents

"The University does not undertake that this work will lead to any particular result, nor is the success of such work guaranteed. Any results are provided 'as is' and no assurance is given as to the suitability of the results for a particular application. Any conditions, warranties, representations or other terms whether express or implied by statute or common law or otherwise are excluded to the fullest extent permitted by law."

Introduction

This review was commissioned in response to growing media reporting that wheat products have been implicated in, or associated with, adverse dietary issues, despite their known and substantial health benefits. Reports in the popular media of digestive issues caused by consumption of wheat-based products and the profusion of low carbohydrate diets has resulted in many consumers switching to grain- and wheat-free diets. This is viewed by many health professionals as a worrying trend as wheat is estimated to supply 20% of global food calories and have a number of important health benefits beyond just nutrition.

The objective of this review is not to provide a rebuttal to heavily promoted diet plans but to provide a counterpoint; a science and research-based assessment of the benefits of whole grain consumption. A message that appears to have been lost in media headlines and the reporting of pseudo-science.

The principal aim of this review is to examine the status of whole grain products, including wheat, and their role in providing a healthy and nutritious contribution to diet. In addition, the review will consider the definition of whole grain and derivatives, environmental issues associated with the supply chain of selected breakfast cereals, intolerance to wheat and the human adaptation to consuming whole grains. This is a short review with a wide scope but it is hoped that the holistic approach will inform the discussion on the value of whole grains for human consumption.

The starting point for the review was the identification and evaluation of a number of conceptual statements attributed to whole grain and wheat-based products; these are listed below:

- Whole-wheat is a confusing and poorly defined term;
- Lightly processed wheat has dietary and nutritional benefits;
- Wheat is as nutritionally rich as oats;
- Wheat is an important source of micronutrients, with breakfast cereals an important natural source of these for the whole family;
- British grown whole-wheat is better for the environment;
- True wheat allergy and intolerance is rare;
- Whole-wheat is a rich source of fibre and carbohydrates;
- Humans are adapted to digesting whole grain cereals.

The review was based on a search of the academic and grey literature using a systematic keyword search. The keywords were wheat, gluten intolerance, gluten sensitivity, c(o)eliac disease, whole grain, wholemeal, health, environment and Life Cycle Assessment. The approach was to consider each statement separately, to assess the level of accuracy or ‘truth’ within each statement, and incorporate the evidence into a broader structure. The purpose is to provide a compact assessment and try and bring some clarity and clear perspective to a complex subject.

The review was commissioned and funded by Weetabix Food Company.

1. The definition of whole grain, wholemeal and whole-wheat

This section considers the definition of whole grain and how this term compares to others in common usage, e.g. whole-wheat. It will also address the levels of processing that wheat undergoes and the range of products that are produced as a result.

Defining the difference between whole grain and processed (i.e. refined) cereals

The terms 'whole grain', 'wholemeal' and 'whole-wheat' appear frequently, and sometimes inter-changeably, and create a considerable level of confusion in both the agri-food industry and their customers.

The difference between whole grain, wholemeal and whole-wheat is scientific, cultural and marketing. Studies have suggested that the term 'whole grain', which originated in the United States, actually means the same as whole-meal which is commonly used in the UK (Jacobs, 2001). However, these terms have often been used as a marketing tool to refer to different products. The term whole grain applies to all grain types and is prominently displayed on many food products, e.g. breakfast cereals, breads, biscuits, pasta and noodles. Whilst the usage of wholemeal typically refers to flour made from whole grains.

The term 'whole' refers to the fact that all the components of the grain, e.g. endosperm, bran and germ, are retained during the processing stage. The term whole-wheat is the same as whole grain except that it applies exclusively to wheat products; it could as easily be written as whole grain wheat which would at least reduce the confusion over nomenclature. The term 'whole' can be applied to any grain product although most marketing uses the full version, e.g. whole grain barley, whole grain oats and whole grain rye. The origin of the term 'whole-wheat' is unknown but is now used as a marketing tool to promote the health benefit of a product. Therefore companies often like to use both terms (whole grain and whole-wheat) when marketing their products to highlight its unprocessed status and health qualities; although using both together adds to the confusion over the intended meaning.

In the UK, there is no official definition but the one proposed by the IGD Whole Grain Working Group[1] is generally accepted. This states that whole grain "refers to the edible entire grain after removal of inedible parts such as the hull and glume. It must include the entire germ, endosperm and bran".

From a scientific perspective whole grains are defined by the American Association of Cereal Chemists International and the FDA as "intact, ground, cracked or flaked fruit of the grain whose principal components, the starchy endosperm, germ and bran, are present in the same relative proportions as they exist in the intact grain." This approach is supported by Jonnalagadda et al. (2011) who state that "whole grain foods can contain the intact whole grain or be reconstituted in that they have components of the whole grains recombined to the relative proportion as naturally occurring in the grain kernel. The majority of products found on retail store shelves would be considered reconstituted whole grain products".

[1] IGD. www.igd.com/our-expertise/Nutrition-food-and-farming/Fruit-vegetables-and-wholegrain/3433/UK-Whole-Grain-Guidance/ [Accessed 17/11/2014]

The effects of processing

The section examines how processing may affect both the structure and function of whole grains. Whole grains undergo different levels of processing depending upon their intended purpose. This can range from simple steaming to complete dismantling and reconstitution of their component parts. The level of processing is known to affect their health and dietary properties.

"Whole grain foods that undergo processing and reconstitution must deliver the same proportion of bran, germ, and endosperm as that of the original grain to be considered whole grains. The outer bran layer is composed of nondigestible, mainly insoluble, poorly fermentable carbohydrates (such as cellulose, hemicelluloses, arabinoxylan), and the inner germ and starchy endosperm contain viscous soluble fibers, fermentable oligosaccharides, resistant starch (RS), lignans, vitamins, minerals, polyphenols, oils, and other phytonutrients. During the refining of whole grains into white flour, the outer bran and inner germ layers are removed and the remaining endosperm is processed into flour. Thus, compared with refined grains, whole grains are inherently richer in dietary fiber, containing ~80% more dietary fiber than refined grains. Furthermore, as a consequence of the refining process, there are substantial losses in essential minerals, vitamins, and phytonutrients" (Jonnalagadda et al., 2011).

The difference between relatively unprocessed or lightly processed (unreconstituted) whole grain and highly processed (reconstituted) whole grain adds another level of confusion, and one that is more than just of academic interest. While both types may be called whole grain, a number of research articles point out that reconstituted whole grain products lack the 'synergistic' value of lightly processed whole grains and therefore will lack some of the nutritional and health benefits that are attributed to relatively unprocessed or lightly processed whole grain products.

Where science has tried to provide a clear distinction between whole grain and wholemeal, the definitions have failed due to the pressure of brand marketing. Jenkins et al. (1988) suggested that "wholegrain should be used for products containing specified percentages of un-milled components (for example, 80% whole grain, 50% whole grain) and some other term, perhaps "wholemeal", should be used to indicate a milled flour product containing all the components of the whole grain." This could perhaps reflect that the components were not present in the same ratio as in the original grain. Since the late 1980s when this article was published the term wholemeal has evolved to mean the flour produced from milling whole grains, where nothing is removed. This evolution has been recognised by Smith et al. (2003) who reported that "in preparation for human consumption grains are usually subjected to some type of processing. This grain treatment is useful in terms of enhancing various organoleptic properties to optimise consumer acceptance, producing shelf-stable products and conditioning the product for digestion and absorption. During processing, the milling procedures remove contaminants but also remove the nutrient-rich bran and germ layers from the starchy endosperm".

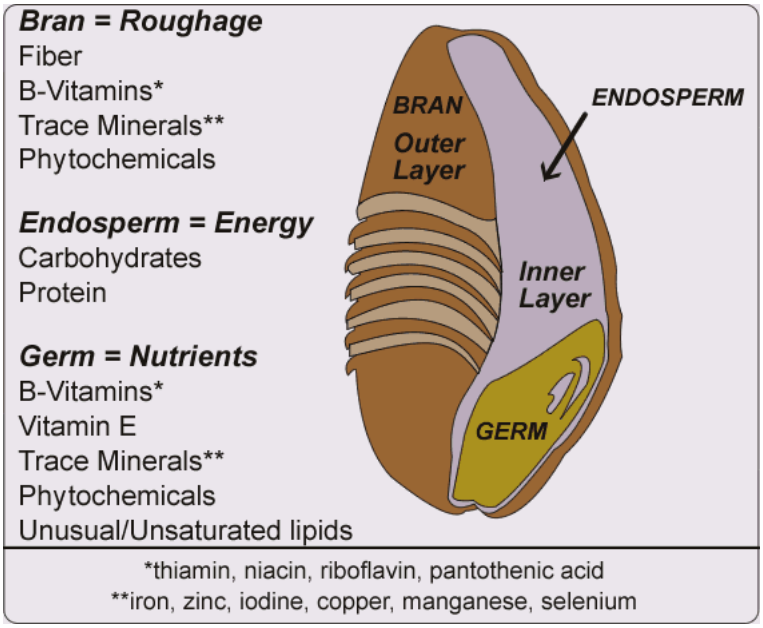

Figure 1. Wheat kernel components (Whole Grain Cereal, n.d.)[2]

A wheat grain (kernel) is composed of bran (14%), germ (3%) and endosperm (83%) (Figure 1). When kernels are milled for the production of flour, all or parts of the grain can be extracted during the process. The higher the share of grain used for the production of flour, the higher its extraction. Hence, wholemeal flour made using the entirety (100%) of the original grain is denominated 'high extraction' and it will contain all original components of grains, i.e. the bran, the germ and the endosperm (Smith et al., 2003). In contrast, white flours are low extraction (70 to 75%) and only contain the endosperm. Brown flour is situated in between high and low extraction with approximately 90% extraction, equating to the endosperm and the germ but very little bran. This information is illustrated in Figure 2. Lang and Jebb (2003) summarise the outcome from the milling stage by stating "the milling process determines how much of the whole grain is retained, with different retention levels inevitably impacting on the nutrient and non-nutrient components of the end product". This understanding of the influence of extraction rate on the description of the resultant flour is confirmed by The National Wheat Improvement Committee (2014) which stated that fortified refined (white) flour is not whole grain.

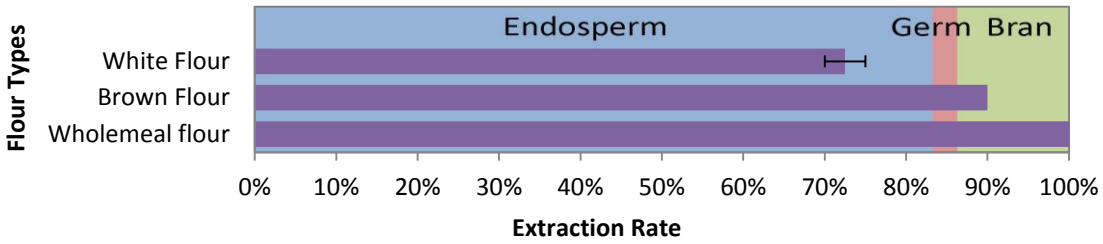

Figure 2. Extraction rates for different types of flour

[2] Whole Grains Council. http://wholegrainscouncil.org/whole-grains-101/definition-of-whole-grains [Accessed 17/11/2014)

The degree of processing not only affects the amount and ratio of the major components but has an indirect effect on both the efficacy of these individual components and their combined synergistic value. So while the work conducted by Slavin et al. (2001) suggests that "most research finds that the processing of whole grains does not remove biologically important compounds", other research by Seal (2006) identifies that reconstituted products may lack the synergistic health benefits of the original material. The process of synergy within unprocessed whole grain products is difficult to show although an increasing number of studies are suggesting that it may have considerable health benefits (Fardet, 2010).

The effect of processing is shown in Table 1. Five flours are used to illustrate how the progression from lightly processed (wholemeal) to heavily processed (white self-raising) affects product composition. Wholemeal flour has the highest protein, fat and dietary fibre values but these reduce as the level of processing increases. In contrast, the energy and starch content increases with processing level as the less dense but healthy bran layer is removed.

The evidence from different flour grades is fairly conclusive. The lower the level of processing and therefore higher extraction rate, the greater the health benefits of the products. However, this is not surprising since multiple studies over the years have consistently shown this to be the case. For the vast majority of people, consuming whole grain products is beneficial and these products should feature in all healthy diets. This recommendation is supported by all major public health bodies. The difference between relatively unprocessed or lightly processed and highly processed but reconstituted whole grain products is still an area of emerging evidence. Research to date suggests that the former, where the different components maintain their structural integrity, has a synergistic value that is greater than highly processed whole grain product.

Table 1. Comparison of the nutritional value of different types of wheat flour (Food Standards Agency, 2014)

Composition of food per 100g edible portion							
			Wholemeal	**Brown**	**White**, breadmaking	**White**, plain	**White**, self-raising
Water		g	11.1	11.6	11.7	11.6	11.3
Total nitrogen		g	2.0	2.2	2.0	1.6	1.6
Protein		g	11.6	12.2	11.3	9.1	8.9
Fat		g	2.0	2.0	1.2	1.4	1.5
Carbohydrate		g	69.9	72.5	79.2	80.9	79.6
Energy		kcal	327	339	353	352	348
		kJ	1,390	1,441	1,504	1,501	1,480
Starch		g	61.8	66.8	73.9	76.2	74.3
Total sugars		g	1.4	1.0	0.5	0.6	0.6
Individual sugars	Gluc	g	Tr	Tr	Tr	Tr	Tr
	Fruct	g	Tr	Tr	Tr	Tr	Tr
	Sucr	g	0.3	0.9	0.4	0.5	0.5
	Malt	g	0	0.1	Tr	0.1	0.1
Diet. fibre	NSP	g	8.8	6.9	3.1	3.4	3.1
Fatty acids	Satd	g	0.3	0.3	0.3	0.4	0.4
	Mono-unsatd	g	0.2	0.2	0.2	0.2	0.2
	Poly-unsatd	g	0.9	0.8	0.3	0.2	0.4

2. Health benefits

Health benefits of plant based diets

There is considerable discussion as to the role of diet in health and to what extent lifestyle exerts a greater or lesser influence on health in comparison to food and drink consumed. Despite the complicated nature of human lives and the different aspects that can influence human health, what we eat is a clear and readily identifiable component to increase or decrease our risk of disease.

Considerable research supports the main conclusion that people should eat a healthy diet to enable them to live longer and that a healthy diet should contain a balance of the main dietary requirements (carbohydrates, proteins, fats, fibre, essential nutrients, vitamins and minerals). Whilst there are contrasting views on how that can be achieved, as witnessed by the sheer number of different diet plans on offer, typically a diet to reduce weight revolves around limiting calorie intake. However, it is important to maintain the correct balance between the proportions of carbohydrates, proteins and fat to ensure a healthy lifestyle as well as an optimal body weight. For many people attaining and maintaining this balance is difficult which is probably the reason why so many different diet plans exist. A meta-analysis by Johnston and colleagues compared 59 articles reporting on 48 unique randomised trials and confirmed that significant weight loss could be achieved by following a low-carbohydrate or low-fat diet but that weight loss differences between individual diets were small (Johnston et al., 2014).

The different food products that comprise a healthy diet are many and varied but there is a general level of understanding around a few of them. For example, there is evidence to suggest that consumption of high levels of meat, especially red meat, is damaging to health (Chauveau et al., 2013; Ashen, 2013; Pilis et al., 2014). Whilst the clarity on the health benefits provided by a completely vegetarian diet is debated, it is considered that a diet with a reduced meat content is better for health. Research undertaken by Le and Sabate (2014) reported that “vegetarian diets confer protection against cardiovascular diseases, cardiometabolic risk factors, some cancers and total mortality and that lacto-ovo-vegetarian diets seem to offer additional protection for obesity, hypertension, type-2 diabetes, and cardiovascular mortality”. The aforementioned conclusion was further supported by work conducted by Ashen (2013) who endorsed that “there is growing evidence that consumption of a vegetarian diet as well as specific components of a vegetarian diet lower the incidence of cardiovascular disease (CVD) and death” and Pilis et al. (2014) who also noted that “on balance it can be reasonably concluded that the beneficial effects of a vegetarian diet significantly, by far, outweigh the adverse ones”.

However, on balance, the change in diet is much more subtle than diets with and without meat. Several researchers have noted that there is a significant shift towards more processed foods, taking place all over the world, that’s contributing to a rising epidemic of obesity and related diseases (Gibbons, 2014). It has been considered that if more people ate more fruits and vegetables, a little meat, fish, and some whole grains (as in the highly touted Mediterranean diet), and exercised for an hour each day, the reduction in health risk would be significant (Lang and Jebb, 2003). This consideration and the research by Lang and Jebb (2003) reiterate that regularly consuming whole grain foods were found to have other beneficial dietary and lifestyle habits. Research studies have also identified that a much larger proportion of people who keep to a healthy

body weight do so with diets that are high in fruits, vegetables, low-fat dairy products, lean meats and whole grains compared to those who follow other types of diets (Jones, 2012).

Health benefits from the consumption of whole grains

Whole grain products have a reputation for being healthy; a reputation which is based on a wide and robust evidence base. The benefits can roughly be divided into direct health benefits (nutritional value, body weight management and gastrointestinal health), supplying dietary nutrients and the protection against, and reduction in risk of, various diseases (coronary heart disease, diabetes, and cancer).

This evidence is recognised and acted upon by public health authorities globally. In the UK, NHS Choices[3] recommends that people should base their meals on starchy foods and choose wholegrain varieties since they contain more fibre and can make help the feeling of fullness. This advice is also available in the United States, where the US Department of Health and Human Services and US Deparment of Agriculture (2010) recommendation is to "reduce intake of refined grains and replace some refined grains with whole grains". Internationally, "The *CINDI*[4] *dietary guide* highlights 12 key areas for action. Their top two actions are: eat a nutritious diet based on a variety of foods originating mainly from plants, rather than animals; and eat bread, grains, pasta, rice or potatoes several times a day. The World Health Organisation recommends that more than half the daily energy should come from a mixture of foods containing bread, grains, pasta, rice and potatoes. This means that, in a diet comprising 6,000 kJ (1,400 kcal) at least half of total energy (3000 kJ / 700 kcal) should come from this group" (World Health Organisation, 2000). In the UK, the Scientific Advisory Committee on Nutrition, which advises Public Health England and other government agencies and departments on nutrition and related health issues, recently reviewed all relevant evidence to produce a draft carbohydrates and health report[5]. They recommended that "the dietary reference value for total carbohydrate should be maintained at a population average of approximately 50% of dietary energy".

However, there is growing concern amongst medical and dietary professionals that individuals do not consume enough fibre. Consumption of bread has been in decline for many years which combined with greater consumption of processed products has resulted in a drop in whole grain and fibre consumption. This trend was highlighted by Thane and colleagues who reported that the "whole-grain intake of British adults was low in 1986–7 and became even lower over the subsequent decade. (…) Breakfast cereals and bread (mainly wholemeal bread) contributed most to whole-grain intake, with modest contributions from biscuits (7–12%). However, whereas bread contributed most (54%) to whole-grain intake in 1986–7, followed some way behind by breakfast cereals (28%), by 2000–1 the contributions of these two major sources were almost identical (44–45%), reflecting the increased popularity of wholegrain breakfast cereals and overall decline in bread consumption in recent years" (Thane et al., 2007). The 2014 National Diet and Nutrition Survey[6] contains the

[3] NHS Choices. www.nhs.uk/Livewell/Goodfood/Pages/eight-tips-healthy-eating.aspx [Accessed 17/11/2014]

[4]Countrywide Integrated Noncommunicable Disease Intervention (CINDI), http://www.euro.who.int/en/health-topics/noncommunicable-diseases/cancer/publications/pre-2009/a-strategy-to-prevent-chronic-disease-in-europe.-a-focus-on-public-health-action.-the-cindi-vision (Accessed 27/10/2014].

[5]SACN. www.gov.uk/government/uploads/system/uploads/attachment_data/file/339771/Draft_SACN_Carbohydrates-_and_Health_report_consultation.pdf [Accessed 17/11/2014)

[6] NDNS. www.gov.uk/government/statistics/national-diet-and-nutrition-survey-results-from-years-1-to-4-combined-of-the-rolling-programme-for-2008-and-2009-to-2011-and-2012

results from the years 2009 to 2012 and shows a further decline in fibre consumption. Mean adult intake at 13.8g per day is well below the recommended level of 18g per day.

A similar result was reported for British young people aged 4 to 18 years which showed that "the consumption of whole-grain-containing foods by young people in Great Britain is very low, with a median whole-grain intake of just 7g/d. There was no whole-grain intake by 27% of participants during the survey period. The low whole-grain intake of the present study is consistent with that reported in the USA, among young people (Albertson & Tobelmann, 1995; Kantor et al., 2001; Harnack et al., 2003) and adults (Cleveland et al., 2000), and among British adults (Lang et al., 2003). (…) The major sources of whole-grain intake in these British young people were breakfast cereals (56%) and bread (25%), with modest contributions from biscuits (9%). However, one-half consumed no whole-grain-containing breakfast cereal and three-quarters no wholemeal bread. (…) Breakfast cereals contributed more to whole-grain intake in young people than to consumption occurrences of whole-grain foods in adults (56% versus 34%) while the contribution from wholemeal bread was significantly lower (21% versus 46%)" (Thane et al., 2005). This trend suggests that whole grain breakfast cereals are playing an increasing important role in the supply of dietary fibre. But it remains a fact that overall consumption of whole grain products is decreasing while over the same period of time there has been a substantial rise in childhood obesity, as well as adult obesity, with obesity being the single biggest risk factor for type 2 diabetes mellitus.

The diets of many young people remain deficient in some nutrients which can affect health later in life. (Ruxton and Derbyshire, 2011) reported that "young adults (aged 15 to 24 years) have some of the lowest intakes of fruit, vegetables, low-fat dairy foods and oily-fish in the UK, whilst at the same time having some of the highest intakes of salt, alcohol and caloric soft drinks". They found that "Vitamin A intakes have improved recently, which may be due to slightly increased intakes of vegetables, but they remain below optimal levels but that vitamin D intakes fail to meet the recommended daily allowance of 5mg set by the European Union". In summary, they found that calcium, magnesium, potassium, zinc and iodine were consistently low in diets. They added that "the project EAT (Eating Amongst Teens) study found that 45 per cent of females and 17 per cent of males had unhealthy weight control behaviours. Irregular meal patterns led to poor quality diets and lower intakes of key micronutrients, including calcium and folate. The evidence reviewed here suggests that the diets of young people in the UK often lack key nutrients for development and long-term optimal health. Overall, the diet quality of young people today may not be meeting their physiological and mental needs".

Direct health benefits

The concept that whole grains are good for health is based on the conclusion from multiple investigations and this message has been promoted by various government and public health bodies. Southgate (2000) cited in Smith et al. (2003) reported that "although categorised as 'carbohydrates', grains deliver much more than carbohydrates to our nutrient intakes. Whole grains are important sources of dietary fibre and resistant starch. (…) Grains are also major sources of plant proteins. (…) Grains also serve as important sources of many vitamins including vitamin B complex and vitamin E, and many minerals including Fe, Mg, Se and Zn. Most of these nutrients are concentrated in the outer bran and germ layers, although the endosperm contains much of the starch and protein as well as considerable quantities of riboflavin and pantothenic acid". Smith et al. (2003) reviewing the behavioural, attitudinal and dietary responses to the consumption of whole grain foods found that "whole grains deliver a wide range of important nutrients and phytochemicals to our diet, which may

work in synergy to promote health and help prevent disease". They concluded by saying that "breakfast foods may be important intervention targets for increasing whole grain consumption. Indeed, the present breakfast study has shown that for this meal very favourable changes in nutrient intakes can be achieved through a dietary change that is simple and, potentially, readily transferable".

The understanding of the 'synergy' effect has improved to the point where Fardet, in his 2010 review, could state that epidemiological studies have clearly shown that whole grain cereals can protect against obesity, diabetes, cardio-vascular diseases and cancers. He concluded that the 'whole grain package' was the result of "the synergistic action of several bioactive compounds (which) contribute to the health protection and/or maintenance of one physiological function, not just one compound". He also warned against "destroying the botanical structure" since the same components in a reconstituted form would lessen the health benefit (Fardet, 2010).

Truswell is his 2002 review concluded that the higher soluble fibre in oats could result in a modest reduction of cholesterol but that there is "no clear association, negative or positive, between total cereal consumption of the different cereal species and products vary between communities" (Truswell, 2002).

Fibre

All whole grain products are rich in dietary fibre and increased consumption of fibre for improved gastrointestinal health is recommended. The US Department of Health and Human Services and US Deparment of Agriculture (2010) recognise that "whole grains are a source of nutrients such as iron, magnesium, selenium, B vitamins, and dietary fiber. Whole grains vary in their dietary fiber content. Moderate evidence indicates that whole grain intake may reduce the risk of cardiovascular disease and is associated with a lower body weight. Limited evidence also shows that consuming whole grains is associated with a reduced incidence of type 2 diabetes. Consuming enough whole grains helps meet nutrient needs. Choosing whole grains that are higher in dietary fiber has additional health benefits. At least half of recommended total grain intake should be whole grains. Less than 5 percent of Americans consume the minimum recommended amount of whole grains, which for many is about 3 ounce-equivalents per day. On average, Americans eat less than 1 ounce-equivalent of whole grains per day".

These findings are supported by the 2014 draft report from the UK Scientific Advisory Committee on Nutrition which states that "cohort studies indicate that a diet rich in dietary fibre is associated with a lower incidence of cardiovascular diseases, coronary events, types 2 diabetes mellitus and colo-rectal cancer". The report clarifies this further by stating that "higher whole grain consumption is associated with a lower incidence of cardiovascular disease, stroke, hypertension, type 2 diabetes mellitus and colon cancer". They recommend that adults should consume 30g of dietary fibre per day which should be achieved from whole grains, pulses, potatoes, vegetables and fruits.

The role of dietary fibre in health has been the subject of much research. Jonnalagadda et al. (2011) reported that "whole grains provide the gastrointestinal tract with more than fibre, thus contributing to their role in maintaining gastrointestinal function and protection against disease. The various components present in whole grains may act synergistically to help improve bowel function and provide protection against gastrointestinal cancers, inflammation, and other disease states while strengthening barrier function and

providing immune support. Increasing intake of whole grains is highly recommended for improving gastrointestinal health". They also added that "future research is needed to better understand the mechanism of action of whole grains in gastrointestinal health".

The amount of dietary fibre (or non-starch polysaccharides, NSF) varies with grain type and processing. Barley contains the highest amount of fibre, followed by rye, wheat and oats. Rice is a poor provider of dietary fibre (Table 2).

Table 2. Fibre (NSP, g/100g dry matter) in cereals and grains

Commodity	Soluble	Insoluble	Total
Bread, wholemeal	2.3	6.9	9.2
Bread, rye	6.7	6.6	13.3
Barley	4.5	12.2	16.7
Bread, white	1.6	1.1	2.7
Quaker oats	5.0	3.5	8.5
Wheat	2.4	9.0	11.4
Rice (pearled)	0.3	0.5	0.8
Whole wheat breakfast cereal			9.7

(modified from Kumar et al., 2012)

Differences between types of whole grains

The major health benefits arise from the consumption of whole grain as compared to more processed grain based products although there are some differences between the whole grains themselves. This short section considers the differences between wheat, oats and rice. This discussion is based on the analysis of oatmeal (quick cook, raw), rice (brown, raw) and wheat (wholemeal flour); the composition and nutritional values are shown in Table 3.

Nutritional value

The nutritional value of these grains differs very little. Wheat has the highest protein content, oats the highest fat content and rice the highest carbohydrate content; however, the variation across the three grain types is fairly small and the differences are unlikely to be significant in a typical diet. Their energy, starch and sugar contents are also similar which given that they are all plant-based grains is unremarkable.

The fatty acid content of the three products are, however, quite different with wheat containing the lowest amount. However, care should be exercised when interpreting these data since the levels of both saturated and unsaturated fatty acids in oats are still less than those found in many other food products, e.g. yoghurt. In terms of vitamins, there is little difference between the grains and this area may be inconsequential since many products are fortified with vitamins during the processing stage.

Indirect health benefits

The role of whole grains in preventing type 2 diabetes has also been investigated over many years. A study by McDougall working on the potential role of phytochemicals in whole-grain cereals for the prevention of type 2 diabetes found that diets high in whole grains are associated with a 20-30% reduction in risk of developing type 2 diabetes (McDougall, 2014). Type 2 diabetes is an epidemic that affects an ever-increasing proportion of the U.S. and global population. The interactions among genes, environment, diet, and lifestyle all play an important role in insulin resistance and the subsequent multifactorial pathogenesis of diabetes. Lifestyle modification and weight control are major factors in the prevention and treatment of diabetes.

Table 3. Comparison of the nutritional value of oatmeal, brown rice and wheat flour (FSA, 2002b)

		Unit	**Oatmeal**, quick cook, raw **(A)**	**Brown rice** raw **(B)**	**Wheat flour**, wholemeal **(C)**
Total nitrogen		g	1.9	1.1	2.2
Protein		g	11.2	6.7	12.7
Fat		g	9.2	2.8	2.2
Carbohydrate		g	66.0	81.3	63.9
Energy		kcal	375.0	357.0	310.0
		kJ	1,587.0	1,518.0	1,318.0
Starch		g	64.9	*80.0*	61.8
Total sugars		g	1.1	*1.3*	2.1
Individual sugars	Gluc	g	Tr	*0.5*	0.1
	Fruct	g	Tr	*Tr*	Tr
	Sucr	g	0.8	*0.8*	1.0
	Malt	g	0.3	0.0	-
	Lact	g	-	0.0	-
Dietary fibre	NSP	g	7.1	1.9	9.0
Fatty acids	Satd	g	1.6	0.7	0.3
	Mono-unsatd	g	3.3	0.7	0.3
	Poly-unsatd	g	3.7	1.0	1.0
Na		mg	9.0	3.0	3.0
K		mg	350.0	250.0	340.0
Ca		mg	52.0	10.0	38.0
Fe		mg	3.8	1.4	3.9
Cu		mg	0.5	0.9	0.5
Zn		mg	3.3	1.8	2.9
Mn		mg	3.9	2.3	3.1
Se		μg	3.0	*10.0*	6.0
Vitamin E		mg	1.5	0.8	1.4
Thiamin		mg	0.9	0.6	0.5
Riboflavin		mg	0.1	0.1	0.1
Niacin		mg	0.8	5.3	5.7
Trypt/60		mg	2.6	1.5	2.5
Vitamin B6		mg	0.3	Na	0.5
Folate		μg	60.0	49.0	57.0

(A) 10 samples, 8 brands
(B) Literature sources
(C) Data from voluntary flour sampling scheme (VFSS), 1977-81 plus literature sources

Gross and colleagues suggested that increased intake of refined carbohydrates, along with decreased intake of fibre, contributes to the increasing prevalence of type 2 diabetes in the US. Evidence from epidemiological studies shows an inverse association between whole grain consumption and risk of type 2 diabetes (Gross et al. (2004) cited in Jonnalagadda et al. (2011)). It has also been noted by various researchers that many components in whole grains may act as antioxidants and thereby reduce or prevent the damaging effects of chronic inflammation that can arise in the gastrointestinal tract (Jacobs et al., 2007; Whole Grains Council and Oldways, 2009). This area of science is still developing but work by Liu (2007) suggested that "the majority of phytochemicals of whole grains that are beneficial for health are present in the bran/germ fraction" and therefore by deduction that eating less fibre and more refined carbohydrates is detrimental to health.

Further support for this view comes from Thane et al. (2007) who compared whole-grain intake of 2,086 adults aged 16 to 64 years from the 1986–7 Dietary and Nutritional Survey of British Adults with that of 1,692 adults aged 19 to 64 years from the 2000–1 National Diet and Nutrition Survey. They noted that the "epidemiological evidence suggests that higher consumption of whole-grain foods can significantly reduce the risk of chronic diseases such as cardiovascular disease, type 2 diabetes and some cancers". They concluded that the consumption of whole-grain-containing foods by young people in Great Britain is very low, with a median whole-grain intake of just 7g/d and that there was no whole-grain intake by 27% of participants during the survey period. They noted that low whole-grain intake in Great Britain was consistent with that reported in the USA, among young people (Albertson and Tobelmann, 1995; Harnack et al., 2003; Kantor et al., 2001) and adults (Cleveland et al., 2000), and among British adults (Lang and Jebb, 2003).

Whilst the health benefits that are associated with consumption of whole grain may not be new, it has taken some time to gather the evidence due to the complexity of human diets and lifestyles. As early as 1998, Jacobs et al. (1998) reported that "the case-control evidence is supportive of the hypothesis that whole-grain intake protects against various cancers". While Slavin (2000) found that "whole grains are rich in many components, including dietary fiber, starch, fat, antioxidant nutrients, minerals, vitamin, lignans and phenolic compounds, all of which have been linked to reduced risk of cancer". However by 2007, Liu could say that "the majority of phytochemicals of whole grains that are beneficial for health are present in the bran/germ fraction. In whole-wheat flour, the bran/germ fraction contributed 83% of total phenolic content, 79% of total flavonoid content, 78% of total zeaxanthin, 51% of total lutein, and 42% of total *β*-cryptoxanthin" (Liu, 2007). This was confirmed by Jonnalagadda et al. (2011) who reported that "whole grains play an important role in lowering the risk of chronic diseases, such as coronary heart disease, diabetes, and cancer and also contribute to body weight management and gastrointestinal health".

Micro-nutrients and fortification

Wheat is an important source of macro- and micro-nutrients, with breakfast cereals an important natural source. However, processing whole grains damages their structure, and certain components, e.g. bran, may be removed depending on the product and its purpose. Adding back the goodness, or fortification, recognises the importance of breakfast cereals (and other cereal based products) in delivering important vitamins and minerals to individuals. UK law states that non-wholemeal white and brown flour must be fortified with iron, thiamin and niacin as these important components may be removed with the bran during the milling process. An industry body, the British Nutrition Foundation (2009) recognises that "cereal and cereal products play an important role in the diet and are a major source of many nutrients for both children and adults, due in part

to the mandatory fortification of all wheat flour (apart from wholemeal) with iron, thiamin and niacin, and all flours (except wholemeal and some self-raising varieties) with calcium. Many breakfast cereals are also fortified on a voluntary basis and, according to the National Diet and Nutrition Survey (NDNS) these contribute 20%, 29% and 23% of the average iron intake of British adults, boys and girls, respectively. Fortified breakfast cereals also contribute 13% of the average daily vitamin D intake in men and women 20% of the average daily vitamin D intake in girls and 24% in boys".

Fortification, whether it is mandatory or voluntary is a complicated, divisive and ethical decision. The ability to fortify staple food products, such as bread and breakfast cereals, is central to the debate over the rights of individuals against the public health requirements of a country. However, there is recognition that some foods, e.g. wholemeal flour (and by association whole grain products) do not need fortification to provide a balanced supply of essential vitamins and minerals.

Gluten free diets

The adoption of a gluten-free diet by individuals diagnosed with coeliac disease can result in changes, either positive or negative, to their body mass index which indicates that weight maintenance counselling should be an integral part of coeliac dietary education (Kabbani et al., 2012). This issue was examined by Salazar Quero and colleagues who demonstrated positive results of the adoption of a gluten free diet. They reported that "clinically, at year of gluten free diet there was an improvement in weight and size. Analytically, there was an improvement in hemoglobin, ferritin, vitamin D, and parathyroid hormone in plasma. The gluten-free diet has minimal deficiencies, similar to those present in the diet with gluten, with an improvement in the lipid profile by increasing the proportion of monounsaturated fatty acids to the detriment of saturated fatty acids" (Salazar Quero et al., 2014).

However, other studies have shown the opposite result. Miranda and colleagues examined the nutritional differences between diets containing gluten and gluten-free diets and found that "following a diet based on gluten free products could suppose a nutritional imbalance for celiac[7] patients as well as for non-celiacs who follow a diet that includes many gluten free rendered foodstuffs". It has been observed by Rea et al. (1996) that following a gluten free diet resulted in an excess in energy, animal protein, and lipid intake, thus being partially responsible for the high percentage of overweight celiac children. Information obtained in the present study also suggested that a gluten free diet was related to a higher intake of fat in women (apparently saturated fat) and a lower dietary fiber in all patients. Several studies present in the literature have described excessive fat and protein intake, and reduced intake of carbohydrates and fiber in gluten free diets, which together are determining factors in cardiovascular disease risk. Taking these data as well as those from the present study into account, we suggest that following a gluten free diet could lead to a risk of cardiovascular disease for celiac patients. This fact is attributable to the nutritional composition of specific foods without gluten. (…) it can be concluded that there are marked differences between following a diet with gluten free products and a diet with gluten-containing products. This may represent a nutritional concern for celiac patients, but it may also be a problem for non-celiacs who consume many gluten free rendered foods, such as people trying to lose weight and/or who consider that this kind of diet is even healthier (Miranda et al., 2014).

[7] Coeliac is spelt as 'celiac' in the USA

Saturni and colleagues reviewing the safety and nutritional quality of gluten-free diets reported that "previous studies have demonstrated that gluten-free diet products are poor sources of minerals (such as iron), vitamins (such as folate, thiamine niacin and riboflavin) and fibre, therefore the nutritional content of gluten-free foods is an increasing area of concern. A promising area is the use of minor or pseudo-cereals such as amaranth, buckwheat, quinoa, sorghum and teff. (…) Minor cereals and pseudo-cereals are important sources of proteins and carbohydrates, especially fibre, and would permit a wider choice of foods for celiac individuals when selecting foods" (Saturni et al., 2010). Lee et al. (2009a) have suggested that the alternative grains such as oats and quinoa could represent less expensive alternatives with respect to standard gluten-free diet choices, quinoa and oats could increase dietary compliance also by reducing the economic burden of the diet". As far as concerns food price, Stevens and Rashid (2008) have reported previously that commercially available products labelled gluten-free were significantly more expensive than comparable products.

Satiety and weight loss

Satiety is the absence of hunger caused by the sensation of feeling full. Jonnalagadda et al. (2011) reported that "several mechanisms have been suggested to explain why whole grain intake may play a role in body weight management. Fiber content of whole grain foods may influence food volume and energy density, gastric emptying, and glycemic response. Whole grains has also been proposed to play an important role in promoting satiety; individuals who eat more whole grain foods may eat less because they feel satisfied with less food. Some studies comparing feelings of fullness or actual food intake after ingestion of certain whole grains, such as barley, oats, buckwheat, or quinoa, compared with refined grain controls indicated a trend toward increased satiety with whole grains". It has also been suggested that "… the processing of cereals is not only an important determinant of the glycaemic and insulin response, but also affects the level of postprandial[8] satiety" (Smith et al., 2003).

The evidence linking the consumption of whole grains to body weight is robust and suggests that consumption of whole grains increases satiety and can reduce body weight. A study conducted by Good et al. (2008) to examine the relationship between whole grain consumption and body mass index in women in the USA found that women consuming at least one serving of whole grain (per day) had a significantly lower mean body mass index and waist circumference compared to a control group with no whole grain consumption. They concluded that "these data support other research suggesting that increased whole grain intake may contribute to a healthy body weight in adult women". Jonnalagadda and co-workers also reported that "cross-sectional and prospective epidemiological studies indicate that consuming whole grains is associated with reduced risk of obesity and weight gain. To date, 14 cross-sectional studies, the majority of which were conducted in the US, have found that higher intake of whole grains (a daily intake of ~3 servings) is associated with lower BMI (kg/m^2) in adults; 3 studies observed that adults who consumed higher intakes of whole grains had smaller waist circumferences" (Jonnalagadda et al., 2011). Waist circumference is an important indicator as an increase in central fat accumulation, rather than generalised fat accumulation, is coupled with an increased risk of type 2 diabetes mellitus.

In general terms, Giacco et al. (2010) hypothesised that "since wholemeal cereal intake is associated also with lower body weight gain in prospective epidemiological studies, it can be said that habitual wholemeal

[8] Postprandial refers to the period immediately following a meal.

consumption could improve metabolic parameters and reduce the risk of cardiovascular diseases and type 2 diabetes, mainly by preventing body weight gain in the long term". Thane et al. (2005) postulated that the situation might be similar to "fruit and vegetables, where the multitude of nutrients and phytochemicals in whole grains may act synergistically to exert a greater benefit to health from the 'whole package' than might be achieved from the sum of the individual components". Jenkins et al. (1988) reported that "breads containing a high proportion of whole cereal grains may be useful in reducing the postprandial blood glucose profile in diabetics because they are more slowly digested". The nutritional value of oatmeal, brown rice and wheat flour is shown in Table 3[9].

Super foods

A super food is one whose consumption is considered to be better for health compared to 'normal' food. The term is often applied to fruits and vegetables, notably blueberries and broccoli. However, 'super food' is not a scientific term and has no precise definition but refers to products that may contain high levels of antioxidants, vitamins, or other nutrients. Our search of the scientific literature search identified no references to wheat as a super food. However, whole grain products are undoubtedly good for health and given their multiple beneficial aspects could easily be described as a super food. It might be possible to argue that they are superior to many other fruit and vegetable super foods since they have multiple modes of action and provide both short- and long-term health benefits.

[9] Food Standards Agency, 2002b. McCance and Widdowson's The Composition of Foods, Sixth summary ed. Royal Society of Chemistry, Cambridge.

3. Provenance and environmental burdens of cereal ingredients

Provenance

Consumers are becoming increasingly aware of food provenance. Recent food scares have illustrated the global nature of the agri-food supply chain and how even the most trusted brands often have little idea of the security and safety of their extended supply chains. In terms of safety and provenance, food products that have only a limited number of ingredients and short supply chains should be regarded favourably in comparison to those that do not. While this approach applies predominantly to meat products, consumers are becoming more aware that not all products are the same.

In the aftermath of the 2013 meat adulteration scandal ('horsegate'), Which[10] reported that "Consumer trust in the food industry has dropped by a quarter (24%) since the horsemeat scandal broke; 30% of shoppers are now buying less processed meat and a quarter (24%) are buying fewer ready meals with meat in, or choosing vegetarian options. Two thirds of people (68%) don't think the government has been giving enough attention to enforcing labelling laws, with half of consumers (47%) not confident that ingredient information is accurate". The scandal may have arisen within the meat sector with highly processed meat products being the target but the knock-on effects have shaken confidence across the whole food industry. Research from Mintel reveals a startling lack of confidence among British consumers in the UK food industry's ability to provide food that is safe to eat: "six months on from the horse meat scandal, British consumers remain highly sceptical about the efficiency of the British food industry"[11].

The cereals sector has not been directly affected by food scares although consumer awareness of supply chains has increased. The location and identify of ingredient producers is a key aspect of supply chain security and understanding and promoting that provenance is a key aspect of brand management. Cereal ingredients for breakfast cereals for the UK market come from a vast range of producer countries. Wheat and oat based products are typically sourced from within the UK but maize and rice based products rely on imported ingredients. Maize typically comes from the USA or South America while rice can be sourced from Europe (Spain) or Asia. While the supply chain security of the major brands is very good, it is likely that local producers of known and trusted provenance would offer better brand promotion.

Environmental burdens of production

The production of cereal grains uses considerable natural resources (land, water, energy) and is responsible for multiple environmental impacts (emission of greenhouse gases, eutrophication, acidification, waste and pollution). This section considers the environmental impact of different cereal types and their environmental burden.

It is difficult to generalise on the environmental burdens of any particular ingredient or breakfast cereal. This is not because the environmental impact is unknown; there is a large body of evidence in the literature, but because the management strategies and agronomy of individual producers are diverse and therefore the data

[10] Which? http://www.which.co.uk/news/2013/03/horsemeat-scandal-dents-trust-in-food-industry-313016/ (accessed 11/11/2014)
[11] Mintel. http://www.mintel.com/press-centre/food-and-drink/food-safety-after-horse-meat-scandal (accessed 11/11/2014)

available are insufficiently robust to allow conclusions to be drawn. Audsley et al. (2009) estimated the carbon footprint of a number of different cereal crops and reported the value for wheat as 0.52 kg CO_2e/kg (Table 4). However, more extensive field-based research by Lillywhite and colleagues found that the mean carbon footprint value in the UK for winter wheat was 0.31kg CO_2e/kg but that the variation in results was considerable and ranged between 0.20 and 0.43kg CO_2e/kg (Lillywhite et al., 2009). Given that farmers operate at both ends of this scale, it illustrates how difficult it is to be precise in this area. Domestically produced oats have a lower carbon footprint compared to either wheat or maize but all these cereal grains have a lower carbon footprint than rice. The differences in the values reported by Lillywhite and Audsley are indicative of the level of variation involved in the production process and it is likely that only minor differences occur in practice between wheat, oats and maize.

Table 4. Greenhouse gas emissions (CO2e/kg) from the production of commodities in the UK, the rest of Europe (RoE) and the rest of the world (RoW) for direct UK consumption (Audsley et al., 2009)

Commodity	kg CO2e/kg commodity		
	UK	RoE	RoW
Wheat, milling	0.52	0.63	0.66
Oats	0.38	0.12	
Maize		0.45	
Rice, paddy			3.50

Because biological and farming systems are inherently variable, variation of this type is inevitable and makes extrapolation unwise so unless an individual production system can be identified and its outputs quantified, it is generally better to work at a large scale. In addition, these values are pre-farm-gate value and therefore exclude the processing and logistics stages. Since these stages, and their associated environmental burden, will vary with product it is not possible to draw any firm conclusions from a generalised approach. However, it is possible to state that a local to market product which undergoes minimal processing is likely to be associated with a lower environment impact compared to a product which uses imported grain which undergoes a higher level of processing. For example, on a weight basis, a UK produced lightly processed wheat biscuit or cereal will have a lower environmental footprint compared to corn flakes or a rice-based product based on imported food products. The public evidence base for product analysis is very limited and future work should focus on this area.

The use and conversion of energy is another area of current concern, especially the ratio between the energy used in the production of a product compared to the metabolic energy contained within the product. Heller and Keoleian (2003) citing Pimentel and Pimentel (1996) reported that “breakfast cereals, for example, which contain about 15,070 kJ of food energy per kilogram, require on average 65,630 kJ/kg to process and prepare”. The latter value includes all stages of production and processing, some of which will be the same for all products but some breakfast cereals undergo considerable processing so those which the least processing will have better embedded to metabolic energy ratios.

4. Intolerance and sensitivity to cereal grains

Gluten is a protein found in many grass species including wheat, barley, rye, triticale, spelt, farina and many others. Gluten is naturally present in all food items made from these cereal grains, e.g. breakfast cereals, bread, biscuit, pasta and beer, and is used as an additive in many other food products including malted milk, milkshakes, malt extract, malt syrup, malt vinegar and Brewer's yeast. Gluten is not considered a toxin although a very small number of people (<2% of the population) should avoid consumption if they suffer from gluten intolerance, or coeliac disease.

Difference between gluten intolerance, gluten sensitivity and wheat allergy

Coeliac disease is an autoimmune disease caused by intolerance to gluten. Thompson et al. (2005) describe the disease as "a genetically based autoimmune disease characterized by a permanent sensitivity to certain sequences of amino acids found in the prolamin fraction of wheat, barley and rye. When persons with coeliac disease consume these grains, the mucosa of the small intestine is damaged, leading to malabsorption of nutrients. Consequently, persons with coeliac disease are advised to follow a life-long gluten-free diet, strictly avoiding wheat, barley and rye". Celiac disease affects approximately one in every hundred people[12]. Symptoms range from mild to severe, and can include bloating, diarrhea, nausea, wind, constipation, tiredness, headaches, mouth ulcers, sudden or unexpected weight loss (but not in all cases), hair loss and anemia. People suffering from coeliac diseases are intolerant of gluten.

"Individuals with celiac disease generally are advised to follow a lifelong gluten-free diet and avoid consumption of the prolamins gliadin (wheat), secalin (rye), and hordein (barley). Although the designation of the diet as gluten free may imply that the diet contains zero gluten, this is not necessarily true. In some countries (e.g. United States, Canada), the gluten-free diet is completely devoid of gluten and is based on foods such as rice and corn that are naturally gluten free. In others (e.g. Scandinavia, United Kingdom), the gluten-free diet may include foods such as wheat starch that have been rendered gluten free but nonetheless contain small amounts of toxic prolamins. The discrepancy in the use of foods rendered gluten free exists because the amount of toxic prolamins that individuals with celiac disease may consume without damaging the mucosa of the small intestine is unknown" (Thompson, 2001).

Irritation to, and inflammation, of the different parts of the gut can be caused by a myriad of different issues which include diabetes, cancer, heart disease. This is relevant because a reduction in inflammation via the gut and changes in gut flora may have both a local as well as systemic impact to reduce disease. High-fibre diets are considered to reduce the inflammatory response and therefore represents a manner to reduce the development of inflammatory diseases. McDougall (2014) suggested that "promoters of low-carbohydrate diets, those high in meat, dairy, fish, and eggs, claim dietary carbohydrates are packed with inflammatory ingredients, and that inflammation is at the heart of virtually every disorder and disease. The evidence linking carbohydrates to inflammation is convoluted, theoretical, and largely limited to an uncommon condition, Coeliac disease. Research does not support the theory that carbohydrates from wheat, other grains, or starchy vegetables are the source of injury that leads to chronic inflammation. In contrast, scientific research does solidly support that the source of injury leading to chronic inflammation is animal foods".

[12] Coeliac UK. www.coeliac.org.uk/coeliac-disease/about-coeliac-disease-and-dermatitis-herpetiformis/ [Accessed 14/11/2014]

The relationship between coeliac disease, irritable bowel syndrome and other gastrointestinal complaints is not yet clear. In 2011, Biesiekierski et al. (2011) examined the role of gluten in gastrointestinal symptoms in subjects without coeliac disease and concluded that non-coeliac gluten intolerance may exist but no clues to the mechanism could be elucidated from their study. Recent research by Mearin and Montoro (2014) reported that "for many years irritable bowel syndrome and celiac disease have been considered two completely separate entities: with celiac disease being clearly related to a permanent gluten intolerance and irritable bowel syndrome having no relation with gluten ingestion. However irritable bowel syndrome and celiac disease symptoms may be indistinguishable, especially when diarrhea, bloating or abdominal pain predominate. In the last decade several studies have shown that the separation between celiac disease and irritable bowel syndrome is not so clear. Thus, some patients who have been diagnosed of irritable bowel syndrome suffer in fact from celiac disease. In addition, it seems that there is a group of patients who, without having celiac disease, suffer gluten intolerance that cause them digestive symptoms similar to those of irritable bowel syndrome. Gluten sensitivity is defined as the spectrum of morphological, immunological and functional abnormalities that respond to a gluten-free diet. (…) The increase of wheat gluten consumption, especially through the worldwide increased application of 'vital gluten' in a broad variety of food products and through increased consumption of wheat flour-based products, may have contributed to the increased prevalence of celiac disease during the last decades since the 1950s" (Gilissen et al., 2014).

Gluten sensitivity is a more wide ranging condition whose existence and causes are still a subject of debate. What is clear is that sensitivity to gluten is not a disease like coeliac disease but is likely to have multiple origins. Verdu et al. (2009) defined gluten sensitivity as "one or more of a variety of immunological, morphological or symptomatic manifestations that may also be shared by celiac disease and irritable bowel syndrome (IBS)". This led to the term non-celiac gluten sensitivity (NCGS) being used to describe a range of conditions that while real in a medical sense were not caused by gluten. A number of researchers contend that NCGS is not related to gluten at all and that FODMAPs (Fermentable Oligo-, Di- and Mono-saccharides and Polyols) might be the problem (Gibson & Shepherd, 2010; Biesiekierski et al., 2013). This suggests that a reduction of FODMAPs, rather than gluten or other wheat proteins, might be the mechanism by which low-gluten diets improve gastrointestinal symptoms. These findings also suggest that gluten sensitivity may not play a significant role in the aetiology of functional gastrointestinal disorders like irritable bowel syndrome. The evidence base for these approaches is increasingly robust and low FODMAP diets are being proposed as a solution to gastrointestinal symptoms.

The causes of NCGS are confounded by other aspects of lifestyle. A major factor is hypothesised to be the 'western lifestyle', which is characterized by limited exercise, over-consumption of, in particular, highly-refined processed foods and sugar-sweetened beverages, high levels of hygiene, widespread use of antibiotics, and stress, apparently has far reaching impacts on human physiology, the immune system and the composition of the intestinal micro-flora. About a quarter of the population in Europe, USA and Japan suffers from allergies and intolerances (UCB, 1997; Gao et al., 2012; cited in Gilissen et al., 2014). The allergy burden in developing countries (China, India, Brazil) is also increasing concomitantly with economic growth, urbanization and lifestyle transitions (Gao et al., 2012 cited in Gilissen et al., 2014). This suggests that economic growth and the changes in lifestyle and diet that accompany it may be the root cause of NCGS and that gluten sensitivity has been wrongly identified as the major component rather than perhaps one of many.

A recent review of approaches to reduce the incidence of allergies and intolerances to cereals by Gilissen and colleagues found that the prevalence of allergy to cereals is generally low (Gilissen et al., 2014). They reported that the most widely suggested sources were wheat, maize and rice and allergic reactions involving barley and oats were rare. However, it should be noted that wheat is the dominant global cereal so these results are not surprising and that only 2% of individuals are sensitive to wheat so overall the extent of the problem is very small.

Although allergies to food items, including cereals, are not uncommon, many other substances can trigger an allergic reaction, including grass and tree pollen, dust mites, animal dander and many non-grain food items, e.g. fruit, shellfish and nuts[13]. An allergy to wheat is one of the less common forms. According to Allergy UK[14], one in four people in the UK suffers from an allergy at some point in their lives. The numbers are increasing every year and up to half of those affected are children. The reason for the rise is unclear. Some experts believe it is associated with pollution. Another theory is that allergies are caused by living in a cleaner, germ-free environment, which reduces the number of germs our immune system has to deal with. This causes it to overreact when it comes into contact with harmless substances. Allergies can only be properly diagnosed through systematic investigation by medical professionals; this leads many people to incorrectly self-diagnose. Self-diagnosis can often lead to poorly founded changes in lifestyle which may disguise real underlying issues. Approximately one-third of self-diagnosed individuals are unlikely to have coeliac disease (Lewis et al., 2000).

Gluten-free diet

The demand for gluten-free food products is greater than the number of sufferers from coeliac disease. It is estimated that one in five people buy gluten-free products[15] but that only one in a hundred require them for clinical reasons. This position is interesting for a number of reasons. It suggests that sales of gluten-free products are not driven by medical reasons (suffering from coeliac disease) but by other dietary and lifestyle reasons. Gilissen et al. (2014) reported that "of particular interest is the rapid growth of the population embracing a gluten-free diet: the gluten-free food market shows an annual increase of 25–30%, and by now represents an annual market value of almost €2.5 billion worldwide".

One reason for the increase in the consumption of gluten-free products is that their availability allows individuals to try the latest diet craze or fad as an accelerated method of weight loss rather than the more considered approaches recommended by dietary professionals. Gilissen also noted that "no clear and unambiguous medical and scientific symptoms are yet available to consider this so-called 'non-coeliac gluten sensitivity' (NCGS) as a new health threat. A correlation with IBS (Irritable Bowel Syndrome) is suggested. (…) In this regard, the overall growing interest in gluten-free foods should be considered a positive challenge to the food industry for product-innovation. A sustainable reduction in the incidence and the prevalence of immune-related diseases, including cereal allergy and intolerance, will require increasing the knowledge and understanding of the interactions between the three major pillars: the food (eating pattern and lifestyle), human genetics and physiology, and the intestinal micro-flora". The challenge of identifying and defining the health responses to gluten is on-going. Ludvigsson and colleagues identified that a lack of consensus in the

[13] NHS Direct. http://www.nhs.uk/conditions/Allergies/Pages/Introduction.aspx (Accessed 11/11/2014)
[14] Allergy UK. http://www.allergyuk.org/?cookieaccept=true (Accessed 11/11/2014)
[15] Daily Telegraph. www.telegraph.co.uk/foodanddrink/healthyeating/10430422/The-great-gluten-free-scam.html (Accessed 11/11/2014)

use of terms related to coeliac diseases and gluten was hampering the comparison and evaluation of clinical studies and research findings. They suggested that gluten intolerance should be referred to as gluten related disorders because it could also be the consequence of poor digestion, lectin-like properties of gluten or intolerance to non-gluten components in wheat (Ludvigsson et al., 2013).

Earlier comments regarding product innovation are interesting since many manufacturers and retailers have noticed the increase in consumption of gluten-free products and have consequently increased the range and availability of gluten-free foods which may therefore be the main factor in increased consumption. However, any evidence of the benefits of switching to a gluten-free diet for non-coeliac sufferers is limited. The Food Standards Agency commissioned a review to establish whether the diet of UK consumers with coeliac disease is nutritionally adequate and whether there was a need for specific dietary advice or other strategies to ensure that these consumers can maintain a nutritionally adequate diet whilst avoiding gluten containing cereals. It concluded that there is no existing robust evidence to show that individuals with coeliac disease adhering to a gluten-free diet experience any nutritional deficiency. There was also no firm evidence to show that individuals following a gluten-free diet had an inadequate intake of iron, calcium, and B vitamins. However, these conclusions may reflect the small amount of data, rather than a genuine absence of nutritional deficiencies between conventional and gluten-free diets[16].

There is some evidence to support the theory that eating a gluten-free diet may be detrimental. Ivarsson et al. (2002) reported that "the gradual introduction of gluten-containing foods into the diet of infants while they are still being breast-fed reduces the risk of celiac disease in early childhood and probably also during the subsequent childhood period". In the UK, the advice from NHS Choices is that starchy foods can be fed from the age of eight to nine months onwards[17]. A number of researchers have also suggested that gluten-free diets could be harmful for people who do not have coeliac disease, as gluten-free diets in western society are generally poor in, amongst others, dietary fibre (Aziz et al., 2012; Di Sabatino et al., 2013; Elli, 2012). More recent work has suggested that the nutritional value and quality of the gluten-free diet is currently receiving increasing attention (Arendt et al., 2011; Lee et al., 2009b) and is rapidly becoming an equivalent to gluten-containing diets (Gilissen et al., 2014).

The physico-chemical properties of flour and dough make wheat highly popular in all kinds of food applications. In many wheat-based foods, such as bread and bakery products, pasta, pizza, noodles, and breakfast cereals, the presence of wheat is evident. But it is increasingly being used as a hidden ingredient in a large number and diversity of food items, mainly since the 1960s, and especially since the 1990s. (…) The network forming properties of wheat gluten means that it is highly versatile in food technological applications" (Gilissen et al., 2014).

The major cereal grains of wheat and barley underpin most of the bread, baking and pasta, and brewing industries. Wheat especially is a major part of an individual's diets and is one of the most popular grain worldwide. In general, its advantages easily out-weight any disadvantages and it remains the corner stone of most diets.

[16] Food Standards Agency. www.food.gov.uk/science/research/allergy-research/t07053 (Accessed 11/11/2014)
[17] NHS Choices. www.nhs.uk/conditions/pregnancy-and-baby/pages/solid-foods-weaning.aspx#close [Accessed 17/11/2014]

5. Humans are well adapted to digesting different food types

The human diet, and the ability to digest different foods, has changed over time. For most of human evolution the human diet has consisted of whatever foods were available; so what could be hunted and collected, and latterly cultivated. The different regions of the world provided different types of food and no one adaptation strategy was the same as another. Humans as a species evolved through their ability to adapt and learn rather than evolve to digest different food types.

Stone Age hunter-gatherers (50,000 years ago) had a very different diet to modern day consumers. Based on research by Eaton (2006), it is estimated that fat provided approximately 35% of their total energy intake (varying between 25% in the tropics and 60% in the Arctic regions) which is the upper limit recommended by current health professionals. About 30% of their energy came from protein sources which is three times higher than current health recommendations while the balance (35%) came from carbohydrate. This was mostly fruits and vegetables since cereal grains were unavailable. In contrast, current consumers obtain 50% of their energy from carbohydrates of which 15% is contributed by added sugar.

The differences between the Stone Age hunter-gatherers' diet and a modern western diet are pronounced, however, what is missing is any examination of the health of Stone Age hunter-gatherers (understandably difficult to collect) or any indication of their life expectancy. There are undoubtedly positive outcomes to be gained from eating simpler, unprocessed or lightly processed foods but it would also be a mistake to ignore dietary recommendations from public health professionals. Most dietary advice is based on the consumption of moderate amounts of a wide variety of foods which is probably little different in concept to what the Stone Age hunter-gatherers were forced to live on. As has been remarked on before in this review, individuals generally know what diet, food types and consumption pattern are best for a healthy lifestyle but it is the inability to adhere to them that has caused the current crisis in public health.

The argument is sometimes advanced that humans were not designed to eat certain food types. This is erroneous as humans were not designed for anything but evolved to their environment and adapted to the available food. The success of *Homo sapiens* is testament to that adaptive ability. Humans consume food products now (cereals, dairy products, etc.) in vast quantities, that would have been unrecognisable to Stone Age hunter-gatherers and the very fact that so few people are immune or sensitive to them is demonstration of that adaptive ability. Linderberg (2009) concluded that "other examples (… to selection pressure) are a relative resistance against diseases of affluence in Northern Europeans and a relatively low prevalence of gluten intolerance in populations with a long history of wheat consumption. Humans are well adapted for lean meat, fish, insects and highly diverse plant foods without being clearly dependant on any particular proportions of plants versus meat".

Discussion and conclusions

This review is unusual since it considers a number of different disciplines in an attempt to provide an overview of the multiple facets of a single product. The review encompasses the medical sciences, in considering the direct and in-direct health benefits, or otherwise, of whole grains, it touches upon the social sciences and why individuals choose to adopt one diet over another, and discusses the environmental impacts of different cereal products. The aim of the review is to set out a balanced assessment of these different aspects of one of the world's staple food crops. However a short review cannot possibly consider all the literature, e.g. a search using the key words 'whole grain' and 'health' returns 1,119 relevant articles, so the process itself is selective as reading and collating that quantity of information to include all the key words in full would be an almost impossible task.

The term whole grain is clearly defined in the literature and understood within general usage to mean all the components of a whole grain; that is nothing is removed during the processing stage. Flour made from whole grain is referred to as wholemeal. In contrast, the term whole-wheat has no clear and accepted definition and is likely a marketing tool used by brands using wheat based products. To add clarity and avoid confusion, consideration should be given to dropping the term 'whole-wheat' and replacing it with 'whole grain wheat'. This is especially true where the two terms are used in close proximity and interchangeably. Greater clarity between whole grain and non-whole grain, especially in dietary fibre content, would also allow consumers to make informed decisions on healthier eating. Given the enhanced role of breakfast cereals in supplying fibre in the diet, it is important that individuals can identify the healthiest choice from multiple options.

The evidence that consumption of whole grain cereals is healthy, and that the health benefits reduce with processing, is overwhelming so any level of processing is likely to degrade the health benefits. The evidence for low extraction rate flour-based cereals providing reduced health benefits is strong. Less well described and understood is the synergistic value obtained from relatively unprocessed or lightly processed whole grain cereals in comparison to 'whole grain' products that have been highly processed and then reconstituted to mimic whole grain. The synergy appears to be real and effective in protecting against a number of common diseases.

Whole grains and especially wheat-based products have been accused of causing a number of gastrointestinal issues yet the evidence for many is weak since the robustness of the evidence is confounded by other life style choices. Evidence from other countries suggests that economic growth and increased individual wealth results in greater levels of gastrointestinal issues which may be derived from consumption of greater levels of all highly processed products. In contrast, the evidence for promoting consumption of whole grains is overwhelming. Multiple studies have shown that whole grains are better for maintaining a healthy body weight, gastrointestinal health, will lessen the incidence of type 2 diabetes, cardiovascular disease and some cancers. The scientific evidence has been reviewed by public health bodies globally who recommend that individuals should increase their consumption of whole grains.

Most recommendations focus on whole grain cereals rather than an individual species. The choice of cereal type is probably dependant on three main criteria: availability and affordability, sensitivity to gluten and concerns over cholesterol. Wheat is the one of the dominant global cereal grains and for most people in most circumstances is the obvious choice to satisfy all three criteria. However, where reduction in individual

cholesterol is required, there is evidence that oats contain more insoluble fibre and are therefore a better choice. Some individuals do not have a choice and for the one percent of the population who suffer from coeliac disease, wheat is not a viable option since it contains gluten and in these circumstances a non-gluten whole grain product is recommended.

The beauty of whole grain products is their simplicity. Recent food scares have highlighted to the public how insecure long supply chains can be so a product that is lightly processed and with a short supply chain is likely to be more acceptable within the consumer market. Ingredients sourced domestically with a known provenance should be able to reassure customers in comparison to other breakfast cereals where highly processed flour is sourced from distant countries. Breakfast cereals produced from mixed low extraction rate flours and produced from non-domestic crops like maize and rice offer neither health nor security benefits in comparison. Domestically produced ingredients are also likely to have a lower environmental impact due to a shorter supply chain although given the paucity of data this cannot be proved. It is also likely that more lightly processed products will be more energy efficient per serving and display a better embedded to metabolic energy ratio.

This review was commissioned to examine two fundamental questions: Are whole grain products good for health? and What is behind the rise in popularity of gluten- and wheat-free diets? The answer to the first question is undoubtedly yes. Apart from the 1% of the population who suffer from coeliac disease and the other 1% who suffer from some other form of sensitivity to wheat, the evidence to suggest that consumption of whole grain wheat products is good for individuals is overwhelmingly positive and consumption of whole grain will increase both health and help to maintain a healthy body weight.

The scientific evidence behind many of the most popular wheat- and carbohydrate-free diets is surprisingly thin and selectively used. Some will result in a short-term reduction in body weight but the same result could be achieved in the long-term by eating less of higher quality or relatively unprocessed foods. The low carbohydrate diet has now generated its own industry and new product development in the ‘free-from’ sector means that a typical low cereal and carbohydrate diet may cost more yet deliver less. One area of concern would be if the less included a decline in public health.

Brands recognise that financial margins are higher in the free-from sector which has encouraged new product development which has generated increased sales. The increased availability of these food types, with their perceived health benefits for all, may have persuaded consumers to switch from staple products to specialist foods intended for those who genuinely need to avoid gluten. The evidence here is contradictory. There is some evidence to suggest that gluten-free diets may be beneficial but any benefits are difficult to disentangle from other lifestyle choices. However, there is also evidence to suggest that gluten-free diets are detrimental to the health of non-coeliac sufferers. For many individuals, body weight, and losing it, can be both narcissistic and health-driven and too many people have neither the desire nor ability to follow a sensible long-term weight reduction programme and seek a ‘quick-fix’ instead. This market has long been recognised by both dieticians and brands. It may be the case the new product development is a self-fulfilling prophecy in driving expansion of the ‘free-from’ market.

References

Albertson, A.M., Tobelmann, R.C., 1995. Consumption of grain and whole-grain foods by an American population during the years 1990 to 1992. Journal of the American Dietetic Association 95, 703-704.

Arendt, E., Moroni, A., Zannini, E., 2011. Medical nutrition therapy: use of sourdough lactic acid bacteria as a cell factory for delivering functional biomolecules and food ingredients in gluten free bread. Microbial Cell Factories 10, S15.

Audsley, E., Brander, M., Chatterton, J.C., Murphy-Bokern, D., Webster, C., Williams, A.G., 2009. How low can we go? An assessment of greenhouse gas emissions from the UK food system and the scope to reduce them by 2050. WWF-UK.

Ashen, D.M., 2013. Vegetarian diets in cardiovascular prevention. Current treatment options in cardiovascular medicine 15, 735-745.

Aziz, I., Hadjivassiliou, M., Sanders, D.S., 2012. Does gluten sensitivity in the absence of coeliac disease exist?

Biesiekierski, J.R., Peters, S.L., Rosella, O., Muir, J.G., Gibson, P.R., 2013. No effects of gluten in patients with self-reported non-celiac gluten sensitivity after dietary reduction of fermentable, poorly absorded, short chain carbohydrtaes. Gastroenterology 145(2), 320-328.

Biesiekierski, J.R., Newnham, E.D., Irving, P.M., Barrett, J.S., Haines, M., Doecke, J.D., Shepherd, S.J., Muir, J.G., Gibson, P.R., 2011. Gluten Causes gastrointestinal symptoms in subjects without celiac disease: A double-blind randomized placebo-controlled trial. American Journal of Gastroenterology 106, 508-514.

British Nutrition Foundation, 2014. 8 Healthy Eating Tips.

Chauveau, P., Combe, C., Fouque, D., Aparicio, M., 2013. Vegetarianism: Advantages and Drawbacks in Patients With Chronic Kidney Diseases. J. Renal Nutr. 23, 399-405.

Cleveland, L.E., Moshfegh, A.J., Albertson, A.M., Goldman, J.D., 2000. Dietary Intake of Whole Grains. Journal of the American College of Nutrition 19, 331S-338S.

Di Sabatino, A., Giuffrida, P., Corazza, G.R., 2013. Still waiting for a definition of nonceliac gluten sensitivity. Journal of Clinical Gastroenterology 47, 567-569.

Eaton, S.B., 2006. The ancestral human dirt: what was it and should it be a paradigm for contemporary nutrition?. Proceedings of the Nutrition Society 65, 1-6.

Elli, L., 2012. Where's the evidence for gluten sensitivity? BMJ, 345:e7360

Fardet, A., 2010. New hypotheses for the health-protective mechanisms of whole-grain cereals: what is beyond fibre? Nutr Res Rev 23, 65-134.

Food Standards Agency, 2002a. The balance of good health. Leaflet FSA/0008/0201. Food Standards Agency, London, UK.

Food Standards Agency, 2014. McCance and Widdowson's The Composition of Foods, Seventh Edition ed. Royal Society of Chemistry, Cambridge.

Gao, Z.S., Shen, H.H., Zheng, M., Frewer, L.J., Gilissen, L.J.W.J. (Eds.), 2012. Multidisciplinary Approaches to Allergies. Zhejiang University Press and Springer- Verlag GmbH, ISBN 978-3-642-31608-1.

Giacco, R., Clemente, G., Cipriano, D., Luongo, D., Viscovo, D., Patti, L., Di Marino, L., Giacco, A., Naviglio, D., Bianchi, M.A., Ciati, R., Brighenti, F., Rivellese, A.A., Riccardi, G., 2010. Effects of the regular consumption of wholemeal wheat foods on cardiovascular risk factors in healthy people. Nutrition, Metabolism and Cardiovascular Diseases 20, 186-194.

Gibbons, A., 2014. The Evolution of Diet, National Geographic, September 2014 ed, USA, pp. 32-65.

Gibson, P.R., Shepherd, S.J., 2010. Evidence-based dietary management of functional gastrointestinal symptoms: The FODMAP approach. Journal of Gastroenterology and Hepatology 25, 252-258.

Gilissen, L.J.W.J., van der Meer, I.M., Smulders, M.J.M., 2014. Reducing the incidence of allergy and intolerance to cereals. Journal of Cereal Science 59, 337-353.

Good, C.K., Holschuh, N., Albertson, A.M., Eldridge, A.L., 2008. Whole grain consumption and body mass index in adult women: an analysis of NHANES 1999-2000 and the USDA pyramid servings database. J Am Coll Nutr 27, 80-87.

Gross, L.S., Li, L., Ford, E.S, Liu, S., 2004. Increased consumption of refined carbohydrates and the epidemic of of type 2 diabetes in the United States: an ecological assessment. American Journal of Clinical Nutrition 79, 774-779.

Harnack, L., Walters, S.-A.H., Jacobs Jr, D.R., 2003. Dietary intake and food sources of whole grains among US children and adolescents: Data from the 1994-1996 Continuing Survey of Food Intakes by Individuals. Journal of the American Dietetic Association 103, 1015-1019.

Heller, M.C., Keoleian, G.A., 2003. Assessing the sustainability of the US food system: a life cycle perspective. Agricultural Systems 76, 1007-1041.

Ivarsson, A., Hernell, O., Stenlund, H., Persson, L.Å., 2002. Breast-feeding protects against celiac disease. The American Journal of Clinical Nutrition 75, 914-921.

Jacobs, D.R., 2001. Grain v. cereal: an impediment to public understanding of food and a study in language. British Journal of Nutrition 86, 543-544.

Jacobs, D.R., Jr., Andersen, L.F., Blomhoff, R., 2007. Whole-grain consumption is associated with a reduced risk of noncardiovascular, noncancer death attributed to inflammatory diseases in the Iowa Women's Health Study. Am J Clin Nutr 85, 1606-1614.

Jacobs, D.R., Marquart, L., Slavin, J., Kushi, L.H., 1998. Whole-grain intake and cancer: An expanded review and meta-analysis. Nutrition and Cancer 30, 85-96.

Jenkins, D.J., Wesson, V., Wolever, T.M., AJenkins, A.L., Kalmusky, J., Guidici, S., Csima, A., Josse, R.G., Wong, G.S., 1988. Wholemeal versus wholegrain breads: proportion of whole or cracked grain and the glycaemic response. BMJ 297, 958-960.

Jones, J.M., 2012. Wheat Belly - An Analysis of Selected Statements and Basic Theses from the Book. Cereal Foods World 57, 177-189.

Johnston, B.C., Kanters, S., Bandayrel, K., Wu, P., Naji, F., Siemieniuk, R.A., Ball, G.D.C., Busse, J.W., Thorlund, K., Guyatt, G., Jansen, J.P., MIlls, E.J., 2014. Comparison of weight loss among named diet programs in overweight and obese adults. Journal of the Amercian Medical Association, 312(9), 923-933.

Jonnalagadda, S.S., Harnack, L., Liu, R.H., McKeown, N., Seal, C., Liu, S., Fahey, G.C., 2011. Putting the Whole Grain Puzzle Together: Health Benefits Associated with Whole Grains—Summary of American Society for Nutrition 2010 Satellite Symposium. The Journal of Nutrition, 1011S-1022S.

Kabbani, T.A., Goldberg, A., Kelly, C.P., Pallav, K., Tariq, S., Peer, A., Hansen, J., Dennis, M., Leffler, D.A., 2012. Body mass index and the risk of obesity in coeliac disease treated with the gluten-free diet. Alimentary Pharmacology & Therapeutics 35, 723-729.

Kantor, L.S., Variyam, J.N., Allshouse, J.E., Putnam, J.J., Lin, B.H., 2001. Choose a variety of grains daily, especially whole grains: a challenge for consumers. J Nutr 131, 473S-486S.

Kumar, V., Sinha, A.K., Makkar, H.P.S., de Boeck, G., Becker, K., 2012. Dietary roles of non-startch polysaccharides in human nutrition: A review. Critical reviews in Food Science and Nutrition, 52(10), 899-935.

Lang, R., Jebb, S.A., 2003. Who consumes whole grains, and how much? Proceedings of the Nutrition Society 62, 123-127.

Le, L.T., Sabate, J., 2014. Beyond Meatless, the Health Effects of Vegan Diets: Findings from the Adventist Cohorts. Nutrients 6, 2131-2147.

Lee, A.R., Ng, D.L., Dave, E., Ciaccio, E.J., Green, P.H., 2009a. The effect of substituting alternative grains in the diet on the nutritional profile of the gluten-free diet. Journal of human nutrition and dietetics : the official journal of the British Dietetic Association 22, 359-363.

Lee, A.R., Ng, D.L., Dave, E., Ciaccio, E.J., Green, P.H.R., 2009b. The effect of substituting alternative grains in the diet on the nutritional profile of the gluten-free diet. Journal of Human Nutrition and Dietetics 22, 359-363.

Lewis, C., Book, L., Black, J., Sawitzke, A., Cannon-Albright, L., Zone, J., Neuhausen, S., 2000. Celiac disease and human leukocyte antigen genotype: accuracy of diagnosis in self-diagnosed individuals, dosage effect, and sibling risk. Journal of pediatric gastroenterology and nutrition 31, 22-27.

Lillywhite, R.D., Collier, R., Pole, J., 2009. Assessing the costs and benefits of agricultural production using an ecosystems approach. Aspects of Applied Biology 95, 39-44.

Lindeberg, S., 2009. Modern human physiology with respect to evolutionary adaptations that relate to diet in the past. In: Evolution of Hominin Diets (Eds. Hublin and Richard).

Liu, R.H., 2007. Whole grain phytochemicals and health. Journal of Cereal Science 46, 207-219.

Ludvigsson, J.F., Leffler, D.A., Bai, J.C., Biagi, F., Fasano, A., Green, P.H.R., Hadjivassiliou, M., Kaukinen, K., Kelly, C.P., Leonard, J.N., Lundin, K.E.A., Murray, J.A., Sanders, D.S., Walker, M.M., Zingone, F., Ciacci, C., 2013. The Oslo definitions for coeliac disease and related terms. Gut 62, 43-52.

McDougall, J., 2014. The Smoke and Mirrors Behind Wheat Belly and Grain Brain. Dr. McDougall's Health & Medical Center.

Mearin, F., Montoro, M., 2014. Irritable bowel syndrome, celiac disease and gluten. Med. Clin. 143, 124-129.

Miranda, J., Lasa, A., Bustamante, M.A., Churruca, I., Simon, E., 2014. Nutritional Differences Between a Gluten-free Diet and a Diet Containing Equivalent Products with Gluten. Plant Foods Hum Nutr 69, 182-187.

Pilis, W., Stec, K., Zych, M., Pilis, A., 2014. Health benefits and risk associated with adopting a vegetarian diet. Roczniki Panstwowego Zakladu Higieny 65, 9-14.

Pimentel, D., Pimentel, M. 1996. Energy use in fruit, vegetable, and forage production. Food, Energy, and Society, University Press of Colorado, Niwot, CO (1996), pp. 131–147

Rea, F., Polito, C., Marotta, A., Di Toro, A., Iovene, A., Collini, R., Rea, L., Sessa, G., 1996. Restoration of body composition in celiac children after one year of gluten-free diet. Journal of pediatric gastroenterology and nutrition 23, 408-412.

Ruxton, C.H.S., Derbyshire, E., 2011. The Diets of Young People in the UK. Complete Nutrition 11, 12-14.

Salazar Quero, J.C., Espín Jaime, B., Rodríguez Martínez, A., Argüelles Martín, F., García Jiménez, R., Rubio Murillo, M., Pizarro Martín, A., in press, Nutritional assessment of gluten-free diet. Is gluten-free diet deficient in some nutrient? Anales de Pediatría.

Saturni, L., Ferretti, G., Bacchetti, T., 2010. The Gluten-Free Diet: Safety and Nutritional Quality. Nutrients 2, 16-34.

Seal, C.J., 2006. Whole grains and CVD risk. Proceedings of the Nutrition Society 65, 24-34.

Slavin, J.L., 2000. Mechanisms for the Impact of Whole Grain Foods on Cancer Risk. Journal of the American College of Nutrition 19, 300S-307S.

Slavin, J.L., Jacobs, D., Marquart, L., 2001. Grain Processing and Nutrition. Critical Reviews in Biotechnology 21, 49-66.

Smith, A.T., Kuznesof, S., Richardson, D.P., Seal, C.J., 2003. Behavioural, attitudinal and dietary responses to the consumption of wholegrain foods. Proceedings of the Nutrition Society 62, 455-467.

Southgate, D.A.T., 2000. Cereals and cereal products, in: Garrow, J.S., James, W.P.T., Ralph, A. (Eds.), Human Nutrition and Dietetics. Churchill Livingstone, London, pp. 333-347.

Stevens, L., Rashid, M., 2008. Gluten-free and regular foods: a cost comparison. Canadian journal of dietetic practice and research : a publication of Dietitians of Canada = Revue canadienne de la pratique et de la recherche en dietetique : une publication des Dietetistes du Canada 69, 147-150.

Thane, C.W., Jones, A.R., Stephen, A.M., Seal, C.J., Jebb, S.A., 2005. Whole-grain intake of British young people aged 4–18 years. British Journal of Nutrition 94, 825-831.

Thane, C.W., Jones, A.R., Stephen, A.M., Seal, C.J., Jebb, S.A., 2007. Comparative whole-grain intake of British adults in 1986–7 and 2000–1. British Journal of Nutrition 97, 987-992.

Thompson, T., 2001. Wheat Starch, Gliadin, and the Gluten-free Diet. Journal of the American Dietetic Association 101, 1456-1459.

Thompson, T., Dennis, M., Higgins, L.A., Lee, A.R., Sharrett, M.K., 2005. Gluten-free diet survey: are Americans with coeliac disease consuming recommended amounts of fibre, iron, calcium and grain foods? Journal of Human Nutrition and Dietetics 18, 163-169.

Truswell, A.S., 2002. Cereal grains and coronary heart disease. European Journal of Clinical Nutrition 56(1), 1-14.

UCB, The UCB Institute of Allergy, 1997. European Allergy White Paper. UCB Pharmaceutical Sector, ISBN 2-87301-018-5

US Department of Health and Human Services, US Deparment of Agriculture, 2010. Dietary Guidelines for Americans, 2010. 7th Edition. US Government Printing Office, Washington , DC.

Verdu, E.F., Armstrong, D., Murray, J.A., 2009. Between Celiac Disease and Irritable Bowel Syndrome: The [ldquo]No Man's Land[rdquo] of Gluten Sensitivity. Am J Gastroenterol 104, 1587-1594.

Whole Grains Council, Oldways, 2009. Summary of Recent Research on Whole Grains and Health. Whole Grains Council, Massachusetts, USA.

World Health Organisation, 2000. CINDI Dietary Guide. WHO Regional Office for Europe, Copenhagen, Denmark.