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Preface

This report describes in a compact way the four main health and sustainability related topics of cereals and bread from scientific perspective. The report is drafted in line with the latest scientific insights by the authors as mentioned at the end of the report and in each chapter. It is a part of the three year project "Bread from Europe – A Great Story" (2018 – 2020). While it will not be published as such, it will be used as basis for content for other work packages of the project in 2019 and 2020. For example, parts will be translated into sub-articles, advertorials in professional magazines, folders for food professionals, website articles and social media posts.
In short, the following topics are described here: the role of carbohydrates and bread in our diet, the environmental impact of bread, benefits of wholegrain and fiber, facts and figures on discomforts by (gluten in) cereals and bread.

Readers who want to use content of this report should inform the project leader at NBC about their intentions and should be aware that content translated to consumer needs to take into account the EU Regulation of nutrition and health claims (http://ec.europa.eu/food/safety/labelling_nutrition/claims/register/public/?event=register.home) or the national recommendations of the target country (The Netherlands / Belgium).

On behalf of the authors

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Management summary

Carbohydrates with special reference to bread

Like proteins and fats, carbohydrates are macronutrients. They are an important source of energy for our cells, and certainly for our brain and red blood cells. All natural, digestible carbohydrates provide 4 kcals per gram. Starch, in e.g. bread, potato, rice and pasta is a complex carbohydrate c of both long consisting of quasi linear (amylose) and branched (amylopectin) chains of glucose.

Bread is a starch rich staple food. It provides carbohydrates, proteins, dietary fiber and a broad range of health supporting components such as vitamins (B1, B6, and B11), minerals (iron, copper, magnesium, zinc, and iodine, …) and some bio-actives (e.g. polyphenols, plant sterols). Especially whole grain bread is an important source of dietary fiber in our diet.

Diets low in carbohydrates and high in fat and proteins include the Atkins diet and the South Beach diet. A low carbohydrate diet provides 50 to maximum 150 gram carbohydrates per day. A so-called 'ketogenic' contains 20-50 gram carbohydrate per day and those adhering to it evidently do not consume much carbohydrate.

For diabetes prevention a healthy bodyweight, a balanced diet and sufficient physical activity are important. A balanced diet is recommended which consists of whole grain products, fruits and vegetables, pulses and nuts and low levels of refined grain products (white bread, white rice, cookies and cakes, low-fiber breakfast cereals), and red and processed meat. As part of a balanced diet, only moderate alcohol consumption and low intake of sugar-containing beverages (regular soft drinks and fruit juices) is recommenced. Although lowering carbohydrate intake in overweight diabetic persons on the short-term is more effective than reducing fat intake, the quality of the carbohydrates and fats are more important than the consumed amounts. [15,16]

Environmental performance of the bread and consumption

Life Cycle Assessment (LCA) is a methodology to quantify and evaluate the environmental impacts associated with the life of a product or service. Today, it is common practice to consider more than ten environmental impact categories in LCA. These include the impact on climate change, depletion of resources, acidification, eutrophication, water scarcity, and a number of human toxicity and eco toxicity impact categories. For bread, this level of standardization has not yet been reached. The Product Category Rule (PCR) available for bread is far from compliant with the latest LCA requirements defined in the PEFCR framework (EPD, 2012). The LCA methodology for LCA studies on bread needs further harmonization as it is currently hard to evaluate and compare the available LCA results for bread. A way forward could be to set up a standard for bread LCAs according to the PEFCR methodology.

A contribution analysis for climate change (Figure 2) shows that the main contributor is the baking process, followed by cultivation, milling (loss of mass due to bran production) and consumption (losses at household level). For many other environmental impacts (acidification, toxicity impacts, and eutrophication impacts) cultivation is the most important stage.

The environmental impact of food products (including white and whole grain bread) have been listed and compared. See: http://www.blonkconsultants.nl/portfolio-item/de-cijfers-op-een-rijtje/. Bread's carbon footprint is relatively low (whole grain 1.1 kg CO_2 equivalent/kg product and refined bread 1,3 kg CO_2 equivalent/kg product). This includes land use and waste at household

level. The minimal difference between white and whole grain bread (delta 0.2 kg CO_2 equivalent) is mainly due to the fact that refined flowers co-product (bran/fiber) is used in mainly due to the feed industry.

In practice, as long as there is no official LCA standard for bread, the functional unit is a matter of substantiated choice and depends on the scope and goal of the LCA. The practical approach usually applied is to first define a simple functional unit such as the weight, e.g. 1 kg. Whether this weight is measured at the bakery exit gate, after selling at retail or as consumed makes quite a difference because of the high wastage further down the chain. Later on, other functional aspects can be considered, which here is done by evaluating the nutritional value of bread.

Scientific paper Goodies from whole grain

The fibres in our diet originate from plant based products, namely from cereals, fruit and vegetables, legumes and to a lesser extent from seeds and nuts. Cereals in general and whole grain in particular are important contributors to our fibre intake. Whole grain wheat samples provide between 11.5 and 15.5% dietary fibre (Andersson et al. 2013). Wheat bran contains about 45% dietary fibre and is thus one of the richest sources thereof. Fibres consumed should be from various sources, the major ones being cereal products (with whole grain products containing more fibre), fruit, vegetables, legumes and from potatoes (Clemens et al. 2012). Grain products and cereals make up almost half (43%) of our daily dietary fibre intake. Without the consumption of grains or a variety of food products, the recommended amount of fibre can hardly be achieved.

Some dietary fibre increases stool bulk and water content and thus to bulky/soft stools that consequently are pass more easily (McRorie & McKeown 2017). The bulking effect of dietary fibres is an important property when assessing the impact on constipation (Stephen et al. 2017). Alterations of bowel regularity, more specifically constipation, remain one of the most prevalent gastro-intestinal disorder in Europe. Its prevalence in Europe ranges from 5-35% of the general population, depending on the definition and criteria used (Peppas et al. 2008). Causes of constipation are multiple and complex, and commonly encountered as related to diet and, more in particular, to low dietary fibre intake. A diet low in fibre, as it is actually the case in Belgium and in The Netherlands (respectively 18 and 20g actual intake versus 30-45g recommended), has been associated with a depletion in gut microbiota diversity, and potentially beneficial metabolites.

As outlined in detail in the EUFIC Whole Grain update (2015) most multi-annual observational studies with large populations – from several ten thousands to more than one hundred subjects - find an inverse association between whole grain consumption and heart diseases, type-2 diabetes, colorectal cancer, other types of cancer and disorders such as obesity. Meta-analyses, where a large number of studies are considered together, convincingly associate a higher whole grain intake with lower risks.

Oxidative stress and inflammation are predominant pathological factors for several major diseases. It has been suggested that the variety of bioactive compounds in whole grains may directly or indirectly inhibit oxidative stress and inflammation.

A recent double-blind, parallel trial in The Netherlands in which 50 overweight 45 to 70 year old men and postmenopausal women were randomly allocated to a 12 week intervention with either whole grain wheat or refined wheat products (98 g/day) for the first time has shown almost 50% more intrahepatic triglycerides in the latter (Schutte et al., 2018) This may contribute to the development of non-alcoholic fatty liver disease, NAFLD, the most common liver disorder in

developed countries, Up to 80% of obese and up to 20% normal weight people might develop it. It is estimated that 24% of the worldwide population is affected in 2017 [11]. NAFLD is the leading cause of chronic liver disease as of 2017. This study indicates that incorporating feasible doses of whole wheat in the diet at the expense of refined wheat contributes to liver health. Overall, hepatic effects could be a crucial underlying mechanism in the positive health effects of whole grain wheat described in observational studies.

Health concerns over cereals and our daily bread

Of all grains, wheat is most widely cultivated worldwide. With over 700 million tons annually wheat is third among all cereals in total global food production, behind maize and rice. Wheat is relatively rich in micronutrients, including minerals and B vitamins, and supplies up to 20% of the energy intake of the global population. Nevertheless, a strongly increasing demand for gluten-free and wheat-free products has developed in recent years.

Gluten is a protein that belongs to the prolamin group and is contained in wheat, rye, barley and spelt. It consists of two components, gliadin and glutenin, which, following the addition of water, form a visco-elastic structure as a result of kneading. In fact, gluten is responsible for the good bread making quality of wheat, giving it an elastic, aerated structure. Gluten-free grains therefore produce a far smaller and more compact loaf.

One question is whether current bread wheat contains more gluten than older wheat varieties. The leading European Health Grain Research Consortium has conducted an in depth study into the composition of wheat. In this study, 150 varieties of wheat from seed banks were sown, cultivated and harvested under exactly the same conditions. The results of the analysis indicated that more recent varieties contain less gluten and more starch than older varieties (see fig 4).

Another question is whether wheat can lead to intolerance or hypersensitivity reactions. The answer to this question is definitely a “yes”. Wheat can indeed cause coeliac disease, a chronic immune reaction to undigested gluten fragments (peptides) which causes damage to the small intestine. Coeliac disease only occurs in people with a specific hereditary predisposition. In the total population, this equates to about 1 %. Contrary to what is often suggested in the media, coeliac disease is not an allergy! It is an immune response related disease condition that develops over many months. In an allergy, the symptoms usually develop within a few hours of exposure, e.g. asthmatic conditions (generally in combination with physical effort) or skin irritations. About 0.2-0.5% of the population are allergic to wheat proteins.

Recently, another type of intolerance known as non-coeliac gluten sensitivity, or sometimes wheat-sensitive irritable bowel syndrome, has been described. This can give rise to specific bowel problems but also to general malaise, headaches and muscle and joint pain. It is not yet clear which substance or substances in wheat play a key causative role in this intolerance, nor is there today an effective diagnostic test. In 2017 an international project named ‘Well on Wheat?' was initiated. It aims to address the health aspects of wheat consumption and gluten avoidance. The project describes the full composition of three selected (ancient) wheat types, and the flours, doughs and breads made from them. As such, the differences in chemical composition of wheat species and compositional changes that may occur as a result of processing (milling, yeast/sourdough fermentation, baking) will be evaluated.

FULL REPORTS

1. Carbohydrates with special reference to bread

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Types of carbohydrates

Like proteins and fats, carbohydrates are macronutrients. Carbohydrates generally consist of one or more components, called saccharides. A saccharide has a ring structure consisting of carbon (C), hydrogen (H) and oxygen (O). The best-known saccharide is glucose ($C_6H_{12}O_6$). Carbohydrates are divided into mono- and disaccharides (1 to 2 saccharides), oligosaccharides (3 to 9) and polysaccharides (>9).

Monosaccharides (e.g. glucose, fructose, galactose) and disaccharides [saccharose (table/crystal sugar), lactose (milk sugar), maltose] are generally called 'sugars'. Polysaccharides are referred to as complex carbohydrates and oligosaccharides are usually digests of polysaccharides.

Carbohydrates are an important source of energy for our cells, especially brain cells and red blood cells. All natural, digestible carbohydrates provide 4 kcals per gram.

Starch, in bread, potato, rice and pasta is a complex carbohydrate consisting of both long quasi linear chains of glucose (amylose) and branched chains of glucose (amylopectin). The complexity of starch refers to both the contents and the structure of its amylose and amylopectin.

Dietary fibers are indigestible carbohydrates, which can be categorized according to their molecular and functional properties such as solubility, gelling power, degree of fermentability and bulk formation in the large intestine. In most plant-based foods the dietary fiber fractions present consist of both soluble fermentable and insoluble less fermentable fibers. The nutritional value and health impact of carbohydrate rich foods are primarily determined by the presence of these and other constituents. The recommended intake of dietary fiber in The Netherlands is 30-40 gram per day and 25-30g for Belgium, but data from the most recent consumption surveys show that intake is on average hardly half of these recommendations [1-4].
s

Bread

Bread is a starch rich staple food providing complex carbohydrates, proteins, dietary fiber and a broad range of health supporting components such as vitamins (B1, B6, and B11), minerals (iron, copper, magnesium, zinc, and iodine) and some bio-actives (e.g. polyphenols, plant sterols). Especially whole grain bread is an important source of dietary fiber in our diet. The Dutch Nutrition Center follows the advice of the Dutch Health Council, in its recommendations of daily bread intakes for different age and gender categories. For example, one of the recommendations is 6-8 slices of preferably whole wheat bread per day for males 14-69 years and 4-5 slices for females 9-50 years. A total of 6 slices of whole wheat bread would provide about 40% of the daily fiber requirement. Dietary advice on food sources for carbohydrates are broadly similar throughout Europe and in favor of the more fiber containing plant-based choices, namely of wholegrain (from locally produced cereals like wheat, spelt, oat, barley and rye), fruits and vegetables and legumes,

rather than from refined cereal products, juices, sweetened drinks and sweet and savory snacks [4-7].

Depending on the way in which bread is made, generally the following main types are distinguished: white, brown, whole meal, and multigrain bread. An additional difference is that between yeast and sourdough bread. Today, bakeries offer a very large variety of breads made from flours from different grains and pseudo-grains and including a wide range of additional ingredients. Examples are: wheat, rye, oat, spelt, teff, maize, soy, muesli, multigrain bread, currant buns, , etc. Wheat bread is by far the main bread consumed.

Impact of milling and dough making on bread

The use of specific milling fractions and dough processing impact on the content of fiber and other nutrients in the bread. The germ and outer layer of the grain kernel (bran) contain most of the fiber, micronutrients and bio-actives. Bread from whole wheat contains all the components as naturally present in the grain kernel. In contrast, when bread is made from white flour, which does not contain the bran and the germ, most of fiber, micronutrients and bio-actives have been removed (see figure 1 and 2).

Figure 1

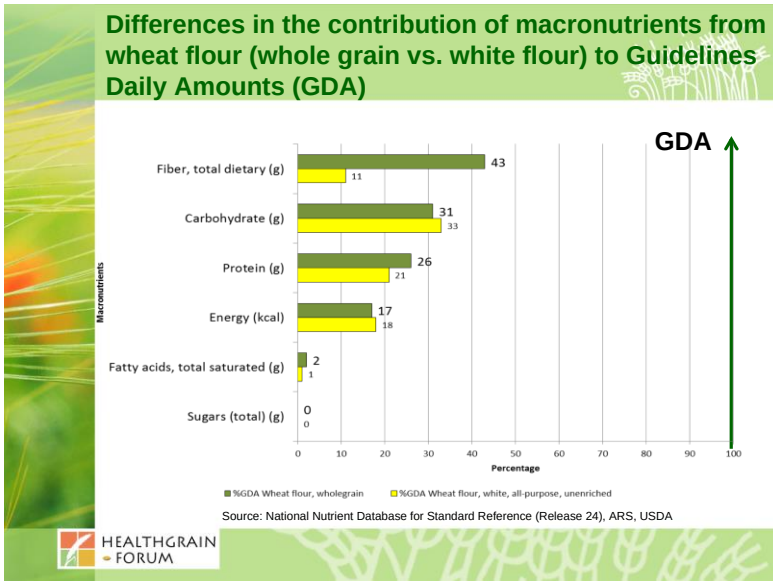
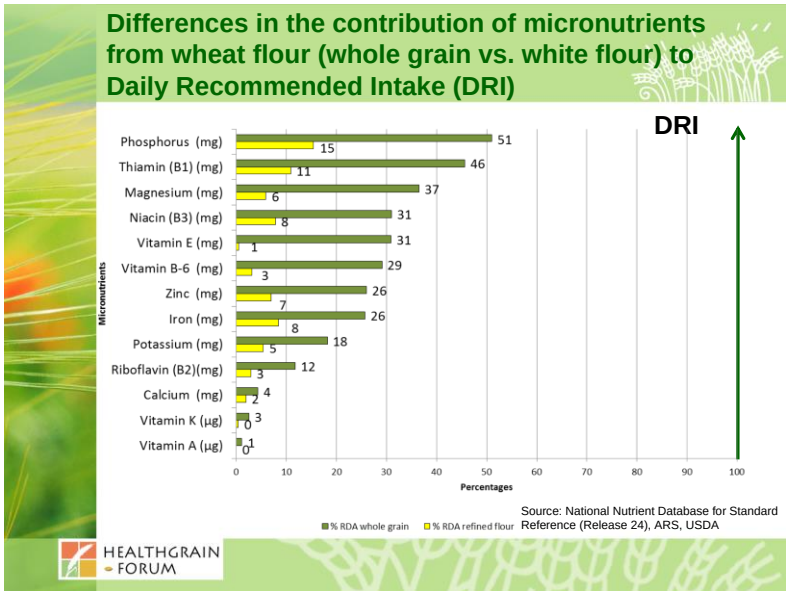


Figure 2



Depending on the degree of fermentability, fibers can be degraded partly or even completely by the colon microbiota resulting in the production of short-chain fatty acids. When being completely fermented, dietary fibers provide an average 2.2 kcals of energy per gram, non-fermented fibers leave the human body without providing energy.
The consumption of fibers from whole grain, fruits, legumes and vegetables results in a range of beneficial effects: i.e., decrease of toxic compounds in the gut, stimulation of favorable gut bacteria, and inhibition of growth of unfavorable bacteria. In addition, the formed short chain fatty acids increase the acidity of the colonic contents, which indirectly stimulates the colonic absorption of minerals and trace-elements that were not absorbed in the small intestine. The formed short chain fatty acids supply energy to the colon cells, inhibit inflammation effects and when absorbed enhance insulin sensitivity of tissues. Non-fermentable fibers stimulate the formation of a soft fecal bulk and help to prevent constipation. The overall effects of more non fermentable and fermentable fiber in the daily diet are a significant improved stool consistency and regularity as well as risk reduction of colonic diseases, diabetes and cardiovascular disease.

Glycemic and health impact of bread

The ingestion of digestible carbohydrates supplied by various foods results in an increase in the blood glucose level. This so-called postprandial glycemic response not only depends on the amount and the type of carbohydrates but also on other characteristics of the food, such as matrix and presence of protein and lipid. In addition, other factors, such as insulin sensitivity of the person, level of physical fitness and previous meal consumed play a role. As a measure of the glycemic response to a food or a drink the glycemic index (GI) is used. This index is calculated using blood glucose changes after intake of a standard amount of glucose (50 gram), of which the area of the blood glucose curve above the initial baseline value [area under the curve (AUC)] is set to 100%. When another carbohydrate rich test food is consumed, the observed AUC is then expressed as a percentage of the original glucose AUC. For example, the AUC a white flour-based wheat bread is about 70% of the glucose AUC. Accordingly, the GI of a white wheat bread is defined as being 70.

The chemical structure of complex carbohydrates such as starch plays a role in the rate of digestion and absorption of the composing monosaccharides. Some products rich in amylose are more resistant to digestion and result in a lower rate of digestion and absorption of glucose, thus in a lower GI. In most common bread types, the proportion of amylose and amylopectin are very similar. As a result, the glycemic impact of different breads is also about similar (see figure 3a and

3b). A white yeast made bread from finely milled flour has a light open structure and is rapidly digestible because it ‘falls apart’ fast under the influence of saliva and gastric fluids, resulting in a GI of around 70. Whole wheat bread made from finely milled whole meal has, despite the higher content of (also finely milled) fiber similar characteristics, reason why its GI is only a few percents lower, with a GI of around 65. However, when whole wheat bread contains a significant fraction of intact or only partly broken kernels that are more difficult to digest, as is the case in some rye breads, the GI value can be as low a 40-50. Due to its very rapid digestibility, hard toasted white bread results in a higher GI value (see figure 4).

Fig 3 a and 3 b Lanzerstorfer P, Rechenmacher E, Lugmayr O, Stadlbauer V, Höglinger O, Vollmar A. Effects of Various Commercial Whole-Grain Breads on Postprandial Blood Glucose Response and Glycemic Index in Healthy Subjects. Austin J Clin Med. 2018; 5(1): 1031.

Figure 3a: Glycemic responses of different breads. Only breads containing intact seeds/kernels result in a significantly lower glycemic response [8]

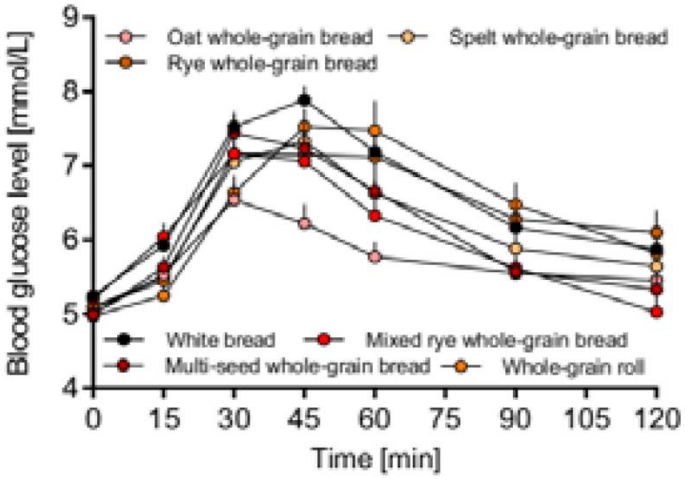


Figure 3b: Glycemic indexes of different breads. Only breads containing intact seeds/kernels result in a sign lower GI value

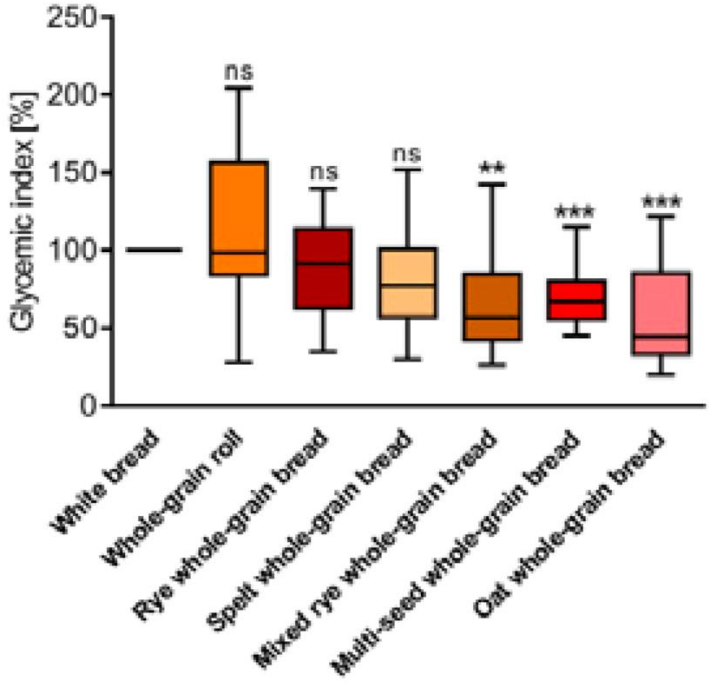
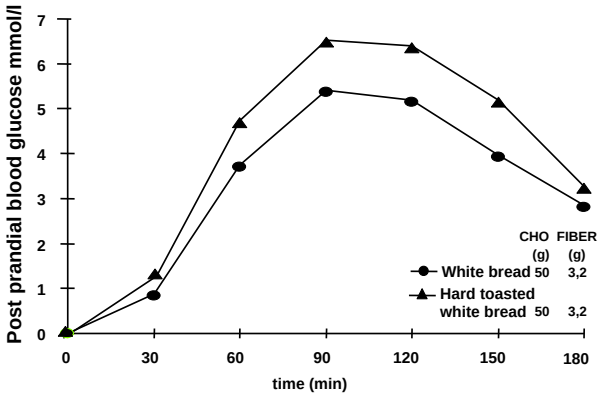


Figure 4: Post prandial blood glucose levels of white bread and hard toasted white bread. Hard toasted white bread results in a higher GI value [9].



In addition to GI, also the amount of carbohydrate consumed will impact on the magnitude of rise in blood glucose. This is referred to as glycemic load (GL). This should be interpreted as follows. Intake of a small portion of digestible carbohydrate such as a sip of a drink containing 50g glucose/liter, may not result in a meaningful elevation of blood glucose. However, intake of 500 ml will raise blood glucose very significantly. Thus, the GL of a food or a meal, as the combined value of (GI x quantity: 100) is an important factor.

Scientific evidence so far suggests that specific GI recommendations don't have added value over the usual dietary advice to consume a fiber-rich diet. More scientific support from long-term studies is needed before recommending a low GI dietary pattern in the prevention of chronic diseases.

However, the GI may be useful to classify carbohydrates in their impact of increasing blood glucose levels. This may be of relevance for subjects with impaired glucose tolerance or in diabetic patients [10].

Recently it is often suggested in social media sources that bread is very high glycemic, thus not good for health. However, this should be put into perspective of the overall diet and other starch rich staple foods that we consume. In this respect studies show that bread results in a lower blood glucose and insulin elevation than the consumption of equal amounts of carbohydrate for example potato or rice (see figure 5)..

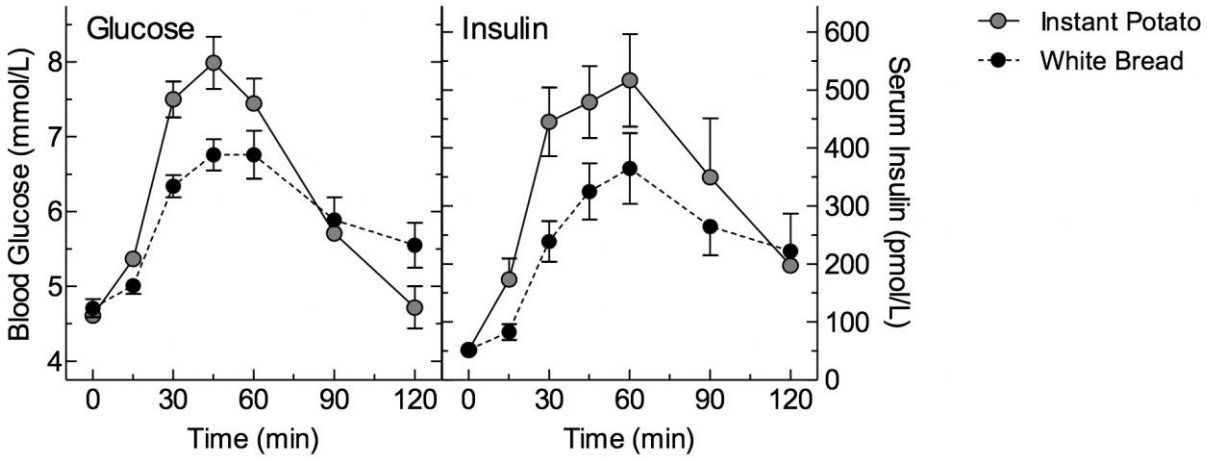


Figure 5: Blood glucose and serum insulin elevation of carbohydrate foods [11].

Highs and lows of blood glucose

The consumption of a significant amount of rapidly digestible carbohydrates induces a rapid increase in blood glucose concentration which is counteracted by an increased release of insulin from the pancreas, which facilitates the uptake of glucose into cells to keep the blood glucose within a relatively small margin. This is important because a longer elevation of blood glucose will lead to a whole range of effects that are unfavorable for health such as protein-glycation and inflammation. Rapidly digestible sugars in liquids lead to a rapid increase in blood glucose and insulin. Because the return to normal blood glucose levels takes place more rapidly than the return of insulin (insulin overshoot) this may lead to blood glucose levels to fall below the initial normal levels. This is called reactive hypoglycemia which is usually accompanied by increased levels of blood fatty acids. In this respect frequent highs and lows in blood glucose are seen as undesirable and are one of the reasons for the recommendation to reduce the consumption of foods and drinks that are high in refined added sugars.

In the case of bread such a reactive hypoglycemia is seldom seen for several reasons: a) the glycemic response to bread is usually the result of what is eaten along with the bread. It is the whole meal composition that determine gastric filling and subsequent digestion and absorption rate. As an example, the use butter spread and a topping of cheese and/or ham or an egg/omelet will impact on the overall rate of digestion and will reduce the glycemic impact. On the contrary, the use of a large amount sugary sweet topping and addition of a large glass of orange juice, will increase the glycemic impact and is reason for the advice to consume in moderation.

Disturbance of this regulation due to decreased insulin sensitivity (insulin resistance) or impaired insulin secretion, as seen in type 2 diabetes - often observed in conjunction with overweight - may induce chronic hyperglycemia and lipidemia. The measurement of 24 hours glucose levels has been proposed as a measure to determine the quantity of time that blood glucose is too high or too low. Frequent deviations from a normal blood glucose are considered undesirable and reason for dietary advice and/or blood glucose regulating medications. Diabetes mellitus type 2 is becoming a growing problem worldwide. The International Diabetes Federation estimates that globally 387 million people had diabetes in 2014 and expects this to increase to 592 million in 2035. [12] In the Netherlands in 2011, a total of 50,5 per 1.000 males and 49,7 per 1.000 females were diagnosed with diabetes. [13] In Belgium, the prevalence of diabetes more than doubled between 1997 and 2013 to 5,3% of the population. [14]

For diabetes prevention a healthy bodyweight, a balanced diet and enough physical activity are important. Since more than 80 percent of diabetic patients are overweight, weight reduction is often the primary target. The aim is a minimum of 5-10% weight reduction through lower energy intake and increased physical activity. A balanced diet is recommended, consisting of whole grain products, fruits and vegetables, pulses and nuts and low intake of refined grain products (white bread, white rice, cookies and cakes, low-fiber breakfast cereals), low intake of red and processed meat, moderate alcohol consumption and low intake of sugar-containing beverages (regular soft drinks and fruit juices). Although, lowering carbohydrate intake in overweight diabetic persons on the short-term is more effective than reducing fat intake, the quality of the carbohydrates and fats are more important than the consumed amounts. [15,16]

Daily consumption of whole-meal products, including whole wheat bread is important for our health and may contribute to the prevention of chronic disorders such as obesity, diabetes, cardiovascular disease and some types of cancer. A slice of bread, however, may replace its health value depending on what is put on top of it. The choice of a healthy spreads and toppings is therefore important.

The human body only disposes limited ways to store carbohydrates (as glycogen in liver and muscle). Chronic overconsumption of food leads to accumulation of lipid storage in adipose tissue and in the liver. This goes hand in hand with impaired insulin sensitivity and impaired metabolism of fatty acids and glucose, ultimately resulting in elevated blood triglycerides and blood glucose levels, which both induce an unnoticeable low-grade chronic inflammation. High triglyceride and/or glucose levels in the blood, abdominal obesity, low HDL cholesterol concentration, and high blood pressure are important variables of what is called ‘metabolic syndrome’. This syndrome strongly increases the risks of diabetes type 2 and cardiovascular disease. The prevalence in the Netherlands is quite high: metabolic syndrome is seen in one in three males (34.0%) and one in four females (24.1%), aged 30-70 years. [17] In Belgium, the prevalence of comorbidities in the 65+ age group rose from 30,6 to 36,1% between 1997 and 2013. [14]

Diets low in carbohydrates

Diets low in carbohydrates and high in fat and proteins are known for a long time; examples are the Atkins diet and the South Beach diet. Currently, there is an increasing interest in these dietary regimens among the public at large as well as dietary treatment for diabetic patients. A low carbohydrate diet provides 50 to maximum 150-gram carbohydrates per day. In a so-called ‘ketogenic’ diet with extremely low carbohydrate intake, the carbohydrate content is only 20-50 gram per day. Short-term intervention studies in diabetics using low carbohydrate diets show both beneficial effects (bodyweight reduction, improved insulin sensitivity, and other aspects of the metabolic syndrome) and adverse effects (loss of muscle mass, loss of calcium, increased LDL

blood cholesterol). Unknown are the long-term health effects of these diets. Moreover, there is no consensus whether the effects as observed in persons with diabetes and other metabolic disorders also hold for healthy subjects. On the other hand, many short- and long-term intervention studies show similar beneficial effects after following relatively carbohydrate-rich, low-glycemic, fiber-rich diets (such as in vegetarian and vegan diets). These dietary patterns are much less extreme, and implementation and adherence may be easier. [18-20]

From a recent meta-analyses of dietary carbohydrate restriction in patients with type 2 diabetes it is concluded that: a) the optimal amount of carbohydrates in the treatment of diabetes is unknown; b) diets with low to moderate intake of carbohydrates have a higher blood glucose lowering effect compared to diets high in carbohydrates; c) higher carbohydrate reduction results in higher blood glucose change; d) low carbohydrate diets are not superior in their effect on glycemic control, body weight reduction or LDL cholesterol [21]

Sugars in our diet

Sugars (glucose, fructose, saccharose, maltose and lactose) are present in our diets in a large variety of food products and in different moieties, for example complex versus easy digestible, natural/added/hidden, and solid/liquid.

The different types of sugars are categorized as naturally present, added and/or free sugars. Their chemical structure is identical irrespective their nature and the way the human body digest them is the same. Examples of natural sugars in foods are vegetables and fruits, dairy products, and fruit juice. Mono- and disaccharides added to foods by the consumer, chef or industry are defined as added sugars. Examples are sugar in tea/coffee, sugars in soft drinks, cookies, sweets, cake, vanilla pudding. In food processing, sugar is added not only for sweet taste, but also as colorant, to give bulk and texture to foods, and for conservation and fermentation. Free sugars are mono- and disaccharides added by the producer, chef or consumer and sugars naturally present in honey, syrups, fruit juice, and fruit concentrate.

Sugars added to products, where you wouldn't expect them are called hidden sugars. Examples are savory foods such as salad dressings, meat products and sauces. The intake of hidden sugars in the Dutch diet is low (4 gram per day), contributing 1% to the daily energy intake. In the Netherlands, the total sugar intake (natural and added) is on average 122 gram per day of which 71 gram is added. Under the list of ingredients on the food product label the specific type of added sugar as well as the amount is declared.

Sugar sweetened beverages such as soft drinks, sweetened dairy products, but also sugars naturally present in fruit juice are easily digested. Sugar ingested in liquid form is less satiating compared to solid foods containing sugars. This way there is a risk of overconsumption, and the excess of energy may contribute to overweight

Carbohydrate intake recommendations

Worldwide the recommendations for carbohydrate intake are closely to 50% of daily energy intake. The European Food Safety Authority (EFSA) advices in their report Scientific Opinion on Dietary Reference Values for Carbohydrates and Dietary Fiber (2010) to consume 45-60 percent of energy from carbohydrates. EFSA concluded in 2010 that there is insufficient data to further specify the advice into mono-, di-, oligo- or polysaccharides for Europeans [22]. Currently, EFSA is working on an update of the carbohydrate and dietary fiber guidelines which are expected in 2020. The most

recent Dutch Food Consumption Survey (2012-2016) shows that the Dutch population gets 45.1 percent of their energy intake from carbohydrates (21% from sugars, 24.1% from starch). The energy percentage (en%) of carbohydrates in children 1-18 years old is 52.1 en%, for adults >18 years the en% is 43.3 [1]. The latest Belgian Food Consumption Survey (2014-2015) reports a total carbohydrates intake for the population 3-64 years old of 44 en%, of which 20% as mono- and disaccharides or sugars and 24% as polysaccharides or starch. Sugars intake decreases with age from 27% for the 3-5 years group to 19% for the 40-60 years of age. Polysaccharides intake on the other hand stays stable at around 23-24% in all age groups. [3]

POPULATION REFERENCE INTAKE (PRI)	Belgium (HGR 2016)	Nederland (GR 2006)	EFSA 2017
Proteins	0,83g/kg bodyweight	8-11 E%	0,83g/kg bodyweight
Fat E%	>20 <30-35	20-40	20-35
Total CH E%	50-55	40-70	45-60
Of which Added Sugars E%	<10		
fiber (g)	>25-30*	30-45	25

* Secondary prevention

Table 1: Macro-Nutrients recommendations for Adults in Belgium, The Netherlands and Europe [4-6]

Conclusions for professional

1. The complexity of a carbohydrate refers to both the starch molecular structure and the presence of dietary fiber.
2. The overall effects of more fiber in the diet and the resulting short chain fatty acids from its fermentation, are improved stool consistency and regularity and risk reduction of colonic diseases, diabetes and cardiovascular disease.
3. Whole-meal breads containing intact or only partially broken seeds and kernels give a significant lower glycemic response than breads from finely milled flour or meal.
4. A longer elevation of blood glucose leads to a whole range of effects that are unfavorable for health such as protein-glycation and inflammation and may lead to impaired blood lipids.
5. Daily consumption of whole-meal products and healthy toppings or sides may contribute to the prevention of chronic disorders such as obesity, diabetes, cardiovascular disease and some types of cancer.
6. Many short- and long-term intervention studies show similar beneficial effects on weight loss and insulin sensitivity for relatively carbohydrate-rich, low-glycemic, fiber-rich diets as compared to carbohydrate low ones.
7. Recent Food Consumption Surveys in Belgium and The Netherlands show intakes of carbohydrates around 45%, whereas the recommendations range from 45 to 60%. Fiber intake is only roughly half of the recommended 25-45g range.

Consumer Take aways

1. More fiber in the diet improves stool consistency and regularity and reduces the risk of large intestine diseases, diabetes and heart disease.
2. Dietary fiber is only naturally present in plant-based foods such as cereals, fruits and vegetables and legumes.
3. Whole-meal breads containing intact or pieces of seeds and kernels give a longer satiation sensation than breads from finely milled flour or meal, which may help to control appetite.
4. Daily consumption of whole-meal products and healthy toppings or sides may help preventing obesity, diabetes, heart disease and some types of cancer.
5. Low carbohydrate diets and high carbohydrate-fiber rich diets have similar effects on weight loss.
6. Carbohydrate consumption in Belgium and The Netherlands is around 45%, what is the lower limit of the recommendation that carbohydrates should make up 45 to 60% of daily energy intake. Fiber intake is only roughly half of the recommended 25-45g range.
7. Whole wheat products are an excellent source for fiber, only 6 small slices of whole wheat bread will make up 40% of the daily fiber required.

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2. Environmental performance of the bread and consumption

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Wit contributions of Frank Nevens (Ugent), Isabel Roldan (ILVO) and Veerle van Linden (ILVO) who commented on a first draft of this paper

1. Introduction

Bread is a basic food made from flour -mainly from wheat-, water, and yeast mixed together and baked (Cambridge Dictionary, 2018). It is one of the first processed food products that humans made and is still a major staple food in Europe, Middle East, Central Asia, North Africa. Also, in European-derived cultures such as those in the Americas, Australia, and Southern Africa bread is important (Kulp & Lorenz, 2003). The global consumption of bread is more than 83 billion kg with Europe being the biggest consumer by mass (Mordor Intelligence, 2018).

In this chapter we consider the environmental performance of bread using lifecycle assessment to understand the environmental impact and the contribution per lifecycle stage. We use optimization as a technique to evaluate the environmental impact in relation to the nutrition that it delivers. The focus is on bread produced and consumed in the Netherlands.

In section nr 2 some basic lifecycle principles are explained and the results of life cycle assessment of bread are discussed. We also reflect on the state of play of the used Life Cycle Assessment methodology for bread.

To benchmark the lifecycle performance of bread to other food products, a concept of quantifying nutritional value is needed. Several methodologies are available for this, which will be discussed briefly in section 3. Compared to other food products bread has a good balance between the amount of nutrients provided per unit of environmental impact.

2. **Environmental impact of bread production and use**

2.1 Life Cycle Assessment method

Life Cycle Assessment (LCA) is a methodology to quantify and evaluate the environmental impacts associated with the life of a product or service. The methodology is a stepwise and iterative approach for data inventory, and calculation and interpretation of environmental impacts in relation to the goal and scope of a study. Nowadays, it is common practice to consider more than 10 environmental impacts categories in LCA, such as the impact on climate change, depletion of resources, acidification, eutrophication, water scarcity, and a number of human toxicity and ecotoxicity impact categories (see Table 1). The methodology is described in several ISO standards so that LCA executors can conduct LCA transparently and properly (ISO, 2006). Reviewers can then test if LCAs are conducted conform to these standards.

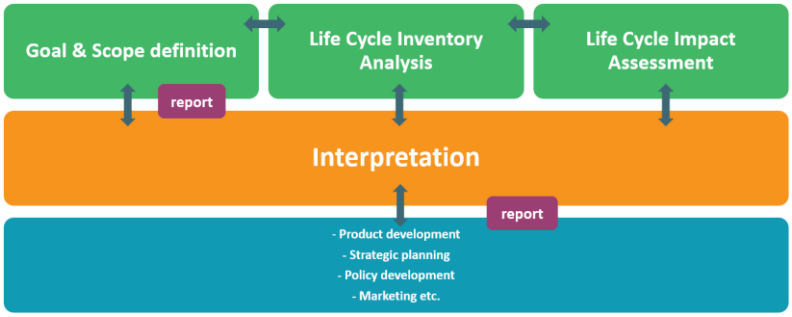

Figure 1. Lifecycle assessment methodology standardized in ISO 14040/44

Based on the LCA ISO standards, or inspired by it, more specific standards are developed for sectors, product groups and impact categories. For example, there is a standard available for calculating the carbon footprint for horticulture products (BSI, 2011) or a standard to calculate the environmental impact of dairy products (International Dairy Federation, 2015). The most comprehensive and specific standards for products are currently the Product Environmental Footprint Category Rules (PEFCR) published by the European Commission (Haslinger & Giljum, 2012; European Commision, 2017). The aim of these standards is to define the methodology and harmonize the use of data in a high level of detail in order to make the assessment independent on the party that is conducting the LCA. Differences in outcomes between studies are therefore reflecting results in environmental performance instead of underlying methodological or data choices.

For bread this level of standardization is not reached yet. There is a Product Category Rule (PCR) available for bread but this is far from compliant with the latest LCA requirements defined in the PEFCR framework (EPD, 2012). It is also not developed with the participation of at minimum 50% representation of producers that supply the EU market, which is mandatory for PEFCR development.

2.1.1 Reference and functional unit

The functional unit is the "quantified performance of a product system for use as a reference unit" (ISO, 2006). Its purpose is to provide a reference to which the inputs and outputs are related, in order to ensure comparability of LCA results of products. The functional unit for bread could be defined around its nutritional functionality, in relation to its "carrier" function of other food products that are eaten in combination, considering the eating experience etc.

Another important characteristic of bread is that it has a relatively short shelf life and use phase at consumer so that wastage is relatively high. Shelf life relates to processing and packaging (for example added preservatives and type of packaging) and consumer behavior. If this is of interest for the analysis, then the shelf life/use life or the packaging used should be considered. The quality of bread and its nutritional value can also change considerably based on the production process (industrial or "craft"), since the spontaneous fermentation confers unique characteristics to the product that are difficult to account for.

In practice, as long as there is no official LCA standard for bread, the functional unit is a matter of substantiated choice, dependent on the scope and goal of the LCA. The practical approach usually applied, is to first define a simple functional unit such as the weight, e.g 1 kg. The quantity of 1 kg can be measured at bakery exit gate, after selling at retail or as is consumed, this makes quite a difference due to the high wastage fractions. Later on, other functional aspects can be considered, which we will do here by evaluating the nutritional value of bread.

Blonk Consultants has listed and compared the environmental impact of food products (including white and whole grain bread); http://www.blonkconsultants.nl/portfolio-item/de-cijfers-op-een-rijtje/. Bread's carbon footprint is relatively low (whole grain 1,1 kg CO2 equivalent/kg product and refined bread 1,3 1 kg CO2 equivalent/kg product). This includes land use and consumer waste. There is a minimal difference between white and whole grain bread (delta 0,2 kg CO2 equivalent), mainly due to the fact that refined flowers co product (bran/fiber) is sold to other industries, mainly the feed industry.

2.1.2 System flow diagram

The bread production chain is rather complex and involves many stages. Usually the cultivation of cereals is considered as a main starting point of the production chain, because it is the main ingredient. Cultivation requires input of materials & energy (such as fertilizer & manure, fuel for machinery and basic infrastructures) of which the production, the transport and the application are also considered. The most used cereal for bread is wheat, even though other cereals can be also used as main or supplementary ingredient (rye, maize, oats, barley etc.).

After harvesting, the grains are transported to the milling plant, where flour production takes place. Different types of flours can be produced, which affects the amounts and composition of by-product (bran). This varies around 20%. Bran is usually used as feed material in compound feed for livestock farms.

The second processing step takes place in the bakery, where the flour is mixed with the other ingredients: water, salt, yeast and some additives (such as ascorbic acid or enzymes). The extraction and production process of each ingredient needs to be considered. Losses at bakery (around 2%) can be brought to animal farms as a wet feed material.

The packaged product from the bakery is then distributed through retail and food services to the consumer. Losses at retailer can be recalculated back to the bakery (bread enriching with stale bread) or used for feed formulation. Finally, after the consumption stage, the end of life (EoL) stage is also considered. This includes the EoL of packaging as well as the EoL of the bread ,
Every processing and transportation step needs energy and materials inputs which are also accounted for.

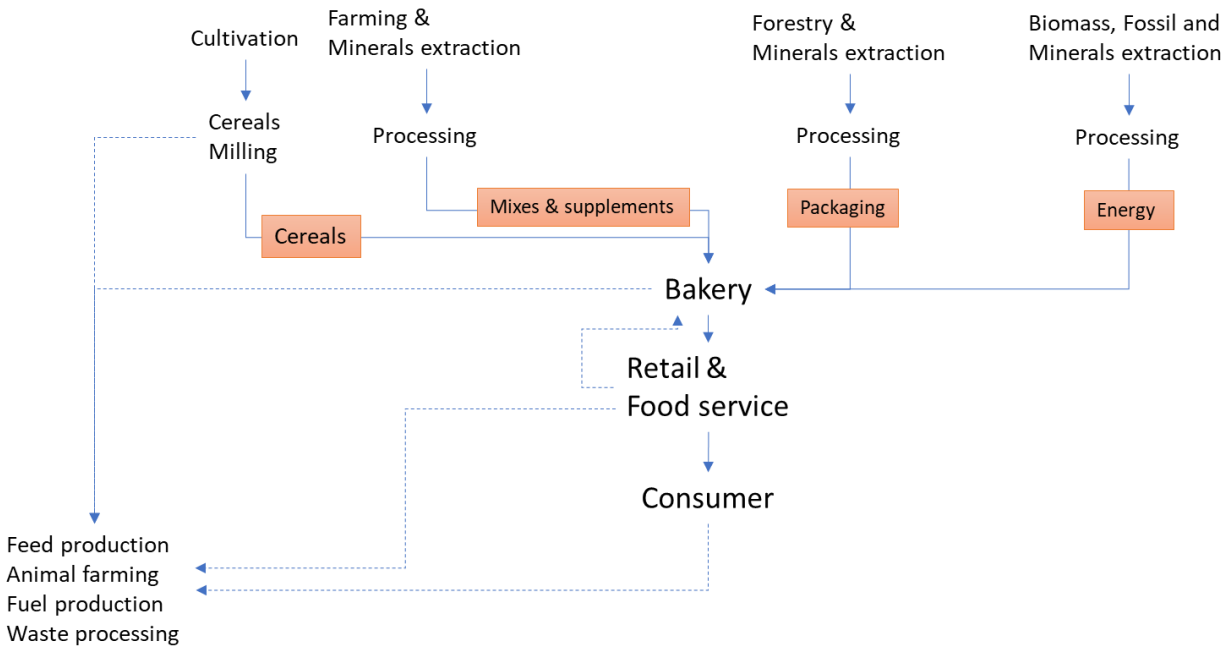

Figure 1 Bread production and consumption chain

2.1.3 Methodology

There are several methodological choices that affect the results, the most important are:

- System boundaries: these are the set of criteria specifying which unit processes are part of a product system (ISO, 2006). A full lifecycle includes cradle-to-grave boundaries. Depending on the goal and scope of the study the system boundaries can be narrowed, for instance from cultivation to consumption (cradle-to-gate).
- Allocation: partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems (ISO, 2006). In almost every stage there is a main product flow and a co-product, and the lifecycle impact up till the point of split in multiple co-products needs to be allocated over the products. In the baseline calculations we decided to use economic allocation (Table 2), therefore the impact is allocated between product and co-products based on the economic share in revenues of each flow.
- Use of background data: data that are not part of the core processes, such as the production of electricity and natural gas or the production of fertilizers. The background data were based on the Blonk Consultants database Agri-Footprint, on the database Ecoinvent and on the database by the European Life Cycle Database (ELCD).

2.1.4 LCA Results

The baseline results we show here are based on several studies that Blonk Consultants performed for the Dutch market (Blonk, 2006; Kuling & Scholten, 2015). The functional unit is the consumption of 1 kg of bread eaten by the consumer and bought at a supermarket in the Netherlands. The wheat and rye used in the bread were cultivated in different countries (with different agronomic practices) and then imported in the Netherlands. The wheat and rye were milled with a 73% and 70% milling yield, respectively. The impacts are shown in Table 1.

Table 1 LCA results of White bread, Whole bread and Rye bread in the Netherlands, from cradle-to-grave, calculated with Recipe Midpoint (H) methodology.

Impact category	Unit	Wheat white bread	Wheat whole bread	Rye bread	White Baguette
Global warming	kg CO2 eq	1.26	1.13	1.29	1.12
Stratospheric ozone depletion	mg CFC11 eq	8.09	6.37	6.49	8.01
Ionizing radiation	Bq Co-60 eq	43.5	42.1	76.0	21.7
Ozone formation, Human health	g NOx eq	1.34	0.96	3.23	1.40
Fine particulate matter formation	g PM2.5 eq	0.28	0.24	0.42	0.23
Terrestrial acidification	g SO2 eq	7.72	5.75	7.30	7.47
Freshwater eutrophication	g P eq	0.12	0.09	0.21	0.12
Terrestrial ecotoxicity	g 1,4-DCB e	0.40	0.21	0.37	0.39
Freshwater ecotoxicity	g 1,4-DCB e	4.39	3.85	14.4	3.67
Marine ecotoxicity	g 1,4-DBC e	5.31	4.59	16.21	4.61
Human carcinogenic toxicity	g 1,4-DBC e	2.81	2.72	11.41	2.67
Human non-carcinogenic toxicity	kg 1,4-DBC e	76.12	37.76	53.58	75.61
Land use	m2a crop eq	0.90	0.72	1.73	0.88
Mineral resource scarcity	g Cu eq	0.39	0.37	1.44	0.37
Fossil resource scarcity	kg oil eq	0.26	0.23	0.27	0.28
Water consumption	m3	0.08	0.08	0.22	0.07

A contribution analysis for climate change (Figure 2) shows that the main contributor is the baking process, followed by cultivation, milling (loss of mass due to bran production) and consumption (losses at consumer). For many other environmental impacts (acidification, toxicity impacts, and eutrophication impacts) cultivation is the most important stage.

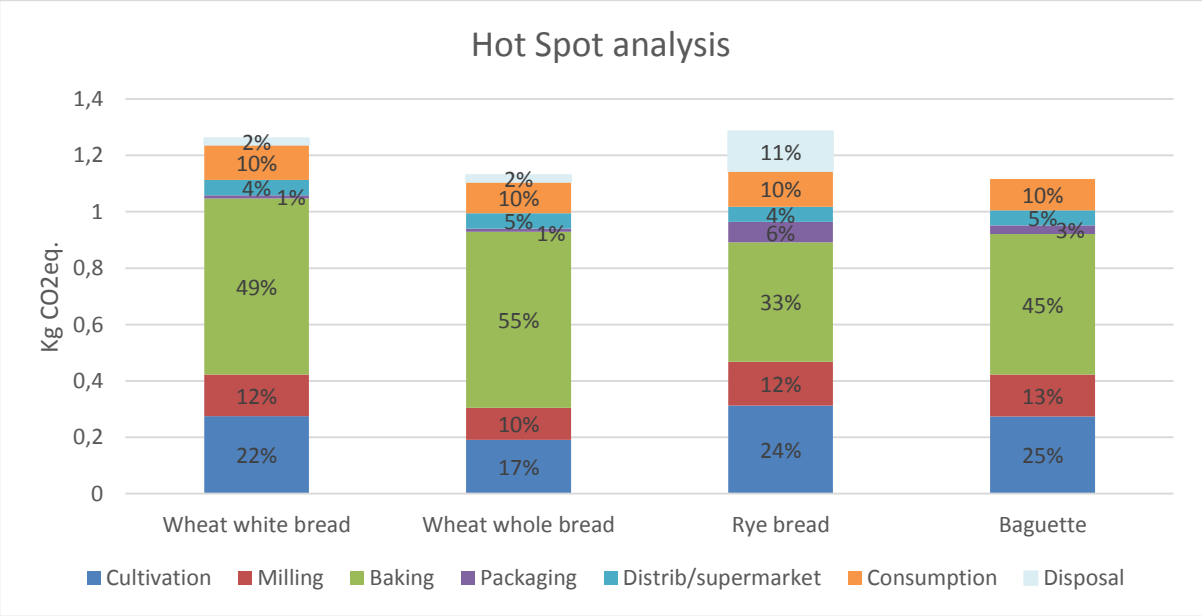

Figure 2 Hot spots analysis of 1 kg of various consumed bread products.

The impact on global warming is comparable to other results from literature (Table 2). In particular the first study cited, analyses many types of bread in Europe and gives a broad range of global warming impact results (Notarnicola, Tassielli, Alexander, & Monforti, 2017). Their calculated European average result (1.09 CO eq/kg bread) is close to the values we calculated but not easily comparable because they use a cradle to bakery exit gate system boundary. So, losses at retail and

consumer and energy use and disposal at consumer are lacking. It is then likely that if included they would come to higher average results than we calculated. The studies done for the UK (Espinoza-Orias, Stichnothe, & Azapagic, 2011; Espinoza-Orias et al., 2011) came to lower cradle to grave results. Since it is hard to identify all the methodological assumptions underlying these results comparison is cumbersome. Only if methodology is more harmonized, meaningful comparisons of lifecycle performance and causes of differences in performance can be easily identified.

Table 2 Global warming results of several other recent studies found in literature.

Author	**Global Warming range (kgCO2eq/kg bread)**	**Comment**
(Notarnicola et al., 2017)	0.5-6.6	21 typical types of bread were analyzed, each for an European country. The European global warming average calculated was 1.09 kg CO2eq/kg bread. Cradle-to bakery exit-gate.
(Kulak, Nemecek, & Frossard, 2014)	0.6-1.7	Lifecycle of wheat bread types from 7 alternative production systems in Europe (also home-baking). Losses and final waste are not included.
(Espinoza-Orias, Stichnothe, & Azapagic, 2011)	0.8	White wheat bread production in UK. Cradle-to-grave).
(Espinoza-Orias et al., 2011)	0.75	Whole wheat bread production in UK. Cradle-to-grave).
(Chiriaco, Grossi, Castaldi, & Valentini, 2017)	1.18	Whole wheat bread conventional production in Italy. Cradle-to-retail.
(Chiriaco et al., 2017)	1.55	Whole wheat bread organic production in Italy. Cradle-to-retail.
(Ingrao, Licciardello, Pecorino, Muratore, & Messineo, 2017)	0.5	Typical wheat bread production in south Italy. Cradle-to-exit bakery gate.
(Henriksen & Korsaeth, 2013)	0.95	Wheat bread production in Norway. Cradle-to-point of sale.
(Jensen & Arlbjørn, 2014)	0.731	Rye bread production in Denmark. Cradle-to-grave.

2.1.5 PCR for bread

The PCR for bread is currently still used by Barilla to generate Environmental Product Declarations. These were the first certified EPDs in the food system and they cover the cradle-to bakery-gate life cycle. Mass allocation is applied at farm and mill and background data are gathered from several sources such as Ecoinvent, literature and international databases. Losses of food at consumer are not considered. The carbon footprint of whole wheat bread (Pagnotta di Gran Duro e Integrale) is 0.91 kgCO2eq/kg (Barilla & EPD, 2015a) and of white soft bread (Pan Bauletto Bianco) is 0.71 kgCO2eq/kg (Barilla & EPD, 2015b). The contribution analysis shows 60% and 70% of the impact coming from cultivation, respectively.

2.2 Improving the Lifecycle environmental performance of bread

Product performance of bread can be improved in many ways, three main clusters are discussed below.

Reducing return flows and wastage

Bread is one of the food products with relatively high "losses of bread" between the bakery exit gate and the product actually consumed. Supermarkets may send 15-20% of the bought bread back to the bakery. From this flow of bread only a fraction is wasted; a big share is consumed by farm animals. A better use could be bringing it back as an ingredient for food production (e.g. for beer or bakery products). The environmental impacts in this shift in application should be evaluated by a lifecycle assessment to be sure about the positive consequences.

Losses at consumer are typically 20-25%. These losses are of higher concern because waste processing may give some benefits (energy or compost production) but are a meager compensation for the environmental impacts of production.

Improving energy efficiency at bakery

The electricity and energy use in the bakery can account for even more than half of the impact at bakery gate. Therefore, increasing the energy efficiency through temperature optimization, steam recovery and oven design seems to be an interesting option. A suggested "greener" alternative is the switching to ovens powered by electricity (Tucker, 2016).

Reducing environmental impacts of cultivation

There is also room for improvement during cultivation of cereals. Nitrogen application is one of the most important contributors at cereals growing. Therefore, avoiding surplus fertilization and additionally reducing leaching and other emissions at application are important. Choosing more environmentally friendly produced fertilizers can also help reducing the impact. Organic production, may not always result in a lower carbon footprint at cultivation (Chiriaco et al., 2017).

3.The environmental performance of bread related to its nutritional value.

3.1 Defining the nutritional value of bread

The nutritional value of bread is mainly determined by the type of cereals used (wheat, rye, oat, etc.), the milling of the cereals (whole grain vs flour and the added ingredients (fats and seeds, ionized salts, enriching supplements, etc.). Whole meal bread has a higher content of vitamins B, fiber and magnesium, contributed by the seed endosperm. Table 4 shows the nutritional contribution of bread in a diet of which it comprises 11% of the energy intake. Moreover, the environmental impact indicators for fossil energy use, land use and carbon footprint are shown which are on average 4 times lower than the energy contribution.

Table 4. Contribution of bread products to nutrition and environmental impact indicators in the Dutch diet anno 2010

	Contribution of bread to the Dutch diet of women between 31 and 50 tears in 2010
Energy (kcal)	11%
Carbohydrates total (g)	17%
Polysaccharides (g)	29%
Fibre (g)	28%
Vitamin B1 (mg)	11%
Folate eq. (µg)	15%
Phosphorus (mg)	11%
Iron (mg)	16%

Sodium (mg)	18%
Magnesium (mg)	16%
Zinc (mg)	11%
Selenium (µg)	11%
Copper (mg)	18%
Iodine (µg)	39%
Cystine (g)	21%
Carbon footprint (kg CO2eq)	3%
Fossil energy use (MJ)	4%
Land Use (m2*a)	3%

3.2 Evaluating the nutritional value of bread in relation to its environmental impact

To get an understanding of how the environmental performance of bread relates to other food products, the nutritional contribution of bread in a total diet should be considered. To capture the nutritional value of bread in comparison to other products there are basically two approaches possible.

1. Using a nutrient index score as a functional unit
2. Using optimization to evaluate the environmental impact of adding or removing bread from the diet

A functional unit in LCA is always defined along the properties that are positively valued by a user and cannot deal with a potential negative outcome for value as such. This is critical for nutrients because capturing the full nutritional contribution means that both positively and negatively contributing nutrients should be evaluated. Applying a nutrient index score that captures both could result in negative values which are thus not applicable as functional unit.
There are several index scores defined for products and diets (Drewnowski, 2018; Kramer, Martinez, Espinoza-Orias, et al., 2018; Omidi & Zargar, 2015)(van Dooren, Douma, Aiking, & Vellinga, 2017) that could be used to capture the positive and negative contribution of bread to a diet. In general, these indexes are focusing on macro nutrients and therefore, except for fibers, not really capturing the important nutritional contribution of bread which is in its micronutrients such as B vitamins especially B1, magnesium, phosphorus, iron and if added iodine. There are more refined index scoring methodologies such as the nutrient balance concept (Fern, Watzke, Barclay, Roulin, & Drewnowski, 2015) which qualifies separately qualifying (26) nutrients and disqualifying (7) nutrients in a product. The qualifying and disqualifying nutrients can be combined in a so-called Nutrient Balance score. The Nutritional Balance Concept score is a dimensionless indicator that evaluates the overall positive and negative contribution of a food product to a diet and could potentially be used as a functional unit because it results in a positive number. It is not evaluated in that respect yet.

Another method could be focusing only on the positive nutritional aspects. There are also suggestions to do this (van Dooren et al., 2017)(Nemecek, Jungbluth, i Canals, & Schenck, 2016) from relatively simple to more detailed. The issue remains however that negative contributions are not being evaluated.

Concluding, the route of defining a functional unit that captures the nutritional properties of food is difficult and has not yet resulted in a satisfying methodology.

Optimization techniques might therefore be an easier method to evaluate the full (positive and negative) nutritional contribution of food products, against its environmental impacts. In Kramer et al 2018 (Kramer, Martinez, Espinoza-orias, et al., 2018) this method has been applied to evaluate if eating more/less cereal grains affects the environmental impact positively/negatively. In this paper

we applied the same method for whole grain bread and calculated three environmental indicators and a weighed environmental impact score based on ReCiPe (Huijbregts, Steinmann, Elshout, & Stam, 2016). Per 100 grams increase/decrease of daily bread consumption and compensating with changes in consumption of other products to remain within nutritional boundaries the carbon footprint of the optimized diet reduced by 0.07 kg CO2e, fossil energy use by 0.74 MJ, land occupation by 0.12 m2*year and the Recipe score by 0.01 pt. The pathway of the reduction goes along a steady line meaning that the average reduction per 100 gram is valid for the full range in scope (0-350 grams), see Figure 3. Bread is thus a product that delivers more nutrition per unit environmental impact than the average of the considered products in the diet (207).

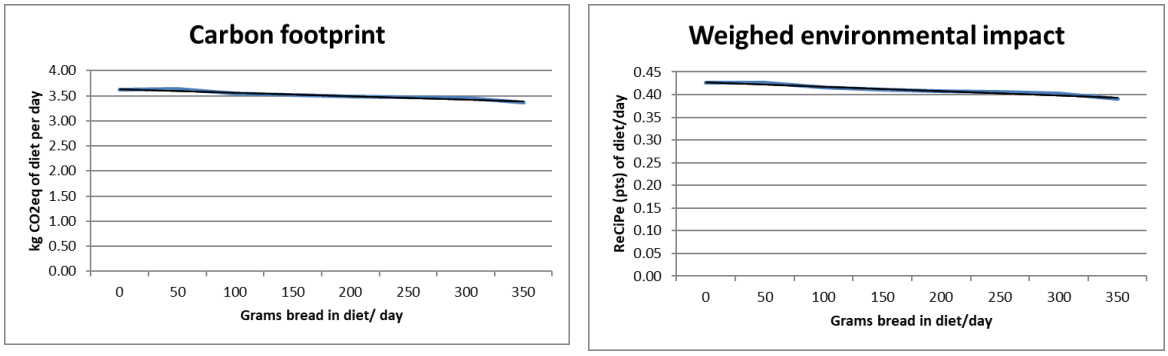

Figure 3. Pathway of the environmental impact of optimized diets where bread consumption is decreased/increased, starting diet 50 grams/per day per person.

4. Concluding remarks

The methodology for evaluating the environmental impact of food stuffs in relation to their nutritional value is evolving but faces some challenges that are inherent to the fact that nutrients can contribute in a negative or positive way to our health. At the moment, the use of optimization techniques to evaluate the balance between nutrient contribution and environmental impact seems most promising. Applying this to whole grain bread shows a favorable balance. Adding more bread to the Dutch diet, while compensating additional consumption by optimization to remain within nutritional boundaries reduces the environmental impact of the diet.

We focused on the most consumed type of bread (whole grain bread) in the Netherlands but the method can also be applied to other bread types (white bread, bread made from other cereals) and also for other countries. Such an assessment is necessary to come to a more generic conclusion. Our expert judgment expectation is that in many cases bread types will have this favorable balance in nutritional contribution and environmental impact.

The LCA methodology for doing LCA studies on bread needs further harmonization. Currently it is hard to evaluate and compare the available LCA results for bread. A way forward could be to set up a standard for bread LCAs according to the PEFCR methodology.

The environmental impact of bread can be improved in many ways. There are three main areas of attention: reducing and managing wastage; energy use at the bakery and optimizing farming practices.

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3. Scientific paper Goodies from whole grain

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Dietary fibres, a wealth of benefits to our health

Dietary fibres are acknowledged to play an important role in our health, and there is nowadays a long history of research substantiating more and more benefits (Stephen et al. 2017). Dietary fibres were traditionally seen as 'undigested substances' that reach the colon, without energy value, and that were excreted as such. This image has changed and we know now that dietary fibres play an important role in bowel habits, but also may decrease our blood cholesterol, reduce blood glucose (Stephen et al. 2017) and are important players in shaping our gut microbial composition.
The first epidemiological observations came with Professor Burkitt who noted that British diet had changed radically with industrialization, as bread became refined and quantity of bread eaten decreased substantially. D. Burkitt noted than within a century, bread consumption of the British population dropped from 600g to only 200g of white bread, containing the merest trace of fibre. These changes resulted in an important decrease in the amount of dietary fibre ingested. D. Burkitt showed lower stool weight and much slower transit time in the British, fibre-depleted diet, compared to that of rural populations in Africa (traditional-unrefined carbohydrates). These changes in bowel habit were associated with a higher prevalence of certain colon related diseases (Burkitt et al. 1972).

Fibre sources

The fibres in our diet come from plant based products, namely from cereals, fruit and vegetables, legumes and to a lesser extend from seeds and nuts. Cereals in general, and whole grain in particular are important contributors to our fibre intake. Whole grain wheat samples provide between 11.5 and 15.5% dietary fibre (Andersson et al. 2013). Wheat bran is one of the richest sources of fibre (~45%), being predominantly composed of non-starch polysaccharides (NSP), and in particular arabinoxylans (Stevenson et al. 2012, EFSA 2010). When grinding cereal grains into flour or peeling rice, the fibres are removed. This is why whole grain products and brown rice are much richer in fibre than white bread or white rice. The fibres that are removed during refining can be used as a fibre concentrate. Examples of isolated fibre concentrates are: corn bran, psyllium, sugar beet fibre, inulin and fructo-oligosaccharides.

Food	Portion	Fibres: grams/portion
Wholemeal bread	35 g / 1 slice	2.3
White bread	35 g / 1 slice	1
Muesli,	1 dish 45g	2.6
Corn flakes,	1 dish 30g	0.9
White rice	50g (crude weight)	0.5
White pasta	50g (crude weight)	1.3
White beans	50g (crude weight)	3.4
Fruit	125g	1.5 – 6
Nuts	30g	2
Vegetables (mean)	200g	~4

Source: Nubel

Fibres: a broad family of compounds

Fibres can be classified according to their chemical composition and physiological behaviour:
Schematically, we can distinguish:

- Soluble versus insoluble fibres
- Viscous, poorly viscous, non-viscous fibres
- Fermentable, partially fermentable and non-fermentable fibres

Different types of fibre provide different sorts of health benefits or improve laxation through various routes:

- **Insoluble fibres**, sediment in water. Think of resistant starch, fruit and vegetable peel fibres and bran (e.g. wheat bran and cellulose).
- **Soluble fibres** may or may not increase viscosity (gel formation). Viscous fibres are for instance pectin present in apples and that is useful to make jam. Soluble gel-forming fibres, have a high water-holding capacity. However, many gel-forming soluble fibres are readily fermented in the large bowel, resulting in the loss of their gelled-nature water holding capacity, thus having a minor impact on stool output and bowel regularity (McRorie & McKeown 2017). An exception is psyllium that is not fermented and keeps its high water-holding capacity (McRorie & McKeown 2017).
- **Fermentable fibres** leverage a wide variety of mechanisms. Fermentation means that bacteria present in our colon (our gut microbiota) are able to break down fibres for their own feeding, thus producing, amongst others, alcohol, short chain fatty acids (SCFA) and lactic acid. The fermentation of fibre within the colon favours the development of a healthy colonic microbiota (i.e. prebiotic effect), hence lowers the concentration of carcinogenic compounds.
- **Poorly fermentable fibres** are for instance: hemi-celluloses (present in carrots, tubers, vegetables) and bran (grain fibre).

Fibres should come from various sources, the major ones being cereal products (whole grain containing more fibre), fruit, vegetables, legumes and potatoes (Clemens et al. 2012). Grain products and cereals contribute for almost ½ (43%) to our daily dietary fibre intake. Without grains or variety, the recommended amount of fibre can hardly be achieved.

Dietary fibres benefits our body

- **Effects on bowel function**

Dietary fibres increase stool bulk and water content, what leads to bulky/soft stools that consequently, are easier to pass (McRorie & McKeown 2017). Not all types of fibre provide the same degree of benefit towards constipation. The bulking effect of dietary fibres is an important property when assessing the impact on constipation (Stephen et al. 2017).
Wheat bran has a very well documented effect on faecal bulking, documented by around 30 studies, all showing a statistical significant increase of wet and/or dry stool weight (EFSA 2010). Cummings reviewed data from various studies, and focused on the different bulking effect of various fibres. The greatest increase in faecal weight with raw wheat bran, which for each 1g consumed, increases wet stool weight by 7·2g (Cummings 2001). Stephen et al. (1986) calculated a bulking index for NSP coming from wheat bran of 5g/g of fibre ingested. This effect being independent of the initial daily faecal weight. A recent systematic review of intervention studies conducted among healthy general population confirms the effect of intact wheat bran on increased stool weight and decreased transit time (De Vries et al. 2015). The bulking index of wheat bran

appears to be more or less equal to that of fruit and vegetables (Cummings 2001). Other cereals (oats and maize) and types of fibres (coming from legumes or pectin) have a lower bulking index.

Wheat bran further delays gastric emptying and accelerates small bowel transit (McIntrye et al. 1997) (EFSA 2010).

Wheat bran is very well-studied and well-documented for its effects on bowel habit and several other cereal fibres are acknowledged by EFSA (claims allowed) for their effects on increased bulk (wheat bran, rye, barley grain, oat grain fibres) on increased faecal bulk (Table 1).

On a population base, observational studies have studied the relationship between fibre intake and bowel frequency/risk constipation. A cross-sectional study from the EPIC-Oxford study, including around 20.000 participants (30% being vegetarians or vegans) showed a significant positive association between bowel movement frequency and intake of dietary fibre. Mean bowel movement frequency was also higher in vegetarians and especially in vegans (Sanjoaquin et al. 2004).

Alterations of bowel regularity, more specifically **constipation**, remain one of the most prevalent GI disorder in Europe. Its prevalence in Europe ranges from 5-35% of the general population, depending on the definition and criteria used (Peppas et al. 2008). In the Netherlands, recent data report that a fourth (24,5%) of the Dutch population suffers from constipation (Meinds et al. 2017).

Constipation can be defined as infrequent (<3 bowel movements/week) elimination of small/hard stools that are difficult to pass (McRorie & McKeown 2017).
It is a disorder of bowel habit characterized by a low stool frequency, but not only. One might strain to pass a single, small, hard stool per day, and be constipated (McRorie & McKeown 2017). Stool consistency (assessed through stool water content in %) and ease of defecation matter as well. Regular stools mean (mostly daily) elimination of bulky/soft/easy-to-pass stools. Definition (Rome IV criteria).
Causes of constipation are multiple and complex, and commonly encountered as those related to diet, and notably to **low dietary fibre intake**.

- **Effects on gut microbiota**

The human gut harbours a vast and diverse microbial ecosystem, an estimated 100 trillion bacteria, residing mainly in the gastrointestinal tract (the adult intestine contains about 1014 bacterial cells) (Xu & Gordon 2003). The past decades, tremendous work has been undertaken to understand composition and functions of the gut microbiota (Qin et al. 2010, Human Microbiome Project Consortium (2012)). It becomes now clear that this microbial community is essential to normal homeostasis, and is also key in several physiological functions, including immune function and metabolism (Sommer and Backhed 2013). Among other functions, the gut microbiota produces essential vitamins, and is required for the development and differentiation of the host's intestinal epithelium and immune system. The gut microbiota confers protection towards pathogens (Sommer and Backhed 2013).

Fibre gap and consequences for the gut microbiota

- The inhabitants of our gut have co-evolved with us and inside us over millennia, but today, they are facing new challenges. We have radically changed the way we are eating over the past 50 years (highly processed and refined foods), and these changes are not in favour of our gut bacteria.
- A diet low in fibre, as it is actually the case in Belgium (18g actual intake vs 30g/day recommended intake) and in the Netherlands (20g actual intake vs 30-45g recommended), has

been associated with a depletion in gut microbiota diversity, and potentially beneficial metabolites.

- It has also been shown that a diet low in total carbohydrate content also has important effects upon the composition and metabolic outputs of the bacterial community in the colon (Duncan et al 2007, Brinkworth et al 2009). These changes are likely reflecting the loss of fermentable material in the form of non-digestible (ND) carbohydrate components (mainly non-starch polysaccharides (NSPs), resistant starch (RS) and certain oligosaccharides) that reach the large intestine (Walker et al. 2011).
- A study in humans has shown that refined wheat in the diet resulted in decrease gut microbiota diversity compared to whole grain wheat (Schutte et al. 2018).
- Loss in diversity, in turn, has been associated with an altered health status (Cotillard et al. 2013, Le Chatellier et al. 2013).

Microbiota in traditional populations:

Some researchers have studied traditional populations, consuming a high fibre diet, to provide a view of gut microbiota composition that would be unperturbed by industrialization and a diet low in fibre notably. They studied the gut microbiota composition of rural farming or hunter-gatherers populations that have conserved a traditional, high-fibre diet. These populations display a much higher bacterial diversity, and sharp differences in microbiota composition compared to that of the Western populations (Yatsunenko et al. 2012, Obregon-Tito et al. 2015, Fragiadakis et al. 2018). The gut microbiota composition of the latter has lost diversity and specific phylogenetic groups, what is putatively caused by modified diet (processed food), as well as modern lifestyle and medical practices. It is further hypothesized this less diverse microbiota is subject to change in functional capacity (notably production of SCFA), which is contributing to modern health issues (Sonnenburg & Bäckhed, 2016).

Gut microbiota and diet/fibres

- Several factors, namely diet, antibiotics, hygiene, lifestyle and genetics, are shaping or influencing the composition of the gut microbiota, with various consequences for host physiology (Sommer and Backhed 2013).
- Diet is an important factor driving the long-term composition of the gut microbiota (Wu et al. 2011). Most of the carbon and energy used by the microbiota is coming from plant- and animal-derived dietary carbohydrates (Sonnenburg & Sonnenburg 2014). Our bacteria are fed by undigested carbohydrates that reach the lower part of the gut, and dietary fibres constitute the most common fuel of our gut microbes (Flint et al. 2012). Indeed, our resident microbes are equipped with an enzymatic material capable of breaking down fibres (Sonnenburg & Sonnenburg 2014).
- Not all fibres are equal also here, and those that are fermented by the gut microbiota will mainly drive the composition of the microbial ecosystem, but also contribute to the generation of short-chain fatty acids (SCFA) as end products of bacterial metabolism, produced mainly in the proximal colon. Those SCFA, primarily acetate, propionate, and butyrate are compounds that impact our physiology in a favourable way, and in fact they contribute to mediate benefits of fibres. The majority of SCFA (up to 95 %) are rapidly absorbed by the colonocytes, with the potential to reach peripheral circulation (Topping & Clifton 2001). SCFA can also be metabolized by other bacteria. Butyrate is the major energy substrate for our colonic cells. SCFA are recognized has having mechanistic links to health outcomes (Koh et al. 2016). The rate and amount of SCFA production depends notably on the substrate source, i.e., the type of dietary fibre (Wong et al. 2006).
- Some fibres, termed prebiotics, have been studied for their ability to manipulate the host's microbiota to the benefit of the host. Prebiotics are substrate that is selectively utilized by host

microorganisms conferring a health benefit (Gibson et al. 2017). Selective microbiota-mediated mechanisms differentiate fermented fibres from prebiotics. These modulations result in documented health benefits for the host.

- Whole-grain cereals constitute an important source of dietary fibres, namely NSPs (including arabinoxylans), resistant starch (RS) and fructans that are degraded by the gut microbiota, modifying thereby its composition and contributing to the generation of SCFA (Bach Knudsen 2015). Whole grain hold the potential to correct dysbiosis (or microbial imbalance of our gut microbiota), one potential mechanism explain their beneficial effects, see lower (Ashwell and Willem van der Kamp 2016).
- The fibres contained in wheat further display prebiotic properties, these are namely inulin and arabinoxylans (Gibson et al. 2017, Vandeputte et al. 2017).
- In the European Union, fibre is defined as "carbohydrate polymers with three or more monomeric units, which are neither digested nor absorbed in the human small intestine and belong to the following categories: (A) edible carbohydrate polymers naturally occurring in foods as consumed, (B) edible carbohydrate polymers which have been obtained from food raw materials by physical, enzymatic, or chemical means and which have a beneficial physiological effect demonstrated by generally accepted scientific evidence, and (C) edible synthetic carbohydrate polymers which have a beneficial physiological effect demonstrated by generally accepted scientific evidence" (Commission directive 2008). The European Commission in its directive clearly recognizes that fermentation by microbiota is a beneficial effect (Commission directive 2008). The latter implies that fructo-oligosaccharides (Roberfroid et al. 2010) which have been obtained from chicory root inulin by enzymatic means can be named fibre. The same holds for arabinoxylan oligosaccharides. Such constituents are obtained by enzymatic action on wheat bran arabinoxylan dietary fibre (Broekaert et al. 2011).
- Some dietary fibres also correspond to the definition of prebiotics, i.e. non-digestible food ingredients that beneficially affect the host by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the colon, and thus improve host health (Gibson and Roberfroid 1995). For a compound to classify as prebiotic it needs to: "(A) resist gastric acidity, hydrolysis by mammalian enzymes and gastrointestinal absorption, (B) be fermented by intestinal microbiota, and (C) selectively stimulate the growth and/or activity of intestinal bacteria associated with health and wellbeing" (Gibson, Probert, Van Loo, Rastall and Roberfroid, 2004).
- Inulin and its fructo-oligosaccharides and galacto-oligosaccharides have been studied as potential prebiotics (Roberfroid et al. 2010). So have wheat bran derived arabinoxylan oligosaccharides from wheat bran (Broekaert et al. 2011). Inulin and fructo-oligosaccharides are now used food ingredients and dossiers have been filed with EFSA on the prebiotic concept. Effects claimed have been worded as "beneficial effect on intestinal microflora, gut integrity, digestion, intestinal bifidobacteria, prebiotic effect, prebiotic, and intestinal health". Effects ascribed to prebiotics have been worded as "beneficial effect on intestinal microflora, gut integrity, digestion, intestinal bifidobacteria, prebiotic effect, prebiotic, and intestinal health". However, EFSA has concluded that no proof has been given that increasing numbers of gastro-intestinal microbiota is a beneficial physiological effect (Regulation (EC) No 1924/2006) and that, under current legislation constituents increasing the number of bifidobacteria cannot be labelled as prebiotics and thus only as dietary fibre.
- A major source of prebiotics in our diet is thus likely coming from the natural presence of fructans and arabinoxylans (AX) in cereals. The Food and Drug Administration U.S. Department of Health and Human Services, further states that AX have a beneficial physiological effect on blood glucose and insulin levels. The evidence from which scientific conclusions could be drawn supports their decision to propose to include AX in the definition of dietary fibre. (FDA, June 2018)

- In contrast, when fermentable fibres are short in the diet, microbes switch to less favourable compounds, such as amino acids (from proteins) or dietary fats (Koh et al. 2016). Protein fermentation results notably in the production of branched-chain fatty acids (isobutyrate, 2-methylbutyrate, isovalerate), S-containing metabolites, phenolic and indolic compounds (notably p-cresol), polyamines, ammonia and amines (Smith and McFarlane 1997, Verbeke et al. 2015, Portune et al. 2016). Some of these metabolites might exert deleterious effects on colonic epithelial cells, affecting epithelial cellular metabolism and barrier function, as shown by in vitro and experimental animal studies (Andriamihaja M et al. 2015, Verbeke et al. 2015). High-protein diets have further been shown to decrease faecal butyrate concentrations and increase exposition of intestinal mucosa to p-cresol, a bacterial metabolite with genotoxic effects (towards coloncytes) (Blachier et al. 2018).

Positive changes with high fibre intake

- Interestingly, intervention studies in humans have demonstrated that dietary fibre and whole grain intake increase gut bacterial diversity or enriched the microbiota composition in certain health promoting bacteria. Changes coincided with improvements in host physiology related to glucose metabolism (Tap et al. 2015, Martínez et al. 2012).
- It has also been shown that short-term shifts are possible. David et al. (2014) showed a significant and reversible modulation of microbiota composition following an all plants-based diet in humans.
- According to EFSA's summary report 2017, "the role of dietary fibre in bowel function was considered the most suitable criterion for establishing an adequate intake. Based on the available evidence on bowel function, the Panel considers dietary fibre intakes of 25 g per day to be adequate for normal laxation in adults. The Panel notes that in adults there is evidence of benefit to health associated with consumption of diets rich in fibre-containing foods at dietary fibre intakes greater than 25 g per day, e.g. reduced risk of coronary heart disease and type 2 diabetes and improved weight maintenance. Such evidence should be considered when developing food-based dietary guidelines."

Material	Health claim	Conditions of use	EFSA opinion reference		
Rye fibre			Normal bowel function	Foods should be high in that fibre (i.e. fibre ≥ 6g/ 100g product) and daily intake ≥ 10g is required	2011;9(6):2258
Barley grain fibre			Increase in faecal bulk		2011;9(6):2249
Oat grain fibre			Increase in faecal bulk		2011;9(6):2249
Wheat bran fibre			Increase in faecal bulk		2010;8(10):1817
Wheat bran fibre			Accelerated intestinal transit	Foods should be high in that fibre and daily intake ≥ 10g is required	2010;8(10):1817
β-glucans (Bg)			Maintenance of normal cholesterol levels (Article 13.1 claim)	Daily intake of 3 g required Food with ≥ 1 g of Bg per quantified portion.	2009;7(9):1254, 2011;9(6):2207
Oat β-glucan			Oat (respectively barley) beta-glucan has been shown to lower/reduce blood cholesterol. High cholesterol is a risk factor in the development of coronary heart disease Article 14.(1)(a) claim (disease reduction claim)	Daily intake of 3 g required Foods which provide at least 1g of oat (respectively barley) per portion	Q-2008-681
Barley β-glucan					Q-2011-00798 and Q-2011-00799
Arobinoxylan produced from wheat endosperm			Reduction of blood glucose rise after a meal	Daily intake ≥ 8g AX rich fibre	2011;9(6):2205
β-glucans from oats and barley				Intake ≥ 4g / 30g digestible carbs	2011;9(6):2207
Resistant starch (RS)				RS Content ≥ 14% of total starch	2011;9(4):2024

Table 1 – Health Claims EFSA

Whole grain and health

As outlined in detail in the EUFIC Whole Grain update (2015) most multi-annual observational studies with large populations – from several 10 thousands to more than 100.000 - find an inverse association between whole grain consumption and heart diseases, type-2 diabetes, colorectal cancer, other types of cancer and disorders such as obesity. Meta-analyses, where a large number of studies are considered together, convincingly associate a higher whole grain intake with lower risks.

Recent meta-analyses also find an inverse association between increased whole grain consumption and all-cause mortality, both for a range of WG products and for wholegrain (wheat) bread. Randomised controlled and other Intervention trials – usually with a duration of some weeks to some months and involving 10-20 persons up to some hundreds - show mixed results, possibly due to differences in study design such as duration of the study, population chosen (ill or healthy), type of whole grain chosen, and compliance with the test diet. However, a meta-analysis with pooled results from 21 RCTs found that a higher whole grain intake is inversely related to weight gain and lowers biomarkers of type-2 diabetes and cardiovascular diseases, such as and fasting blood glucose, insulin, total and low density cholesterol, blood pressure, and weight gain.

Cereal fibre and/or bran may account for much of the reduced risk of chronic disease and death associated with eating whole grains (Cho, Statement of the American society for Nutrition (2013) (Cho et al, 2013; Huang (13) The cholesterol-lowering action of the soluble beta-glucan fibres of oats and barley has been recognized in health claims by EFSA (Table 1) and the FDA. Therefore a wide range of dietary recommendations stress the importance of choosing, in particular, whole grains high in fibre (SEAL 2015)

In assessing the associations between fibre intake of various sources and reduced risks for heart related diseases, type -2 diabetes and colon (including colorectal) cancer a range of associations were found - in detailed comprehensive assessments of the available evidence - for cereal fibre, but hardly any for fruit and vegetable fibre. (Hauner, 2012, SACN, 2015) Therefore the German dietary recommendations for fibre emphasise to include cereal fibre in the total fibre intake.

Wholegrain story

The term “cereal grains” applies to the cereal grains of the grass (Gramineae) family and include, amongst others wheat, rye, oats, barley rice, maize (corn), spelt and teff, whereas the term “pseudo-cereals” includes amongst others amaranth, buckwheat and quinoa. All these grains are made up of three distinct sections: the outer fibre-rich bran, the micronutrient-rich germ and the starchy main ‘body’ of the kernel known as the endosperm. Oilseeds, pulses and other legumes are not classed as grains.

Cereals are the dominant source of carbohydrate in the diet worldwide. They require processing before consumption, either by cooking intact kernels or by milling and fractionation to produce flours. The tendency of the past century for the majority of cereals was to be processed into (refined) flours by removing the outer fibre-rich bran and the germ. More recently, with the growing interest in nutrition and health, an inverse trend can be seen – towards whole grain flours and grain products, including the bran and the germ. This trend goes together with dietary recommendations worldwide for choosing whole grain products as the grain products of choice (SEAL ET AL 2015) and with a wealth of information about (whole) grains and health on important websites such as www.eufic.org of EUFIC the European Food Information Council and www.wholegrainscouncil.org of the USA based Whole Grains Council

The nutritional composition of whole grains

The endosperm, by far the largest portion of the kernel, contains starchy carbohydrates, proteins, and small amounts of fibre, vitamins and minerals. The germ contains essential unsaturated fats, B vitamins, vitamin E, plant sterols, and other bioactive compounds. The bran contains fibre, minerals, such as iron, zinc, magnesium, phosphorus, vitamin E, B vitamins, and a multitude of other bioactive compounds such as flavonoids, carotenoids and a range of compounds with anti-oxidant activity. They may, as suggested by emerging research and illustrated in Figure 1, be responsible for many of the health effects of whole grains. Figure 2 shows fibre levels of a range of cereals and pseudo-cereals and, for wheat, the nutrients and other bioactive compounds in endosperm, bran and germ.

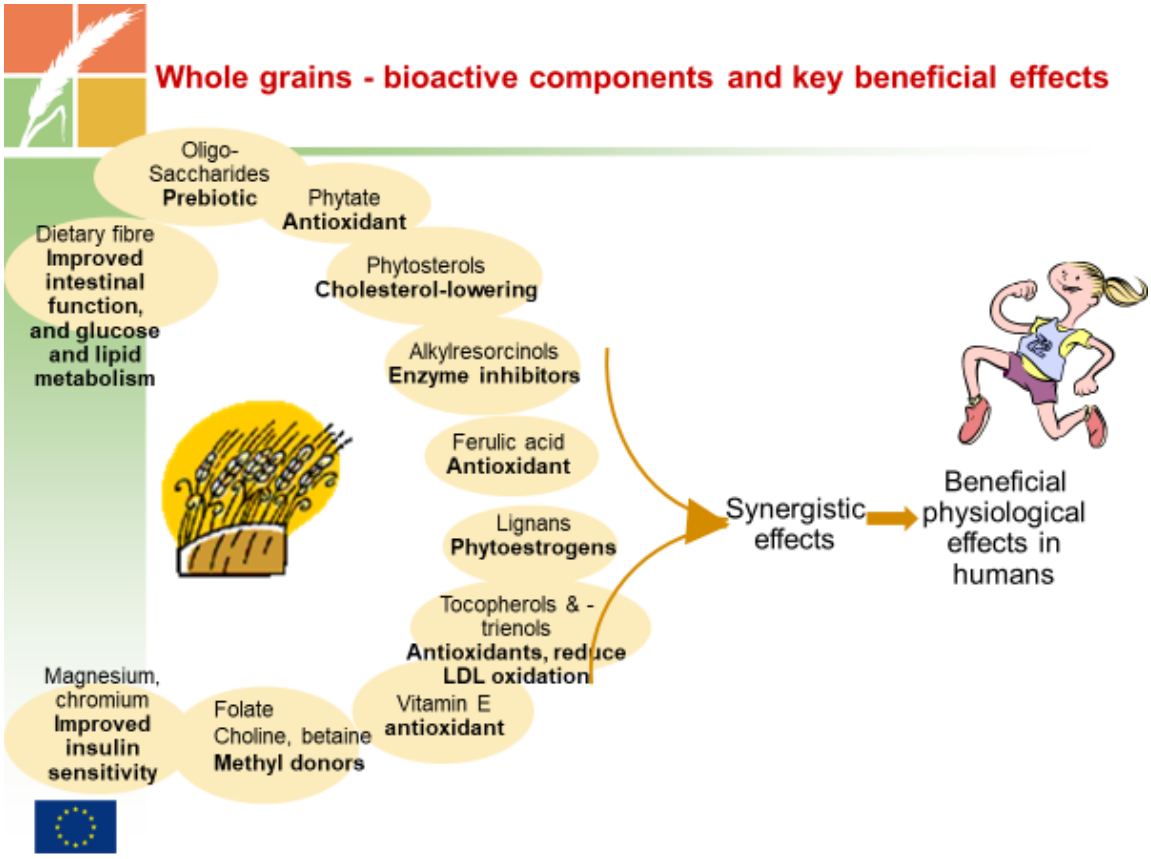

Figure 1

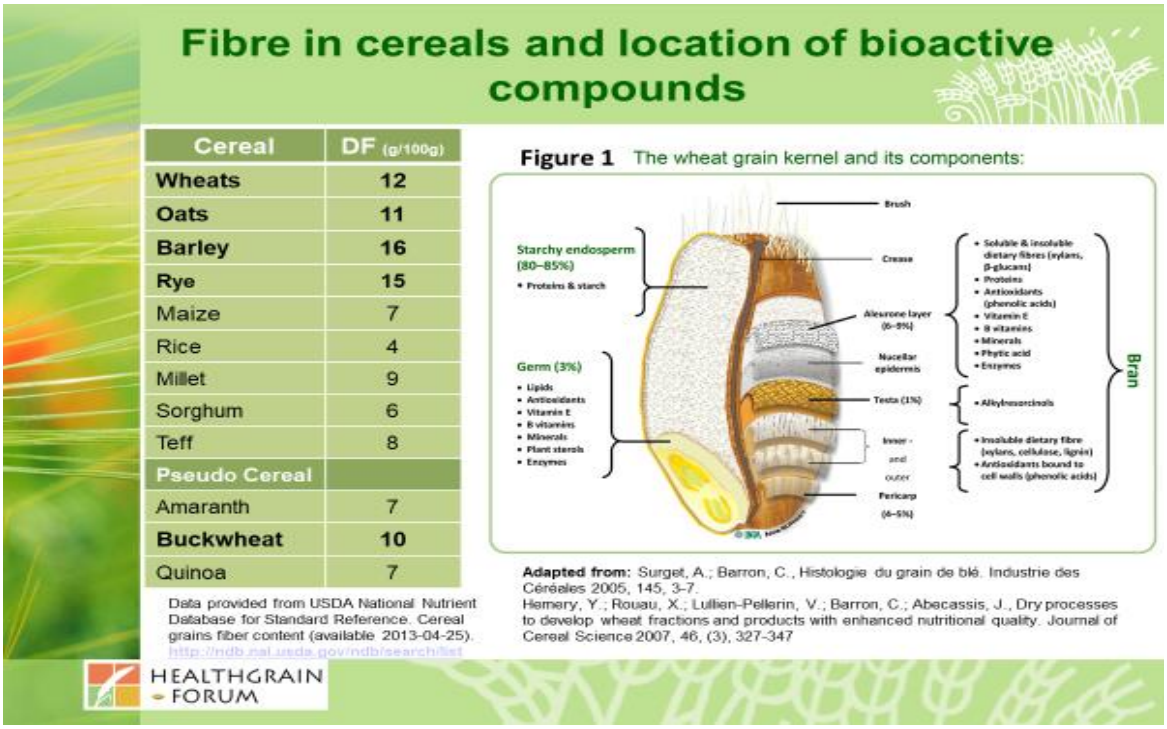

Figure 2

WHOLE GRAINS AND HEALTH - POSSIBLE MECHANISMS

Oxidative stress and inflammation are predominant pathological factors for several major diseases and it has been suggested that the variety of bioactive compounds found in whole grains may directly or indirectly inhibit oxidative stress and inflammation.

Coarsely milled as well as compact (i.e. rye bread, pasta) products are more effective in reducing blood glucose rise after a meal.

The fibre in whole grain foods may decrease the risk of colorectal cancer by increasing stool bulk and speeding up the excretion of waste, thus reducing the contact time between carcinogens (cancer producing substances) and the gut lining. Certain types of fibre and resistant starches can also be fermented in the colon which produces protective substances used by the gut wall.

HEALTH EFFECTS OF WHOLE GRAINS – NEW FINDINGS

A recent double-blind, parallel trial in the Netherlands in which 50 overweight 45- to 70-y-old men and postmenopausal women were randomly allocated to a 12-wk intervention with either whole grain wheat or refined wheat products (98 g/d) showed, for the first time an increase of almost 50% of intrahepatic triglycerides. (Schutte et al., 2018) This may contribute to the development of non-alcoholic fatty liver disease, NAFLD, the most common liver disorder in developed countries, Up to 80% of obese and up to 20% normal-weight people might develop it. It is estimated that 24% of the worldwide population is affected in 2017.[11] NAFLD is the leading cause of chronic liver disease as of 2017. This study indicates that incorporating feasible doses of WGW in the diet at the expense of RW maintains liver health. Hepatic effects could be a crucial underlying mechanism in the positive health effects of whole grain wheat described in observational studies. The authors refer to a possible positive role of Short Chain Fatty Acids – the whole grain diet induced formation of larger amounts of SCFA - but pay most attention to the methyl donors choline and betaine, present as bioactive compounds in – especially - whole grain wheat and, to a lesser extent, the sugar alcohol myoinositol (Choline and myoinositol are precursors for phosphatidylcholine and phosphatidylinositol, which are both indispensable compounds in Very Low density Lipoprotein formation.

Types of Carbohydrates in bread

Bread is a basic food product and essential part of a healthy diet. It provides complex carbohydrates and proteins and is an important source of fibre, vitamins (B1, B6, and B11), minerals (iron, copper, magnesium, zinc, and iodine) and some bioactives (polyphenols). Sometimes a very small amount of sugar is added to the dough in order to help the yeast rise the dough. The sugar is completely fermented and will not be present anymore in the endproduct.

The Dutch Nutrition Center recommends daily bread intake for different age and gender categories. For example, 6-8 slices of preferably whole wheat bread per day for males 14-69 years and 4-5 slices for females 9-50 years. Dietary advice on food sources for carbohydrates are broadly similar throughout Europe and in favour of the more fibre containing plant-based choices, namely of wholegrain (from locally produced cereals like wheat, spelt, oat, barley and rye), fruits and vegetables and legumes, rather than from refined cereal products, juices, sweetened drinks and sweet and savoury snacks [EFSA 2010, HGR 2016, VIGL 2018]. The following main types of bread are distinguished: white -, brown -, wholemeal - and multigrain bread. Nowadays, bakeries offer a very large variety of breads, e.g. muesli bread, currant buns, rye bread, oats bread, leaven bread, maize bread, soy bread, spelt bread, teff bread etc.

Wheat bread is the main source of bread consumed. The degree of grain milling and processing has influence on the content of fibre and other nutrients in the bread. The outer layer of the grain kernel (germ and bran) contains most of the fibre and other constituents. Bread from whole wheat is therefore richer in fibre and micronutrients than white – or brown bread. One slice of white bread delivers 1 gram of fibre, one slice of whole wheat bread more than twice as much. The recommended intake of dietary fibre in The Netherlands is 30-40 gram per day and 25-30g for Belgium, but data from the most recent consumption surveys show that intake is on average hardly half of these recommendations [RIVM 2018, WIV-ISP 2016, HGR 2016, GR 2015]. A total of 6 slices of whole wheat bread would provide about 40% of the daily fibre requirement.

Carbohydrates in our diet

The ingestion of carbohydrates results in an increase in blood glucose level. This so-called postprandial glycaemic response not only depends on the amount but also the type of carbohydrates and other characteristics of the food that provides carbohydrates. As measure of the glycaemic response of a food product the glycaemic index (GI) is used. Moreover, meal/food composition is of influence on carbohydrate digestibility, this is referred to as glycaemic load (GL). For example white bread, with a relatively high GI of 70, is easy digestible because it ‘falls apart’ faster under the influence of gastric fluids. Spaghetti on the other hand has a low GI of 48 because of its elastic structure which is stable in aqueous conditions. Whole wheat bread with a complex matrix of (partly) grounded flour, fibre, granules shows GI values below 50.

Consumption

Daily consumption of wholegrain products can help reaching nutrient and dietary recommendations and should be encouraged above the current intake levels.

In Belgium, 49% of population (3-64 years) consume every day whole grain or multi-cereal bread. 31% of the population consume white bread on a daily basis. The consumption of whole grain bread increases with education level. Between 2004 and 2014, there has been a slight increase in the proportion of individuals (15-64 years of age) consuming whole grain bread.

In 2014, in Belgium, the bread, ‘biscottes’, and breakfast cereals consumption is 141g/day (mean) in the 3-64 years of age group. Men consume on average more (165g/day) than women (117g/day). The consumption of bread, ‘biscottes’ and breakfast cereals decreased form 173 g/day to 141 g/day between 2004 and 2014. Mean bread consumption in Belgium in 2014 is of 104g/day (3-64 yrs.). Men consume more bread (124g) than women (86g/day). (WIV-ISP, 2016)

According to the Dutch Voedselconsumptiepeiling RIVM 2012-2014, adults consume 194 g of bread and cereal products. The highest consumption is seen in the 19-50 years of age group (242 for

men and 170g for women). Half of this consumption is brown or wholegrain. The Dutch Health Council advices a daily consumption of at least 90g of brown or whole grain bread or whole grain foods. More than half of Dutch men and one third of Dutch women comply with this recommendation.

Look out for whole grain

Wholegrain foods contain a broad range of nutrients and bioactive compounds associated with benefits to health. But, for many, consumers and health care professionals alike, it may not be crystal clear what health benefits whole grain and whole grain foods bring and some help may be welcome to pick the more health favourable option. The HEALTHGRAIN Forum's definition got wide recognition in the past and published in the July 2017 issue of Advances in Nutrition this recommendation for whole grain food labelling: "a food may be labelled as 'whole grain' if it contains at least 30 % whole-grain ingredients in the overall product and more whole grain than refined grain, both on a dry weight basis." Still, inconsistencies on what (legally) qualifies as a whole grain food product persist between countries and complicates the consumer's choice for the right or sought after product (Slavin J, et al. 2013)." Food labelling can help but may cover different loads. A useful rule of thumb is to look out for the word whole grain ('volkoren' in Dutch, 'intégral' or 'complet' in French) in the product name or description, this indicates the full grain with all its substances has been used to make the product. Further information can be found in the ingredients list, where all present ingredients must be ranked in decreasing order of quantity used in the recipe and the nutritional values table with information on fibre content. A wholegrain bread will contain around 6g of fibre /100g what is roughly 3 times the fibre content of plain white bread. Complementary, one can look out for claims on the packaging in relation to fibre content. European legislation states that a fibre rich ('vezelrijk'/'riche en fibres') claim can be made for food containing 6g of fibre per 100g or 3g per 100kcal, half of that amount allows a product to claim it is a fibre source ('vezelbron' or 'bevat vezels'/'source de fibres' or 'contient des fibres').

Conclusions & take away messages

Health professionals

1. Fibres are a broad family of compounds with various characteristics determining their effects on bowel function, colonic health and disease prevention
2. Depending on their nature, soluble or not, viscous or not, highly or poorly fermentable, fibres leverage different functional and physiological mechanisms
3. Whole-grain cereals are an important source of dietary fibres, ranging from insoluble bran with well documented bulking effect and fermentable NSP, resistant starch and fructans that are degraded by the gut microbiota, modifying thereby its composition and contributing to the generation of SCFA and other beneficial metabolites
4. The European Commission has authorized health claims for several types of cereal fibres not only on bowel function but also on their lowering effect on cholesterol and post-prandial glycaemia
5. Emerging research indicates whole grain and its bioactive compounds as possible contributors to further benefits on the intestinal function, the glucose and lipid metabolism, insulin sensitivity and hepatic health.
6. Meta-analyses convincingly associate a higher whole grain intake with lower risks for heart diseases, type-2 diabetes, colorectal cancer, other types of cancer and disorders such as obesity
7. Recent meta-analyses find an inverse association between increased whole grain consumption and all-cause mortality, both for a range of WG products and for wholegrain (wheat) bread
8. EFSA states that there is evidence of benefit to health, other than improved bowel function only, associated with consumption of diets rich in fibre-containing foods at dietary fibre intakes greater than 25 g per day
9.

Consumers

1. Food fibres play a very diverse and important role in the normal functioning of the body
2. Fibres are found in plant-based food families, namely cereals such as wheat, barley, rye, oat and spelt, fruits and vegetables, legumes and seeds and nuts
3. Fibres have different characteristics and health effects according to the food family they belong to
4. To comply with the a minimum recommended amount of 25g of fibre a day, all food families should be part of the daily menu
5. Replacing refined cereal products like white bread or pasta and sugared breakfast cereals by their wholegrain variant contributes greatly to the daily fibre consumption

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4. Health concerns over cereals and our daily bread

Emeritus Professor Fred Brouns, Health Food Innovation, University Maastricht Netherlands.

Of all grains, wheat is most widely cultivated worldwide. With over 700 million tons annually wheat is third among all cereals in total global food production, behind maize and rice. The demand for wheat for human consumption is also increasing globally, including in countries, which are climatically unsuited for wheat production, due to the adoption of western-style diets. Wheat is relatively rich in micronutrients, including minerals and B vitamins, and supplies up to 20% of the energy intake of the global population.

Nevertheless, a strongly increasing demand for gluten-free and wheat-free products has developed in recent years. Apparently, social media statements that gluten and wheat cause overweight and health problems, as well the new 'Free from' consumer trend, play a major role in this development. These developments have resulted in increased self-diagnosis of being gluten and/or wheat intolerant and increased belief in being intolerant, which in turn has led to an increasing avoidance of wheat and gluten containing foods. But what is fact and what is perception and emotion? This chapter describes context, history and current status on gluten in bread and possible gluten intolerances.

What are grains and what is gluten?
Grains belong to the grass family (fig 1). Amongst others, this includes wheat, rye, barley, oats and spelt, as well as rice, maize and other grains that are less common here, such as millet (which is mainly eaten in India, Africa and China), sorghum (Africa, USA) and teff (Africa), all grains that grow well in areas with low rainfall. Some of these grains contain gluten, others don't. Quinoa (South America) and chia seeds (South America, Mexico) are in fact not grains at all but are often promoted as gluten-free alternatives. Of all the grains, wheat is the most commonly grown gluten-containing grain.

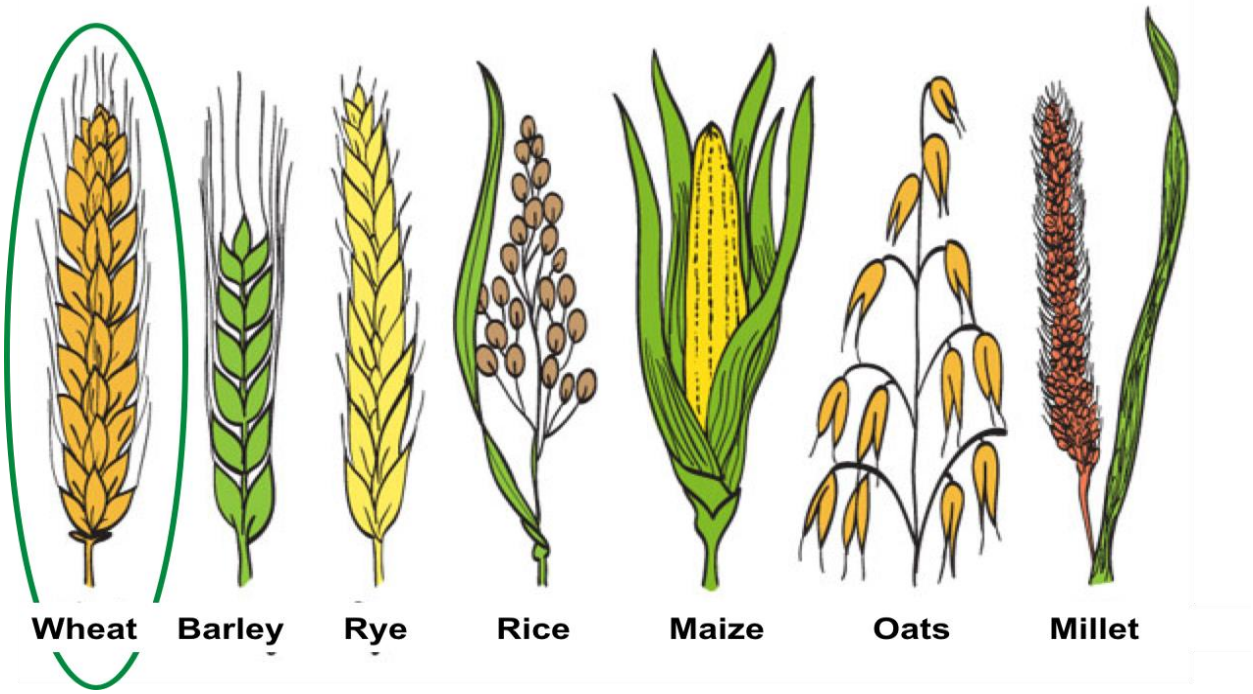
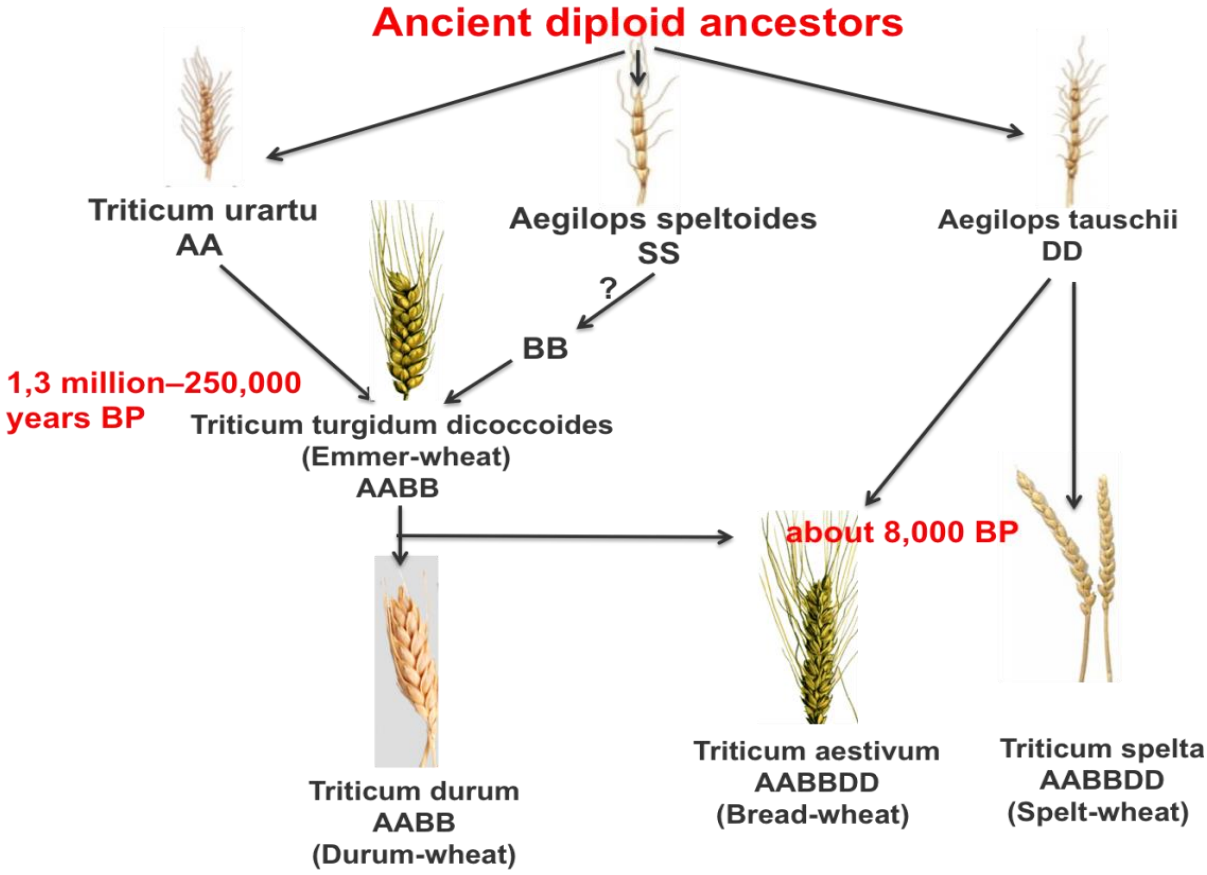


fig 1: Source Cereals-Shutterstock.com

History of wheat

Types of wheat have probably existed for millions of years. The oldest forms are diploid (such as modern einkorn) and tetraploid (such as modern emmer and durum wheats), but modern hexaploid bread wheat only originated about 10,000 years ago. These forms originated from genetically related grass species (with the A, B and D genomes, see fig. 2), with the tetraploid and hexaploidy forms having arisen by hybridizations. These ancestors, and therefore also the genomes of the grains that are cultivated today, are extremely old. They all contain gluten protein. The gluten composition and baking qualities are therefore determined by the genetic characteristics of the A, B and D genomes and combinations thereof.



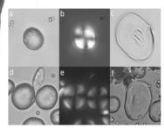
(fig 2). Fred Brouns: Adapted from: Feuillet 2007, Virtueller Sorten Garten Getreide ETH, wheatgenome.org and G.Garmet. Wheat domestication, C.R.Biologies 334 (2011) 212-22

In a continuous selection process, farmers selected a handful of wheat varieties that were the most attractive in terms of yield and workload from the available species. Ultimately, some 8,000 years BC, the popular bread wheat that we consume today produced the best result. It was simply a natural variant with an excellent yield (i.e. it was not a genetically modified grain). Bread wheat produces a yield that is 2 to 4 times greater than and also has far better baking qualities than other supposed wheat species such as einkorn, emmer and spelt.

The rash claim made by many that we have only been eating grains for 10,000 years would appear to be incorrect. Archaeological finds, such as microscopic remains in the holes of millstones found in Ohalo near the Sea of Galilee in Israel, and in the dental enamel of Neanderthals living in Belgium, confirm that, as well as plants, tubers and fruit, people were already eating wheat, rye and barley some 50,000 years ago. (fig 3)

3a

3b



3c

fig 3a: In Ohalo II, an ancient archaeological site in Israel, flour was being produced on a large scale 23,000 years ago, using milling stones(Nadel D et al. Antiquity. Vol. 86, 334, Dec. 2012, Pages 990-1003. doi.org/10.1017/S0003598X00048201) , 3b and c: - 47,000 years, Belgium, Upper Palaeolithic period: Microscopic marks in dental enamel and dental plaque provide evidence of the consumption of dates, vegetables, carrots, wheat, rye and barley (Henry, A.G., et al.,, Journal of human Evolution (2014), http://dx.doi.org/10.1016/j.jhevol.2013.12.014
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The oldest known bread, a kind of pitta bread, was already being baked by hunter-gatherers who lived at the end of the paleolithic age. This type of bread was easy to dry and store for times when food was scarce. So, the claim by many followers of the Paleo diet that our early ancestors ate no grains at all is untrue. Who knows, people may well have been eating ancient wheat varieties far earlier than that but we simply haven't found the evidence to prove it - not yet! But absence of proof that they were eating something does not prove that they weren't.

What is gluten?

Gluten is a type of protein that belongs to the prolamins group and is contained in wheat, rye, barley and spelt. It comprises of two components, gliadin and glutenin, which, following the addition of water and salt, form an elastic structure as a result of kneading. It's a bit like the elastic skin of a balloon. When you blow air into it, the surface expands but the air can't get out, so the balloon "rises". If you burst this skin, the balloon goes down. This is similar to kneaded dough in which yeast and bacteria, in a process called fermentation, form gases that can't escape through the elastic gluten. As a result, the dough rises. If you then prick the dough with a knife or a fork, it sinks and the gases escape. In fact, gluten is therefore responsible for the good baking qualities of bread, giving it an elastic, aerated structure. Gluten-free grains therefore produce a far smaller and more compact loaf.

Does bread wheat have more gluten?

One question that people often ask is whether it is true that bread wheat contains more gluten than other (older) wheat varieties. The leading European Health Grain Research Consortium has conducted an in depth study into the composition of wheat. In this study, 150 varieties of wheat from seed banks were sown, cultivated and harvested under exactly the same conditions. The results of the analysis indicated that more recent varieties contain less gluten and more starch than older varieties (see fig 4). This dispels the myth that the grains that we eat today contain more gluten than older grains. It is clear, however, that the type and composition of the protein fragments (peptides) vary depending on the genome of the grain. Whether this impacts on the occurrence and severity of health problems is the subject of much international research.

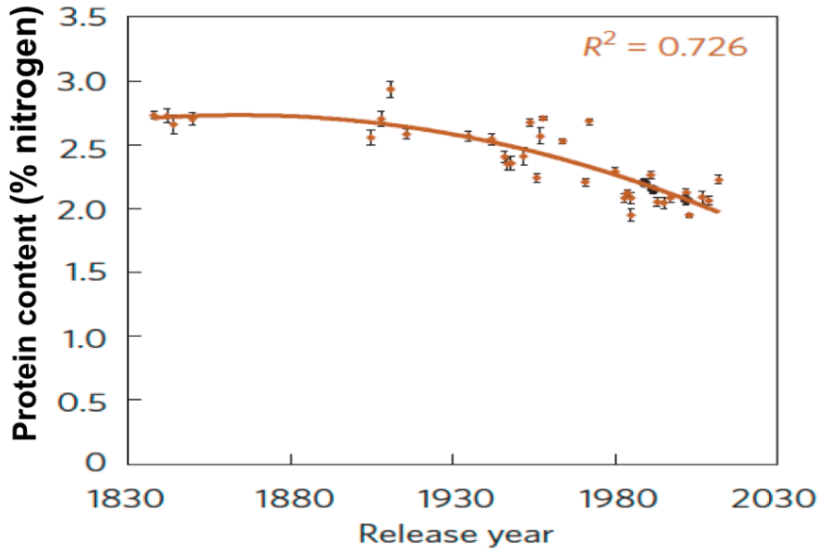

fig 4 Wheat protein changes over time. Data from 150 varieties of wheat all cultivated under the same controlled conditions. Source: Shewry P.R. et al. NATURE plants, July 2016, vol 2, 1-3, DOI: 10.1038/NPLANTS.2016.97

It is also clear that the content of other protein components, such as the natural plant protection protein amylase-trypsin inhibitor (ATI), varies according to the type of grain. ATIs inhibit the digestion of starch and protein in harmful predators such as insects, rendering them harmless. ATIs appear to be resistant to exposure to heat (boiling, baking), gastric acid and digestive enzymes in the gut. Consequently, once the grain product has been consumed, ATIs remain largely intact and can cause immune reactions in the gut of people who are sensitive to them. In addition, it appears that ATIs also have a strong allergenic effect and are partly responsible for asthma symptoms in bakers that occur as a result of the inhalation of flour dust. Wheat has a wide range of ATI types (about 20 iso forms), all of which vary in terms of their biological activity, which is why much research has recently been initiated around the potential role of ATIs in wheat- and gluten -related health problems.

Are ancient grains more nutritious?

The claim that ancient wheat varieties have a higher nutritional value in terms of fibre, antioxidants (polyphenols), vitamins and minerals was investigated in the Health Grain project. The indication was that there are minor differences between them that are not likely to have a significant impact in terms of nutritional value and health.

The research also indicated that the annual variation in climate and growing conditions has a greater impact on grain composition than the grain type itself. So, reverting to ancient grains would not be beneficial. And in terms of sustainability, it would be a retrograde step! In this respect, researchers from the University of Hohenheim in Germany studied the yield of "ancient grains" as currently available and grown on experimental plots with the same soil, and climatological conditions. Nitrogen fertilizer load was adapted for each wheat type to help avoid the risk of lodging (Lodging is the bending over of the stems near the ground level in grain crops, which makes them very difficult to harvest and can dramatically reduce yield). The research group irrefutably demonstrated that the yield of ancient wheat types were considerably lower than that of bread wheat. Spelt, Emmer and Einkorn yielded 40-70% less (see fig 5).

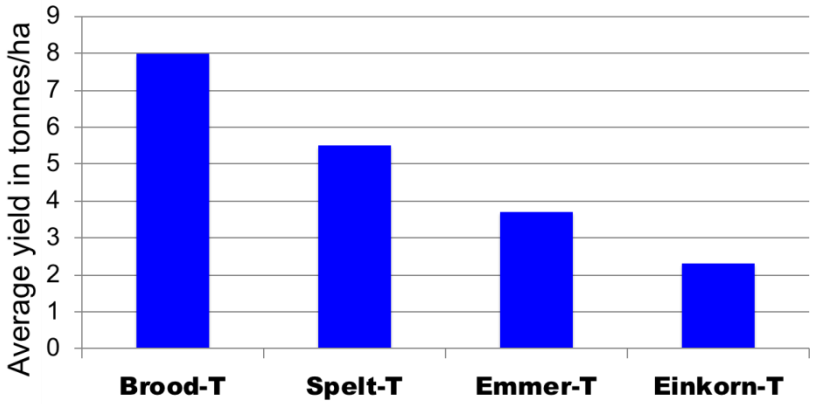

fig 5: Due to their low yield, 'ancient' grains are not really sustainable or cost-effective. Mean values from 15 varieties by type cultivated on 4 trial locations in Germany. By courtesy of Dr. Friedrich Longin, University of Hohenheim, Germany

Intolerance and hypersensitivity

Can wheat lead to intolerance or hypersensitivity reactions? The answer to this question is definitely YES. For example, coeliac disease, a chronic immune reaction to the presence of undigested gluten fragments (peptides), which causes damage to the small intestine. The intestinal villi lose their structure, which results in a "flat" intestinal surface (see fig 6). This leads to a significant decrease in the ability to digest and absorb, which in turn leads to bowel problems, diarrhoea and nutrient deficiency. Coeliac disease only occurs in people with a specific hereditary predisposition.

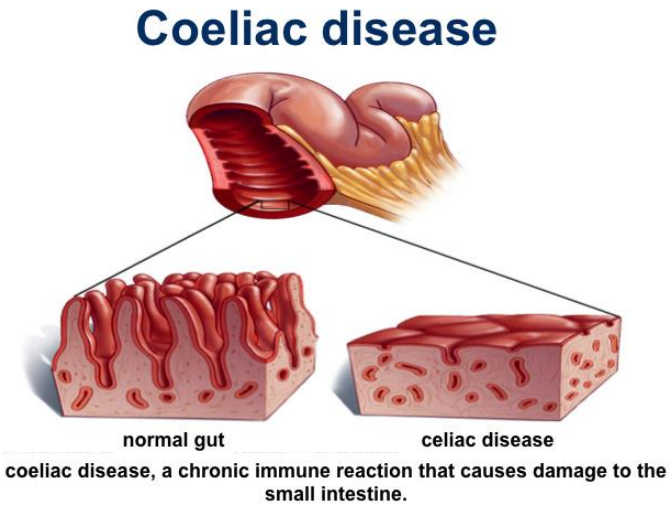

fig 6-: source: "Mayo Foundation for Medical Education and Research"

Depending on the country in which data are collected, this occurs in approximately 20-40% of the population. Of this group, 2-3% will go on to develop the disease. In the total population, this equates to about 1 %, although the actual percentage may be slightly higher because far from everyone is diagnosed. However, diagnosis is straightforward using specific antibodies that can be detected in the blood. Contrary to what is often suggested in the media, coeliac disease is not an allergy! It is an immune response related disease condition that develops over many months. In an allergy, the symptoms usually develop within a few hours of exposure, e.g. asthmatic conditions (generally in combination with physical effort) or skin irritations. About 0.2-0.5% of the population

are allergic to wheat proteins. This is demonstrated by the formation of IgE antibodies, which can be detected in the blood. (see fig 7).

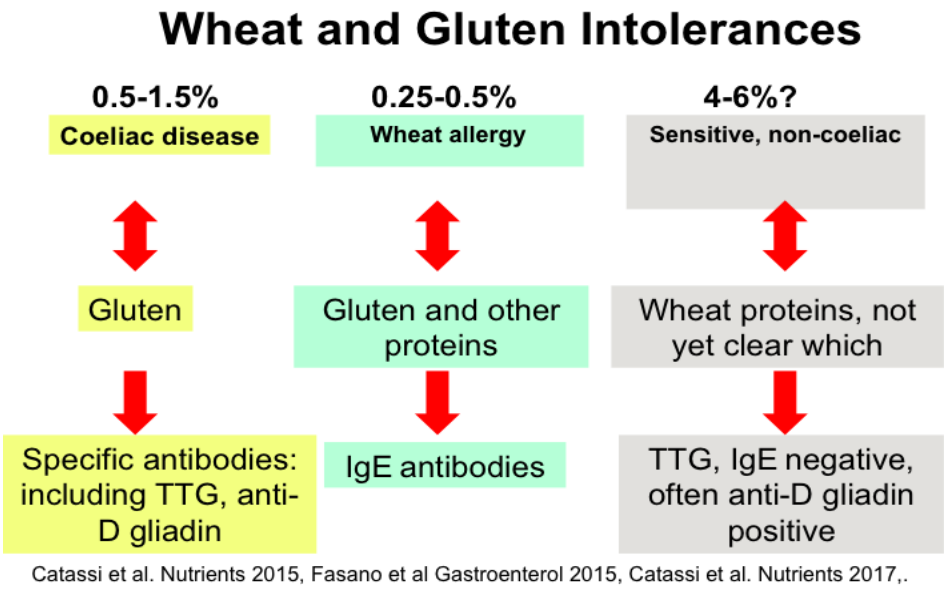

fig 7: Wheat and Gluten Intolerances as described by Catassi et al. Nutrients 2015, 2017 and Fasano et al Gastroenterol 2015

Recently, another type of intolerance known as non-coeliac gluten sensitivity, or sometimes wheat-sensitive irritable bowel syndrome, has been described. This can give rise to specific bowel problems but also to general malaise, headaches and muscle and joint pain. It is not yet clear which substance or substances in wheat play a key causative role in this. Nor, as yet, is there an effective diagnostic test. Consequently, if a person feels that specific health problems may be caused by the consumption of wheat or gluten, it is crucial that they consult a doctor in the first instance in order to exclude the presence of coeliac disease. If the diagnosis is negative, they can then take steps to completely avoid wheat and other gluten-containing grains for a period of between three and six months to establish whether their health problems disappear. It is necessary to do this over a long period of time because significant nocebo effects (the opposite of placebo effects) can occur, and these generally take several months to subside. If their health problems do indeed disappear, they can then double check by eating grains once again for a short period of time. If their health problems come back, it is an indication that they would be better off avoiding wheat and gluten on a lifelong basis. If, however, their health problems don’t come back, they don’t need to do this!

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