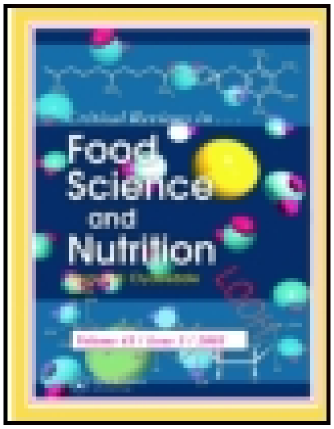

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Whole Grain in Manufactured Foods: Current use, Challenges and the way Forward

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Abstract

Some countries now incorporate recommendations for increased consumption of whole grain (WG) into local dietary guidelines. Cereal and pseudo-cereal grains are good sources of complex carbohydrates, dietary fibre, proteins, phytochemicals, vitamins and minerals. However, research shows that the large majority of consumers are still falling short of WG consumption goals. To address this, we are actively involved in research to help increase the WG content of processed foods without compromising on taste and texture. In order to ensure consumer trust, the advancement of process technologies in incorporating WG to produce tasty food has to go hand in hand with well designed clinical trials that confirm the health benefits resulting from diets rich in WG.

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Introduction

Whole grains (WG) are staple foods with a long history of human consumption, but over the past two centuries grains have been increasingly refined before use in food. WG cereals (**Box 1**) include the true cereals and the pseudocereals (American Association of Cereal Chemists, 1999). Wheat, rice and corn are the most widely eaten cereals worldwide, while other cereals are more regional in their use (e.g. oats, rye, quinoa, millet and sorghum) (Food and Agriculture Organisation, 2004). WG kernels are generally considered inedible as such; traditional food processes have been used to improve the safety, palatability and to provide variation in the diet. Since the early 1980s epidemiological studies consistently found that people who eat more WG have a lower risk of certain chronic diseases (e.g. cardiovascular diseases, diabetes and some cancers) and overall premature mortality (Seal and Brownlee, 2010). These reductions in disease risk are often still significant, even after adjustment for dietary fibre (Ye et al., 2012). This led to the hypothesis that the benefit of the three different anatomical components of the WG (endosperm, bran, germ) together is greater than any single fraction (Harvard Health Letter, 1999). WG contain physiologically important compounds, including vitamins (B-vitamins, tocotrienols), minerals (Mg, Zn) and diverse phytochemicals including phenolics, betaine, phytosterols and phyto-oestrogens) that may promote health benefits either individually, in combination and/or synergistically (Fardet et al., 2010). These findings have triggered a renewed interest in WG food. The 2000 Dietary Guidelines for Americans established separate recommendations for grains and emphasised that at least half of all cereal servings should be WG (at least three 16 g servings of WG per day) (Kantor et al., 2001). Other countries have followed, with higher recommendations of 75 g/2000 kcal in Denmark and Sweden (Kyrø et al., 2012). Despite these efforts, research shows that the public are falling short of consumption goals (Larson et al.,2010; McMackin et al., 2012). The many obstacles to increasing WG consumption include: habitual preference for refined products, limited availability of products made with WG, lack of variety, perceived poor palatability of WG foods, and confusion of WG and fibre messages for health (Adams et al., 2000). While some WG foods are not especially high in fibre (e.g. rice), they are still a rich source of phytonutrients and are always higher in fibre than their refined equivalents.

Manufactured foods can play a key role in helping consumers to include WG as a regular part of their diet. Presently the main sources of WG are bread and ready-to-eat breakfast cereals, but there are opportunities to introduce WG in a broader spectrum of products such as healthy snacks, noodles and pasta, biscuits and even beverages. Many innovative technologies are available for increasing WG content in existing products, which should boost WG consumption. However, such approaches will only meet with success if the primary consumer prerequisites of taste and texture are not compromised.

Development of novel products made with WG within the food industry is hampered by a lack of clear regulations on WG. While most regulatory bodies recognise the Association of American Cereal Chemists definition of WG (American Association of Cereal Chemists, 1999), this is vague with regards to which food processes are allowed to deliver WG-rich foods. In fact, only few countries have legislation as to what makes a WG food (Frølich and Åman, 2010). Attempts have also been made by the Whole Grains Council, a non-profit organisation aiming to encourage WG intake with input from academics, chefs and industry, stating that 8 g per portion makes a significant contribution to daily WG intake (Whole Grains Council, 2012). Defining

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WG throughout the production process is difficult as there are no validated methods available for doing this and those proposed are time consuming and expensive (Hemary et al., 2009). This adds to the challenge that WG flour itself is diverse both in origin and how it is milled, fractionated into the different anatomical components, and recombined.

These challenges faced by those in the food industry aiming to increase the amount of WG available to the public are many, and may not always be well understood by all performing research in the area of cereal science, technology and nutrition. This review outlines some of the areas where applied research is helping to increase WG consumption.

Supporting whole grain health benefit messages with intervention studies

The weight of the epidemiological evidence for the benefits of WG on health were compelling enough for the United States Food and Drug Administration to allow a health claim on WG as part of a healthy diet, for prevention of cardiovascular disease and some cancers (U.S. Food and Drug Administration, 2001). Since then, other countries have also allowed health claims for WG and encouraged WG consumption in the diet (Marquart et al., 2003; Richardson, 2003). A number of intervention studies have found that WG-based diets have effects on markers of disease risk such as cholesterol (Behall et al., 2004; Ross et al., 2011), blood pressure (Hallfrisch et al., 2003; Behall et al., 2006; Tighe et al., 2010) and insulin (Juntunen et al., 2003), though not all studies have found these effects (Brownlee et al., 2010; Andersson et al., 2007). Reasons for variability among intervention results include the control diet used, the population, excessive total food intake and difficulty in maintaining compliance over a long period (Ross et al., 2012). A recent meta-analysis of both observation and intervention data found that the totality of the

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evidence suggests that WG reduce markers of disease risk (Ye et al., 2012). Using biomarkers of WG intake such as plasma alkylresorcinols, as a surrogate measurement of WG intake and compliance check may be useful in understanding optimal study designs for WG intervention trials (Ross et al., 2012; Kristensen et al., 2012). A recent study using alkylresorcinols as a proxy marker of WG intake in an elderly American population found that intake was low, as well as confirming the association of greater WG intake with improved body composition (Ma et al., 2012). Supporting greater knowledge and proof around WG intake patterns and health benefits are important for creating a drive to improve the health value of food, and credibly promoting the greater intake of WG for their health value.

While WG are more nutrient dense compared to their refined counterparts, especially with regards to dietary fibre, micronutrients and potentially beneficial phytochemicals, the mechanisms behind WG health benefits have not been clearly established. It is likely that several different mechanisms are at play, including improvement of gut transit (McIntosh et al., 2003; Ross et al., 2011), changes to the gut microbiota metabolism and population, including prebiotic effects (McIntosh et al., 2003; Costabile et al., 2008; Carlhavo-Wells et al., 2010; Ross et al., 2011), improved methyl donor (betaine) status (Ross et al., 2011) and increased supply of phenolic compounds in the intestinal milieu and body (Vitaglione et al., 2008). These diverse proposed effects of WG on the human system indicate that many different components of WG could be responsible for their overall benefits, rather than one or two components that can be easily isolated. In addition, different grains may have different benefits which add to the complexity of understanding the mechanism of their impact on health.

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Addressing consumer needs

While consumers consider WG to be beneficial for health (Arvola et al., 2007) and WG consumption has increased over the past years there is still a gap to fill to reach the objectives of the American Dietary Guidelines for WG : "Make half of your grains whole" (Whole Grain Council, 2009). Barriers to WG consumption include a lack of knowledge about what WG are, familiarity, how to prepare them, price, poor range of products, perceived lack of taste and poor texture (Adams and Engstrom, 2000; Marquart et al., 2006; Pohjanheimo et al., 2010; Kuznesof et al., 2012). However, consumers also expect WG to be more natural, healthier, more filling, more easily digestible and providing slow release energy compared to refined grains (Arvola et al., 2007; Kuznesof et al., 2012). When people are introduced to WG products, actual acceptance is similar for both WG and matched refined grain foods (Bakke and Vickers, 2007; Sadeghi and Marquart, 2010), and while bran particles are noticeable, these do not affect acceptance (Challacombe et al., 2011). During a WG intervention study, a number of subjects 'learned' to like WG products, even though they had disliked them earlier (Kuznesof et al., 2012). This would suggest that the key barrier to increasing WG consumption is getting people to taste WG products, though there are some people who have a strong preference for refined grain products (Bakke and Vickers, 2007; Challacombe et al., 2011). The combination of strong public health messages, media coverage, improved availability and marketing increased WG consumption after the Dietary Guidelines for Americans 2005 (Mancino et al., 2008), suggesting that some of the barriers can be surmounted with improved awareness. Part of the challenge that remains is to increase WG consumption beyond those that look for WG as a healthy addition to the diet is to provide products that will attract consumers on taste and convenience. Yet it is

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important that such products also deliver a significant amount of WG to the consumer. Traditional food processing methods are one way of increasing the acceptance and consumption of WG.

Increasing WG content and improving nutritional and sensory profile

Food manufacturers face challenges in formulating products which contain levels of WG sufficient to deliver health benefits while retaining a strong consumer appeal in terms of taste, texture and flavour. This becomes a major issue when considering the addition of WG to product categories outside the traditionally recognised source of WG foods (e.g. beverages and confectionary). Several technological approaches are being developed to improve the organoleptic profile of WG and to allow its more versatile application in a range of product categories. Figure 1 gives a schematic overview of the use of these technological approaches in the two main routes for WG applications in food; either as ingredient added to non-WG raw materials, e.g. (route A) or the food itself is composed mainly of WG (route B). In principle, the technologies could either be applied in the pre- and/or main treatment step.

Extrusion

Extrusion-cooking is a versatile process widely used in the food industry. It enables the delivery of aerated cereal-based products with a wide range of shapes and textures. Today, most of the extruded products (e.g. breakfast cereals or savoury snacks) are based on refined flours. The replacement of refined flour by WG flour raises several challenges that need to be addressed, including changes in organoleptic properties, reduced size impression due to a lower expansion at the die exit, darker colour due to the presence of bran and/or Maillard/enzymatic browning and lipid oxidation after extrusion (Camire, 2004).

The bran fraction of cereals has a low physicochemical compatibility with the other grain components and a low water holding capacity compared to starch due to its high content of insoluble dietary fibre (Robin et al., 2011). This leads to reduced expansion and negative texture for extruded WG flours compared to refined flours due to reduced elastic properties of the starchy melt during the extrusion cooking process (Robin et al., 2011).

It is necessary to increase the physicochemical compatibility between cereal bran and the other components of the grain by reducing the size of the grain or bran particle, thus increasing surface contact between different components of the grain. This significantly improved expansion volumes of extruded bran-containing products (Guy & Horne, 1988; Lue et al., 1991; Blake, 2006). Another approach targets the solubilisation of the insoluble fibre in bran. For instance, solubilisation of corn bran was successfully achieved using an alkaline solution which led to hydrolysis of the ferulic acid ester cross-links (Blake, 2006).

Germination

Germination is a complex process during which the seed absorbs water to allow the embryo and radicle to emerge and prepare for further seedling growth (Nonogaki et al., 2010). The metabolic events that occur during germination vary widely among species and consist of a cascade of hydrolysis and synthesis of cellular components, i.e. fibre, starch, proteins, and bioactive compounds. These processes during germination have historically been exploited to improve the taste, flavour, texture and nutritional characteristics of grains (Kaukavirto et al., 2004). Malting of barley is one of the oldest and most widely studied examples of limited-germination. To date, only a few scientific studies have investigated the application of germination as a means of improving the nutritional and sensory characteristics of WG used in cereal products (Yang et al., 2001; Kaukavirto et al., 2004; Skoglund et al., 2008; Alvarez-Jubete, 2010; Hübner et al., 2010; Arora et al., 2011; Omary et al., 2012). Germination was shown to reduce the amount of anti-nutritional compounds, such as tannins and phytic acid (Larsson et al., 1995; Liang et al., 2008; Hübner et al., 2010), and to improve the nutritional quality of the grains by increasing the levels of some vitamins (vitamin C, α-tocopherol) and antioxidants (polyphenols, ferulic acid, vanillic acid and β-carotene) (Yang et al., 2001; Alvarez-Jubete et al., 2010). Germination may also degrade β-glucan in barley and oats, reducing the average β-glucan molecular weight. This has implications for health claims based on β-glucan content for reducing plasma cholesterol, where mid-high molecular weight chains are needed to see an effect (Wolever et al., 2010). Careful optimisation and control of germination conditions can lead to conditions where most of the β-glucan is preserved without any reduction in molecular weight (Wilhelmson et al., 2001).

Germination of brown rice is one of the most successful applications of short germination for the production of a tasty WG ingredient with potential health benefits, especially in Japan (Patil et al., 2011). The germination not only allows an improvement in the texture and palatability of brown rice, but it also results in a major increase in the content of functional compounds, and removal of antinutritional compounds (Liang et al., 2008; Moongngarm et al., 2010; Roohinejad et al., 2011; Xu et al., 2012).

Germination has a considerable potential as a natural low cost process for producing more nutritious and tastier products made with WG. A major effort is required to develop tailored germination processes for each grain focusing on optimizing their nutritional, textural and sensory benefits.

Fermentation

Fermentation of WG cereals is an established process used for the production of cereal-based foods such as beverages, gruels, porridges and breads. The main food grade microorganisms used for cereal food fermentation are lactic acid bacteria (LAB) and yeasts, which can be present naturally or added as starter cultures to the flour (Hammes et al., 2005). The characteristic sensory attributes of fermented WG are conferred by acidification and the synthesis of aroma compounds and/or precursors and texturizing agents, such as exopolysaccharides (Gänzle et al., 2007; Moroni et al., 2009). Fermentation lowers pH, allowing prolonged shelf life and reducing the amount of preservative in the final product. Microbial and enzymatic conversions of carbohydrates, amino acids and lipids during fermentation can strongly modulate the flavour of the fermented product. Fermentation has been reported as one of the most efficient ways of increasing the nutritional value of cereals, by improving the levels and bioavailability of nutritional factors and decreasing the amount of anti-nutritional compounds (Poutanen et al., 2009; Soetan & Oyewole, 2009). In cereal products, LAB and yeasts can produce vitamins, especially B-vitamins, release amino acids and bioactive peptides and decrease the glycaemic index of the fermented cereal through the production of organic acids (Poutanen et al., 2009). Anti-nutritional compounds that can be reduced by fermentation include phytic acid, flatulence sugars, and tannins, (Svensson et al., 2010; Poutanen et al., 2009; Soetan & Oyewole, 2009).

Overall, the desired effects of fermentation are strongly related to the choice of the fermenting strains and to the combination of various process parameters such as temperature, duration, and raw material. A sound choice of the fermenting LAB should rely both on the adaptability of the strains to the fermentation substrate and to their metabolic potentials (Svensson et al., 2010; Moroni et al., 2010). For this, screening of LAB may rely on the genetic or functionality level based on the enzymes and/or metabolic pathways responsible for the beneficial effects on the WG substrates. Nonetheless, further aspects need to be taken into account when designing fermentations with WG. Ideally, fermentation strains should acidify the substrate in a short time, preventing contaminations, while exerting beneficial effects on the substrate.

Enzyme technology

Enzymes are widely utilized in the food industry (e.g. infant formula, dough, and cheese production). Enzymes can target and transform specific compounds leaving the other nutrients intact. Enzymes also release bioactives from the food matrix, increasing bioaccessiblity/bioavailablity.

The use of enzymes enables adding WG to products not normally considered by the consumer as a source of WG in their diet. The addition of WG to a beverage, for example, is challenging owing to the viscosity generated by the starch and protein present in the grain. By treating the WG flour with α-amylases, the starch of the grain is hydrolysed, reducing viscosity and improving the texture and sweetness. This mimics the process already occurring during human digestion. The technology allows the addition of significant amounts of cereal to beverages, and can broaden the selection of products made with WG offered to consumers in beverage products while keeping their health benefits.

Bioactives can also be released through enzymatic treatments. For example, the bioavailability of ferulic acid, one of the most abundant phenolic compounds in wheat, is limited (<3 %) as more than 95 % is covalently bound to indigestible cell wall polysaccharides such as arabinoxylans (Iiyama, K. et al., 1994). Increasing ferulic acid bioavailability is of interest as it has been reported to have several physiological functions, including antioxidant, antimicrobial, antiviral, anti-inflammatory, anti-thrombosis, anti-cancer and cholesterol-lowering activities (Shiyi & Kin-Chor, 2004). An enzymatic treatment capable of specifically hydrolysing the ester linkage involved in the covalent linkage would offer a way of increasing the levels of free ferulic acid in WG and potentially increase its bioavailability. Anson and co-workers showed that subjecting wheat bran to fermentation alone or in combination with an enzymatic treatment increased ferulic acid bioaccessibility five-fold (Anson et al., 2009; Björck et al., 2012).

Dough technology

Dough technology involves a series of processes (kneading, shaping and baking). In the case of bread products, a fermentation step is added. The use of WG flour in products based on dough technology has increased due to consumer demand and the improved nutritional image of WG compared to refined grains.

Gluten proteins are the main structural component of wheat dough-based products. The gluten network must be properly developed to withstand the various stresses and strains associated with dough processing (Hamer et al., 2009). Inclusion of WG flour into dough products can have a detrimental effect on the formation of the gluten network. Adding WG in dough reduces the gluten content compared to regular dough made with refined flour because the gluten is only present in the endosperm. Among other the mechanisms proposed to explain the impact of WG flour on dough, the role of the water holding capacity of the bran fraction merits more attention (Noort et al., 2010). The water-holding capacity of bran has been postulated to result in a reduction of free water available to the gluten proteins for proper development and consequently would help to explain the reduced volume and close-pored structures associated with WG dough-based products (Wang et al., 2003). The particle size distribution of bran particles is thought to play a major role, but there is no general agreement on the optimal size distribution. As an example, fine particles have been shown to both lower (Lai et al., 1989) and increase loaf specific volume (Zhang & Moore, 1999). Different milling practices might partly explain this issue (Seyer & Gélinas, 2009). The bran fraction may in some cases have been ground and in others sifted before being added back to the flour.

To optimize the use of WG flours in food production, it is essential to have a sound understanding of milling practices for success in new product development.

Ensuring the highest safety and quality standards for WG foods

The addition of WG into food products to help consumers meet their daily recommended intake must comply with the laws and regulations governing safety and quality which apply in each country or be in line with the Codex Alimentarius when no guidelines exist. This is a challenge for the supply chain, as while WG are healthy; the outer layers of the cereal grain are more likely to be exposed to undesirable contaminants such as heavy metals from the soil or pesticides. This means rigorous quality checking is required. For particular applications (e.g. infant nutrition), specific quality standards are applied which are compliant with the local legislation. For the most part, these standards are based on monitoring and controlling the microbial and mycotoxin content as well as other contaminants such as heavy metals and pesticides residues in the raw materials.

Conclusion and outlook

To help consumers increase their daily intake of WG the food technologists are actively involved in research to not only increase the WG content in products already containing WG (e.g. cereals, pasta and noodles) but also to develop innovative approaches to increase the range of products made with WG on offer to consumers. Another approach that will gain momentum in the future is the use of alternative grains, such as quinoa, amaranth and buckwheat. Despite their excellent nutritional profile they have received little attention from the food manufacturers and their use is currently limited in mainstream food products. Nevertheless, these under-exploited grains offer opportunities for new product developments and greater consumer options. Further, commercializing these alternative grains will consequently enhance the agriculture, rural development, health and economic well-being of the local communities.

Finally, a clearer regulatory landscape is needed to support food technologists' efforts in increasing tasty WG product offers to consumers to help them meet recommended WG intake goals.

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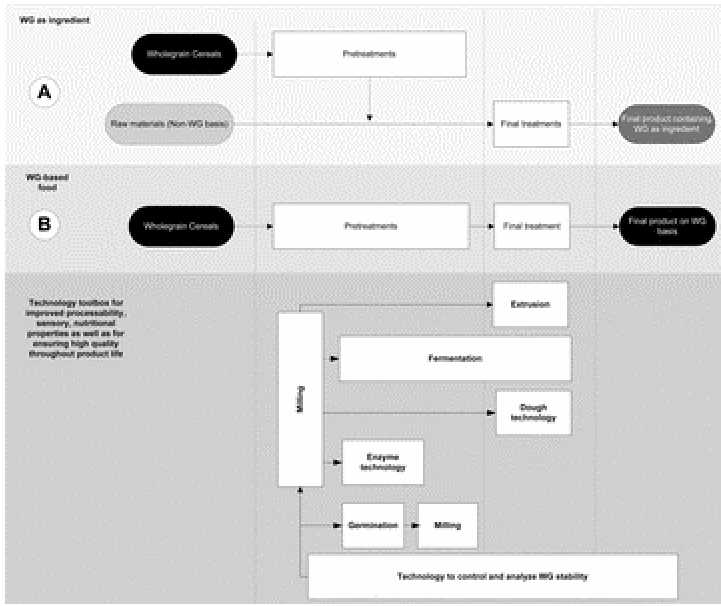

Figure 1. Schematic overview of the main routes for WG incorporation in food as well as different technological approaches to improve the properties of WG

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"Whole grains shall consist of the intact, ground, cracked or flaked caryopsis, whose principal anatomical components - the starchy endosperm, germ and bran - are present in the same relative proportions as they exist in the intact caryopsis."

In 2008 the AACC International Board approved the following statement:

"Malted or sprouted grains containing all of the original bran, germ and endosperm shall be considered whole grains as long as sprout growth does not exceed kernel length and nutrient values have not diminished. These grains should be labeled as malted or sprouted whole grain."

box 1.

Whole grain as defined by the AACC International Board of Directors in 1999