Journal of Food Processing & Technology

Gani et al., J Food Process Technol 2012, 3:3
DOI: 10.4172/2157-7110.1000146

Review Article

Open Access

Whole-Grain Cereal Bioactive Compounds and Their Health Benefits: A Review

Adil Gani*, **Wani SM, Masoodi FA and Gousia Hameed**

Department of Food Science and Technology, University of Kashmir, India

Abstract

Whole-grain cereals have received considerable attention in the last several decades due to the presence of unique blend of bioactive components like phytochemicals and antioxidants. However phytochemicals and antioxidants in whole-grains have not received as much attention as the phytochemicals in fruits and vegetables, although the increased consumption of whole-grains and whole-grain products has been associated with reduced risk of developing chronic diseases such as cardiovascular diseases, type 2 diabetes, some cancers and all-cause mortality. These unique bioactive compounds in whole-grains are proposed to be responsible for the health benefits of whole-grain consumption. In this paper, various whole-grain bioactive compounds and the health benefits associated with their consumption are reviewed.

Keywords: Whole-grains; Phytochemicals; Bioactive compounds; Phenolics; Antioxidant activity

Introduction

Cereals can be defined as a grain or edible seed of the grass family [1]. Cereals are grown for their highly nutritious edible seed, which are often referred to as grain. Some cereals have been staple foods both directly for human consumption and indirectly via livestock feed since the beginning of civilization [2]. The major cereals consumed worldwide are wheat, rice, maize, barley, oats, rye, millet, sorghum. Apart from being an important part of diet, these cereals are also rich in various health promoting components [3]. Cereals are staple foods providing major sources of carbohydrates, proteins, B vitamins and minerals for the world's population. Cereals contain a range of substances which may have health promoting effects, these substances are often referred to as Phytochemicals or Plant bioactive substances [4].

Bioactive compounds are extra nutritional elements that typically occur in small quantities in foods. These substances are beneficial to human health but are not essential for the human body [5]. The majority of bioactive compounds of whole-grains are present in the bran/germ fraction of cereal-grains. These fractions of whole-grain may therefore help in reducing the risk of chronic diseases. Bioactive compounds in whole-grain cereals have not received as much attention as in fruits and vegetables. Epidemiological studies have shown that regular consumption of whole grains and wholegrain products is associated with reduced risks of various types of chronic diseases such as cardiovascular diseases [6,7] type 2 diabetes [8-10] and some cancers [11-13]. Whole-grains or foods made from whole-grains contain all the essential parts, the bran, the endosperm and rarely germ in contrast to the refined grains, in which the bran and the germ of the grains are removed during the milling process. Whole-grains are rich sources of fiber, vitamins, minerals and phytochemicals. Plant based foods such as fruits and vegetables and whole-grains which contain significant amounts of bioactive compounds, may provide desirable health benefits to reduce the risk of chronic diseases [14-16]. Whole-grains are even postulated to deliver more bioactive compounds than many of the fruits and vegetables [17]. These health benefits are achieved through multifactorial physiological mechanisms including antioxidant activity, mediation of hormones, enhancement of immune system and facilitation of substance transit through the digestive tract, butyric acid production in the colon, and absorption and/or dilution of substances in the gut [18]. The additive and synergistic effects of the biologically active compounds may be responsible for the health benefits of diets rich in fruits, vegetables and whole-grains as the reduced risk of chronic diseases [15]. The recent evidence suggests that the complex mixture of bioactive components in wholegrain foods may be more health beneficial than individual isolated components [15]. This review discusses about the general concept of wholegrain cereals, various bioactive compounds in whole-grain cereals and their health benefits.

Whole-Grain Cereals and Health

Whole-grain cereals and foods have been the focus of significant scientific, governmental and commercial interest during the past ten years since epidemiological studies have increasingly shown their protective role against the risks of many chronic diseases, especially those related to metabolic syndrome i.e., type 2 diabetes and cardiovascular diseases [19].

The whole-grain has been defined to consist of the intact, ground, cracked or flaked caryopsis, whose principle anatomical components-the starchy endosperm, germ and bran-are present in the same relative proportion as they exist in the intact caryopsis [20]. Whole-grains are a good source of dietary fiber, vitamins, minerals and bioactive compounds, which have been suggested to contribute to their protective effects as compared to refined grains [3].

The outer layer of grain have been shown to contain much higher levels of bioactive compounds such as phenolic compounds, phytosterols, tocols and carotenoids than the inner parts [21-23]. The phenolic compounds of whole-grains including lignans,

***Corresponding author:** Adil Gani, Department of Food Science and Technology, University of Kashmir, India, E-mail: adil.gani@gmail.com

Received December 12, 2011; **Accepted** February 14, 2012; **Published** February 17, 2012

Citation: Gani A, Wani SM, Masoodi FA, Hameed G (2012) Whole-Grain Cereal Bioactive Compounds and Their Health Benefits: A Review. J Food Process Technol 3:146. doi:10.4172/2157-7110.1000146

alkylresorcinols and phenolic acids have been shown to be metabolized and absorbed in humans and are among the major compounds inducing physiological changes underlying the protective effects [24-26]. Higher whole-grain intake has been associated with reduced risk of hypertension in prospective epidemiological and intervention studies. In a recent intervention study, Tighe et al. [27] reported 6 and 3mm Hg reductions in systolic blood pressure and pulse pressure, respectively, among middle-aged healthy individuals consuming 3 servings of whole-grain foods/day compared with individuals consuming refined grains. This observed decrease in systolic blood pressure is estimated to lower the risk of coronary artery disease and stroke by ≥ 15 and ≥ 25% respectively [27]. It has also been reported that consumption of refined cereal products (bread, pasta and rice) have been associated with increased risk of digestive tract, pharynx, larynx and thyroid cancers [28]. However an association between a lower risk of developing a chronic disease and high whole cereal consumption does not mean a direct casual relationship and provide no information about the physiological mechanism involved [29]. The various metabolic disease are related to our daily life style (lifestyle disorders), notably an unbalanced energy rich diet lacking fiber and protective bioactive compounds such as micronutrients and phytochemicals. Today it is agreed to consider that this is the synergistic action of the compounds, mainly contained in the bran and germ fraction of cereals, which is protective [30,31]. There are some specific mechanisms which are well recognized today. For example, food structures influence satiety and the slow release of sugars recommended for type 2 diabetes. Dietary fiber improves our health, and antioxidant and anti-inflammatory properties of most bioactive compounds can help prevent cancer and coronary vascular disease. However components in whole-grain that is responsible for these effects on the protection of health and homeostasis and their mechanism of action are not fully understood. In fact it is probable that several factors are required and act additively or synergistically to achieve the favourable effects. However the precise physiological mechanisms involved are far from being elucidated [29].

Various Bioactive Compounds Present in Whole-Grain Cereals

Whole-grains contain unique bioactive compounds that complement those in fruits and vegetables when consume together. The major bioactive compounds in whole-grain cereals are phenolic compounds, phytosterols, tocols, dietary fibers (mainly beta-glucan), lignans, alkylresorcinols, phytic acid, γ-oryzanols, avenanthramides, cinamic acid, ferulic acid, inositols and betaine [3,17,18,29,32,33]. Some bioactive compounds are quite specific to certain cereals; γ-oryzanol in rice, avenanthramide and saponins in oats, beta glucans in oats and barley and alkylresorcinol in rye, although these are also present in other cereals like wheat but relatively in fewer amounts. The important bioactive compounds in whole-grain cereals are discussed under:

Phenolic compounds

Phenolic are compounds possessing one or more aromatic rings with one or more hydroxyl groups and generally are categorized as phenolic acids, flavonoids, stilbenes, coumarins and tannins [15]. Phenolics are the products of secondary metabolism in plants, providing essential function in the reproduction and growth of the plant, acting as defense mechanisms against pathogens and parasites, also contributing to the color of plant. In addition to their role in plants, phenolic compounds in our diet provide health benefits associated with reduced risk of chronic diseases. Phenolic compounds have antioxidant properties and protect against degenerative diseases like heart diseases and cancer in which reactive oxygen species i.e., superoxide anion, hydroxyl radicals and peroxyl radicals are involved [34,35]. It is emerging that polyphenols may have far more important effect *in vivo* such as enhancing endothelial function, cellular signaling and anti-inflammatory properties [36-38]. Emerging research has also suggested that undigested polyphenols associated with dietary fiber may provide important protection at the intestinal environment level [39,40]. However, whether the protective effect of polyphenols on health is via antioxidant or other mechanisms, research strongly supports a positive relationship between polyphenol intake and decreased risk of certain chronic diseases [41,42]. Current public health recommendations aimed at reducing the risk of coronary heart disease in the UK suggest including oats and oat-based products as part of a healthy diet [43]. The concentration of phenolic compounds in whole-grain cereals is influenced by grain types, varieties and the part of the grain sampled [18,32,44]. The most common phenolic compounds found in whole-grain cereals are phenolic acids and flavonoids.

Phenolic acid: Phenolic acids are derivatives of benzoic and cinnamic acids and are present in all cereals. Phenolic acids can be subdivided into two major groups, hydroxybenzoic acids and hydroxyl-cinnamic acid derivatives. Hydroxybenzoic acid derivatives include P-hydroxybenzoic, protocatechins, vannilic, syringic and gallic acids. Hydroxyl cinnamic acid derivatives include p-coumaric, caffeic, ferulic and sinapic acids. The phenolic acids reported in cereals occur in both free and bound form. Sorghum and millet have the widest variety of phenolic acids. Free phenolic acids are found in outer layer of the pericarp [22,45-47]. Bound phenolic acids are esterified to cell walls; acid or base hydrolysis is required to release these bound compounds from the cell matrix [45,48,49]. The major phenolic acids in cereals are ferulic acids and *p*- coumaric acid [45,50].

Ferulic acid is the most abundant hydroxycinnamic acid found in cereal grains. It is the main poplyphenol present in cereals in which it is esterified to the arabinoxylans of the grain cell wall. Wheat bran is the good source of ferulic acid which is esterified to the hemicelluloses of the cell walls [51]. The ferulic acid content of wheat grain is near about to 0.8 - 2 g/kg dry weight basis, which may represent 90% of total polyphenols [46,52]. It has antioxidant properties to combat destructive free radicals, and astringency that deters consumption by insects and animals [53]. Ferulic acid can exist in the free, soluble, conjugated and bound form in whole-grains. Bound ferulic acid was significantly higher (> 93% of total) than the soluble conjugated ferulic acid in corn, wheat, oats and rice. The ratio of free to, soluble - conjugated and bound ferulic acid in corn and wheat was 0.1:1.0:100. The order of total ferulic acid content among the tested grains was corn > wheat > oats > rice [32]. Ferulic acid can provide health benefits because of its antioxidant properties [54]. Coumaric acids are hydroxyle derivatives of cinnamic acid. There are three forms of coumaric acids: *p*-coumaric acid, *o*-coumaric acid and *m*-coumaric acid. The three forms differ by the position of the hydroxyl substitution of the phenolic group [55]. Since *p*-coumaric acid is a hydroxyl derivative of cinnamic acid, *p*-hydroxycinnamic acid is synonym for *p*-coumaric acid [56,57]. *p*-coumaric acid is present in the lowest amount in the centre of the grain kernel and in increasing amount towards the outer layers [57,58]. They mainly exist esterified with organic acids, sugars and lipids [55,59]. Coumaric acids are suggested to have antioxidant effect and researches have shown that there is free radical scavenging property in *p*- coumaric acids [55,60]. Coumaric acid also has been suggested to have anti tumor activity against human malignant tumors. Coumaric acid induces cytostasis and inhibits the malignant properties of human tumor cells *in vitro*. A 50% reduction in the level of cell proliferation was achieved by concentration ranging from 1 - 4.5 mmol/l [55,60]. *p*-coumaric acids have also potentially protective effect against heart diseases because of its ability to decrease the resistance of low density lipoproteins (LDL), cholesterol oxidation, lipid peroxidation and of apo-protein B100 [55].

Flavonoids: Flavonoids are compounds with a C_6-C_3-C_6 skeleton that consists of two aromatic rings joined by a three carbon link; they include anthocynins, flavonols, flavones, flavanone and flavonols. More than 5000 flavonoids have been identified in nature [61]. Flavonoids are located in the pericarp of all cereals. Sorghum has the widest varieties of flavonoids reported. Flavonones found in fruits and vegetables are also reported in cereals. For example, the flavones epigenin, a compound found in barley and celery is also reported in millet, oat and sorghum [61,62]. Cereals have only small quantities of flavonoids, except that barley contain measurable amounts of catechin and some di and tri pro-cyanidins [63]. Flavonoids are reported to have antioxidant, anticancer, anti allergic, anti-inflammatory, anti-carcinogenic and gastro protective properties [34,61,64].

Avenanthramides: Avenanthramides are specific polyphenols from oats. They are substituted cinnamic acid amides of anthranilic acids and there are at least 25 distinct entities. The three major aventhramides reported in oats are aventhramide-1, 3 and 4, which are also known as aventhramids B, C and A respectively [65,66]. Levels of aventhramide 1 range from 40-132μg/g in the grain. Oat flakes have more aventhramides (26-27μg/g) than oat bran (13μg/g) [22]. Avenanthramide are bioavailable and they have anti-inflamatory, anti-atherogenic and anti-oxidant properties [67-69].

Lignans: Lignans are polyphenolic bioactive compounds. They are a group of dietary phytoestrogen compounds that are present in a wide variety of plant foods including flax seeds, whole-grains like corn, oats, wheat and rye [70]. The common plant lignin in the human diet includes secoisolariciresinol, matairesinol, lariciresinol, pinoresinol and syringaresinol. When ingested, secoisolariciresnol and matairesinol are converted into the mammalian lignans enterodiol and enterolactone respectively by microbial enzymes in the colon [71]. Mammalian lignans have strong antioxidant activity and weak oestrogenic activity that may account for their biological effects and health benefits [70,72,73] and makes them unique and very useful in promoting health and combating various chronic diseases. Mammalian lignans, enterodiol and enterolactone protect against heart diseases and hormone related breast and prostate cancer [74,75]. Mammalian lignans inhibit colon cancer cell growth and also induces cell cycle arrest and apoptosis *in vitro* [76]. Lower cancer rates have also been associated with high dietary intake of lignans [74]. In a Danish study that followed 875 postmenopausal women, women eating the highest amounts of whole-grains had significantly higher blood levels of enterolactone [75]. A Blood level of enterolactone was inversely related to cardiovascular diseases and all cause death, suggesting the protective effects of lignans against such conditions [77].

Alkylresorcinols: Alkyleresorsinols are plant derived phenolic lipids, especially found in whole-grain cereals. Rye contains the highest amount of alkylresorcinols, which can be twice as that of wheat [25]. They are 1, 3 - dihydroxybenzene derivatives with an alkyle chain at position 5 of the benzene ring, which gives them an amphiphilic feature. Alkylresorcinols have antibacterial and anti fungal properties and anti oxidant property *in vitro* [78]. These compounds are of interest as biomarkers of whole-grain cereals intake, which helps to understand the link between whole-grain cereal consumption and health [78]. Their biological activity is multifactorial [78] from interacting with metabolic enzymes (e.g inhibiting 3-phosphoglycerate dehydrogenase, the key enzyme in triacylglycerol synthesis in adipocytes [79], to decreasing cholesterol in the rat liver [78] to anticancer/ cytotoxic effects but almost exclusively *in-vitro* [80,81]. Several papers claim that alkylresorsinols are antioxidants but they have negligible antioxidant activity as compared to tocopherols and catechol and hydroquinone [82,83]. Alkylresorcinols have hydrophobic nature, so they are able to bind some proteins especially those with large hydrophobic regions, such as serum albumins, and affect their properties. Trypsin could be bound by alkylresorcinols resulting in decreased protease activity [84] alkylresorcinols have been found to reduce the mutagenic activity of some indirect mutagens [85].

Carotenoids

Carotenoids are the most wide spread pigments in nature with yellow, orange and red colors and have also received substantial attention because of both their role as pro-vitamins and antioxidants. Carotenoids are classified into hydrocarbons (carotenes) and their oxygenated derivatives (xanthophylls). More than 600 different carotenoids have been identified, which occur in plants, microorganisms and animals. Carotenoids have a 40-carbon skeleton of isoprene units. The structure may be cyclised at one or both ends, have various hydrogenation levels, or possess oxygen containing functional groups. Carotenoids occur most commonly in trans form. The most characteristic feature of carotenoids is the long series of conjugated double bonds forming the central part of the molecule. This gives them their shape, chemical reactivity and light absorbing properties. Carotenoids commonly found in whole-grain cereals are lutein, zeaxanthin, beta-cryptoxanthin, beta carotene and alpha carotene [18,44,86]. Lutein is the carotenoid present in highest concentration in wheat followed by zeaxanthin and then beta cryptoxanthin [18]. Rice bran contains both lutein and zeaxanthin, which improves eye sight. Cereals are the source of carotenoids [87]. Maize is the best source with about 11μg/kg on dry weight basis [88]. Carotenoids are more evenly distributed within the grain, with significant quantities within endosperm, in contrast to other micro nutrients such as minerals, trace elements and polyphenols [89]. Carotenoids perform important functions in plants. They provide color in whole-grain flour. They also act as antioxidants in lipid environments of many biological systems, through their ability to react with free radicals and form less reactive free radicals. Carotenoid radicals are stabilized by delocalization of unpaired electrons over the conjugated polyene chain of the molecule, allowing addition of other functional groups to many sites on the radicals [86].

Phytic acid

Phytic acid is bioactive compound which is also known as Inositol hexaphosphate (IP6). When IP6 is in salt form, it can also be called phytate. lnositol with lower phosphate groups,IP1-IP5 are called phytates. Almost all mammalian cells contain IP6 and its lower phosphorylated forms (IP1-5) [90,91]. It may account for more than 70% of the total kernel phosphorus [92]. Phytic acid is mainly located in the bran fraction of whole-grain cereals, especially within the aleurone layer. In corn, IP6 is mostly found in the germ [90,93,94]. Phytic acid from whole-grain cereals has long been considered to be nutritionally negative, since it chelates minerals such as Zn, Fe, Ca and /or Mg, thus limiting their intestinal bioavailability [95]. However phytic acid is also a strong antioxidant *in vitro* [96]. It suppresses Fe catalysed oxidative reactions, because of its capacity to chelate free Fe (Fenton reaction) and may be a potent antioxidant *in vivo*, by suppressing lipid peroxidation [97]. Phytic acid also reduces the incidence of colonic cancer by suppressing the oxidative damage caused to the gut epithelium, particularly in the colon where bacteria also yield oxygenated radicals [96]. Phytic acid also inhibits xanthine oxidase-induced superoxide-dependent DNA damage [98]. Xanthine oxidases, which generate superoxide anions (O_2^-) during the oxidation of Xanthine is abundant within the intestine [99]. Results have shown that IP6 significantly inhibits the precipitation of urinary calcium oxalate crystals. It also inhibits the crystallization of calcium oxalate salts in the urine, thus preventing renal stone development. It has been shown that IP6 has an important function in pancreatic β-cells by regulating β-cells stimulus-secretion coupling, regulating β-cells protein phosphatases and reducing the glucose levels *in vivo* [90]. Another effect that has been found is that IP6 may be a key element in modulating insulin secretion via its effect on calcium channel activity and the fact that it is the dominant inositol phosphate in insulin-secreting pancreatic β-cells. Results have shown an influx of extracellular calcium in one of the events that drive insulin release. The mechanism of action is not fully understood but it appears IP6 specifically inhibits serine threonine protein phosphate activity, which in turn opens intracellular calcium channels thus, driving insulin release.

Phytosterols

Phytosterols are a collective term for plant sterols and stanols, which are similar in structure to cholesterol, differing only in the side chain groups. In cereals, plant sterols occur as free sterols, steryl esters with fatty acids, or phenolic acids, steryl glycosides, and acylated steryl glycosides. The level of these components varies in different cereals and in different parts of the kernel [100,101]. The most important natural source of plant sterols in human diets are oils and margarines. Cereal products are recognized as significant plant sterol sources than vegetables [102-104].

Plant sterols are one of the bioactive components currently being actively studied. They have decreased serum cholesterol levels in several studies [105-108] and they may also be beneficial in preventing colon cancer [109,110]. Phytosteros compete with cholesterol for micelle formation in the intestinal lumen and inhibit cholesterol absorption [111].

Tocols

Tocols are natural antioxidants present in food of plant origin including cereals. Tocols include tocopherols and tocotrienols and are naturally occurring antioxidants present in cereal grain and are well recognized for their bioactivity [112]. Tocols occur in eight forms; α-tocopherol (αTP), β-tocopherol (βTP), γ-tocopherol (γTP), δ-tocopherol (δTP) and α- tocotrienol (αTT), β-tocotrienol (βTT), γ-tocotrienol (γTT) and δ-tocotrienol (δ TT). Typically, tocols contain a polar chromanol ring linked to an isoprenoid-derived hydrocarbon chain [113] differing only in the saturation state of the iso-prenoid side-chain. The general structure of tocopherols consists of 2-methyl-2- (4, 8, 12-trimethyl tridecyl) chroman-6-ol. Whereas, tocotrienols consist of 2 methyl-2-(4, 8, 12-trimethyltrideca-3, 7, 11-tri enyl) chroman-6-ol. The phenolic hydroxyl group of the chromanol ring is present to free radicals in order to stabilize them and stop the propagation phase of the oxidation chain reaction [114]. The main source of tocols are vegetable oils, but substantial amounts of these compounds are also reported in most cereal grains (10.7 to 74.7 mg/Kg) including barley, oats, wheat, rye, rice [115,116].

The potential health benefits for humans have been the subject of several reviews that have analysed clinical, animal and *in vitro* evidence for its biological activity. Apart from their antioxidant properties, the tocol content of cereals can confer human health benefits including modulating degenerative diseases like cancer, cardiovascular diseases (CVD) while also lowering blood cholesterol levels [117]. Several reports suggested that the vitamin E activity depends on its chemical structure and physiological factors. e.g isomers of tocols exhibit vitamin E activity as follows: αTP > βTP > αTT > γTP > βTT > δ TP or no activity for γ TT and δ -TT [118,119]. The α-TP has the greatest vitamin E activity, α-TT possess excellent antioxidant activity [113] and contribute to the nutritive value of cereal grains in the human diet. According to current dietary guidelines, the recommended dietary allowance (RDA) of vitamin E is 15mg of 2R-α- tocopherol/ day (although most tocols are considered to have these vitamin E activities), and the estimated average requirement is 12mg [120]. Recent studies have shown that tocotrienols have a number of beneficial functions. e.g they may have a protective effect by lowering LDL-Cholesterol by inhibiting cholesterol biosynthesis [121,122]. Recently tocols have shown positive role on coronary artery diseases [121]. Studies have also shown that the high intake of α- tocopherols decrease lipid per-oxidation, platelet aggregation, and function as a potent anti-inflammatory agent [123].

Gamma-oryzanol

γ-Oryzanol is a component of rice-bran oil and it was first presumed to be a single compound [124]. It was later determined that it is a mixture of substances including sterols and Ferulic acid, and at least 10 Pyhtosteryl ferulates (e.g, methyl sterols esterified to ferulic acid). Its content in whole-grain rice is 18-63mg/100g (DW) [125]. Its concentration in rice-bran is 185-421mg/100g, depending on the rice variety, milling time, and stabilization process and extraction methods [126]. γ-Oryzanol has antioxidant activity and it has been demonstrated both *in vitro* [127] and *in vivo* [128]. It is associated with decreasing plasma cholesterol [129]. It also lowers serum cholesterol. It is also associated with decreasing cholesterol absorption [130] and decreasing platelet aggregation [131]. Oryzanol has also been used to treat hyperlipidemia [132], disorders of menopause [133] and to increase the muscle mass [134].

Beta-glucan

β-glucan are polysaccharides found principally in the cell walls of the aleurone layer and endosperm in barley and oat kernels. In barley they are more concentrated in the endosperm while in oats they are concentrated in the aleurone layer [135]. These are the linear polymers of glucose molecules connected by 70% of β-(1-4) and 30% of β-(1-3) - linkages. The largest amounts of β-glucan are found in barley (3-11%) and oats (3-7%), with lesser amounts reported in rye (1-2%) and wheat (<1%). Only trace amount have been reported in corn, sorghum, rice and other cereals of importance as food [136]. Oat-based breakfast cereals have also gained considerable attention in recent years as they are rich in β-glucan, which has been considered as a bioactive component and has been promoted as a means of reducing serum and plasma cholesterol levels [137,138] and reducing the postprandial glycemic response [139-141].

Due to both linkages i.e., β-(1-4) and β-(1-3) linkages in β-glucan as compared to cellulose, the β-glucan is more flexible, soluble and viscous. It has been shown to have effects in lowering blood cholesterol level and controlling blood sugar, probably mainly due to its high viscosity property as a soluble fiber to bind cholesterol and bile acids and facilitate their elimination from the body. β-glucan is the main component responsible for the cholesterol lowering effect of oat bran [142-145]. In 1997, the food and drug administration (FDA) [146] in the US allowed a health claim that diets low in saturated fat and cholesterol that include soluble fiber from whole oats 'may' or' might' reduce the risk of heart disease [146]. The claim recognized β-glucan as the primary bioactive component [147]. β-glucan had an effect in controlling blood sugar in diabetes and was helpful in reducing the elevation in blood sugar levels after a meal [143,148], probably because of delaying gastric emptying allowing dietary sugar to be absorbed more gradually, as well as by possibly increasing the tissue sensitivity to insulin [143,148]. Studies also suggest that β-glucan from oats plays a key role in management of body-weight, blood pressure and blood cholesterol lowering [149].

Antioxidant Activity of Bioactive Compounds in Whole-Grain Cereals

Whole-grain cereals are good sources of antioxidants especially bran and germ fraction [150-152]. However this may not be the same *in vivo* [114] as the number of studies exploring the *in vivo* antioxidant effect of whole-grain cereals and /or their fractions in human subjects does not exceed eleven [153-155]. Whole-grains especially corn, wheat and oats have been shown to have antioxidant activity [32]. Phenolic compounds in whole-grains contribute to antioxidant activity. Avenanthramides are cinnamoyl conjugates that occur in oats and have high antioxidant activity [65,156]. It has been suggested that a serving of an oat-based breakfast cereal could be a much greater contributor to the overall antioxidant potential of the diet than teas or fruit juices [157,158]. Long chain mono and di-alcohol esters of ferulic and caffeic acids have potent antioxidant activity [159]. The antioxidants in cereals differ in their structure and mode of action [113,160]. There are indirect antioxidants, such as Fe, Zn, Cu and Se which act as co-factors of antioxidant enzymes, and direct radical scavangers such as Ferulic acid other poltphenols (lignans, anthocyanins and alkylresorcinols), Carotenoids, vitamin E and compounds specific to cereals other than wheat, such as γ-Oryzanol in rice and avenanthramides in oats. These can neutralize free radicals and/ or stop the chain reactions that lead to the production of oxidative radical compounds [29].

Phytic acid present in whole-grain cereals also acts as an antioxidant because it chelates Fe and thus stops the Fenton reaction producing the highly oxidative and damaging free radical OH, ultimately reducing lipid peroxidation [97]. Researchers have also shown that *p*-coumaric acid also have a free radical scavenging property [60]. Alkylresorcinols possess antioxidant properties *in vitro* due to their hydrogen donor and radical and radical scavenging abilities [161], but they are less efficient than vitamin E [82]. Alkylresorcinols are considered as membrane-located antioxidants. They are readily absorbed (80%) [25] and can be biologically active. They are therefore potential antioxidants *in vivo*. Their antioxidant potential depends on the chain length, i.e. their amphiphilic nature, and their incorporation into cell membranes. Thus, micro-molar concentrations of cereal grain alkylresorcinols can protect erythrocyte membranes against hydrogen peroxide- induced lipid oxidation [84].

Wheat contains a diverse array of bioactive compounds that may contribute to its antioxidant capacity. These bioactive components include Carotenoids, tocopherols, tocotrienols, phenolic acids, phytic acid, phytosterols and flavonoids [33,162,163]. Wheat antioxidants are mainly concentrated in bran layers and the amount of antioxidants depends largely on the grain variety, with red variety wheat generally containing higher levels than white wheat [48]. Phenolic acids are a group of natural products that have been found to be strong antioxidants against free radicals and other reactive oxygen species, which are the presumed cause of many chronic human diseases such as cancer and cardiovascular diseases. Ferulic acid was shown to be the predominant phenolic acid in wheat bran, present in the range of 99-231μg/g [164]. Other phenolic acids in wheat bran are vanillic and syringic acids [48]. Ferulic acid is the main contributor to the antioxidant capacity, suggesting that ferulic acid could be used as a marker of wheat antioxidants [164].

Rice contains potentially antioxidant compounds, notably in the outer layers of the grain. Significant quantities of vitamin E and γ-Oryzanol can be extracted from rice. Since the γ-oryzanol content of rice-bran is 10 times that of vitamin E, γ-oryzanol may contribute more to the reduction of cholesterol oxidation than vitamin E, which is usually considered to be the major antioxidant in rice bran [165]. Colored varieties of cereals, such as colored rice have more antioxidant capacity than non-colored varieties [166]. The major antioxidants present in black rice are cyaniding-3-glucoside and Peonidin-3-glucoside [166]. These antioxidants are not found in white rice. Procyanidins are the major compounds involved in the antioxidant activity of red rice [167]. Pigments suppressed the oxidative changes in human LDL, reduced the formation of nitric oxide by suppressing inducible nitric oxide synthase activity, and significantly prevented the breaks in super-coiled DNA strands induced by reactive oxygen species [166]. In the end, β-carotene-rich rice varieties (e.g. the yellow Golden Rice) have also been recently developed by genetic engineering, in order to help combat vitamin A deficiency, notably in Asian countries [168].

Importance of Bound Bioactive Compounds in the Prevention of Colon Cancer

Most of the antioxidant bioactive compounds in grain are bound and can survive gastrointestinal digestion to reach the colon intact, where they provide an antioxidant environment [152]. These antioxidant bioactive compounds are in the insoluble form and bound to cell wall materials [18,32,169]. Since cell wall materials are difficult to digest, they survive upper gastrointestinal digestion, and finally reach the colon. In the colon, the fiber is fermented and some of the bioactive compounds which have antioxidant activity are released [39]. Only 0.5% - 5% of the ferulic acid is absorbed within the small intestine, mainly the soluble fraction [32,160,170] and this typical whole-grain wheat phenolic acid would probably exert a major action in the protection of the colon from cancer. Thus, bound antioxidant phenolic acids might act along the whole length of the digestive tract by trapping oxidative compounds [29].

Conclusion and Future Perspective

Cereal and cereal products remain a staple component of diets around the world. They make substantial contribution to intake of carbohydrates, protein and fiber as well as vitamin E, some of the B vitamins, sodium, selenium, magnesium and Zinc. However, it seems that their role in promoting good health goes beyond merely the provision of nutrients; there is much evidence to suggest that regular consumption of cereal products, specifically whole-grains, may have a role in the prevention of chronic diseases such as CHD, diabetes and colon cancer. These health benefits provided by whole-grain cereals are due to the presence of bioactive compounds in the whole-grain cereals, which are mainly present in the bran and germ fraction. Further research is needed to isolate and characterize these bioactive compounds that contribute to health. Many of these compounds are bound to the matrix of the grain, making their extraction difficult. Also, the lack of appropriate standards increases the difficulty of identifying these compounds. Identifying and quantifying cereal bioactive compounds will help us to select grains with increased levels of these health-promoting compounds. Research is also needed to determine their bioavailability, metabolism, and health contribution in humans. Whole-grain cereals contain a much wider range of compounds with potential antioxidant effect than do refined cereals. These include phenolic compounds, tocols, phytic acid, carotenoids, lignans and alkylresorcinols. However the antioxidant capacity of cereal and cereal products have probably been underestimated, since the extraction solvents used in most published *in vitro* studies do not completely release all antioxidant compounds, as an important fraction of antioxidant compounds are strongly bound to fiber fraction of outer layers of grain. The *in vitro* antioxidant potential of cereal is generally correlated with their polyphenol content (mainly Ferulic acid). Correlations with other types of compounds remain to be investigated. Studies on the antioxidant potential of cereal polyphenols have often been carried out on human plasma to investigate their capacity to delay LDL oxidation *ex vivo*, and not directly *in vivo*. Not more than eleven studies have examined the antioxidant activities by post prandial or intervention studies in human subjects to investigate the antioxidant effect of whole-grain cereals. The mechanisms involved are complex, so more information is needed on the mechanisms involved, in order to prepare strong, convincing arguments for an increased consumption of whole-grain cereal products by the people and to provide better information about their health benefits and to develop new health claims in the future. No studies deal with the influx of whole-grain cereal consumption on the induction/repression of genes coding for antioxidant compounds. Further studies are needed to explore this new area of research using the most recent genomic and transcriptomic techniques. The impact of cereal consumption can also be investigated through another recent global approach i.e., metabolomics. This new approach will allow us to investigate further how complex antioxidant-rich foods such as cereal and cereal products can modify general metabolism, and which metabolic pathways are affected by antioxidants. This will provide new information on the health benefits of whole-grain cereals.

Acknowledgement

Authors acknowledge the Department of Biotechnology, Government of India for their financial support for development of departmental library and other resources.

References

1. Bender DA, Bender AE (1999) Bender,s Dictionary of Nutrition and Food technology, 7th edition. Woodhead Publishing, Abington.
2. BNF (British Nutrition Foundation) (1994) Starchy Foods in the Diet. BNF, London.
3. Slavin J (2003) Why whole grains are protective: biological mechanisms. Proc Nutr Soc 62: 129-134.
4. Goldberg G (2003) Plants: Diet and Health. The Report of the British Nutrition Foundation Task Force. Blackwell, Oxford.
5. Kris-Etherton PM, Hecker KD, Bonanome A, Coval SM, Binkoski AE, et al. (2002) Bioactive compounds in foods: their role in the prevention of cardiovascular disease and cancer. Am J Med 113 Suppl 9B: 71S-88S.
6. Anderson JW (2003) Whole grains protect against atherosclerotic cardiovascular disease. Proc Nutr Soc 62: 135-142.
7. Okarter N, Liu RH (2010) Health benefits of whole grain phytochemicals. Crit Rev Food Sci Nutr 50: 193-208.
8. Tapola N, Karvonen H, Niskanen L, Mikola M, Sarkkinen E (2005) Glycemic responses of oat bran products in type 2 diabetic patients. Nutr Metab Cardiovasc Dis 15: 255-261.
9. Liu S, Manson JE, Stampfer MJ, Hu FB, Giovannucci E, et al. (2000) A prospective study of whole-grain intake and risk of type 2 diabetes mellitus in US women. Am J Public Health 90: 1409-1415.
10. Meyer KA, Kushi LH, Jacob DRJ, Slavin J, Sellers TA, et al. (2000) Carbohydrates, dietary fiber, incident type 2 diabetes mellitus in older women. Am J Clin Nutr 71: 921-930.
11. Jacobs DR Jr, Meyer KA, Kushi LH, Folsom AR (1998) Whole-grain intake may reduce the risk of ischemic heart disease death in postmenopausal women: the Iowa Women's Health Study. Am J Clin Nutr 68: 248-257.
12. Kasum CM, Jacobs DR Jr, Nicodemus K, Folsom AR (2002) Dietary risk factors for upper aerodigestive tract cancers. Int J Cancer 99: 267-272.
13. Haas P, Machado MJ, Anton AA, Silva AS, De Francisco A (2009) Effectiveness of whole grain consumption in the prevention of colorectal cancer: Meta-analysis of cohort studies. Int J Food Sci Nutr 21:1-13.
14. Liu RH (2003) Health benefits of fruit and vegetables are from additive and synergistic combinations of phytochemicals. Am J Clin Nutr 78: 517S-520S.
15. Liu RH (2004) Potential synergy of phytochemicals in cancer prevention: mechanism of action. J Nutr 134: 3479S-3485S.
16. Slavin JL (2000) Mechanisms for the impact of whole grain foods on cancer risk. J Am Coll Nutr 19: 300S-307S.
17. Jones JM, Reicks M, Adams J, Fulcher G, Marquart L (2004) Becoming Proactive With the Whole-Grains Message. Nutr Today 39: 10-17.
18. Adom KK, Sorrells ME, Liu RH (2003) Phytochemical Profiles and Antioxidant Activity of Wheat Varieties. J Agric Food Chem 51: 7825-7834.
19. Jacobs DR Jr, Marquart L, Slavin J, Kushi LH (1998) Whole-grain intake and cancer: an expanded review and meta-analysis. Nutr Cancer 30: 85-96.
20. AACC (1999) Definition of whole grain.
21. Liukkonen KH, Katina K, Wilhelmsson A, Myllymäki O, Lampi AM, et al. (2003) Process-induced changes on bioactive compounds in whole grain rye. Proc Nutr Soc 62: 117-122.
22. Mattila P, Pihlava JM, Hellström J (2005) Contents of phenolic acids, alkyl- and alkenylresorcinols, and avenanthramides in commercial grain products. J Agric Food Chem 53: 8290-8295.
23. Heinio RL, Myllymaki O, Pihlava JM, Adlercreutz H, Heinonen SM, et al. (2008) Quantities of phenolic compounds and their impacts on the perceived flavor attributes of rye grain. J Cereal Sci 47: 566-575.
24. Jacobs DR Jr, Pereira MA, Stumpf K, Pins JJ, Adlercreutz H (2002) Whole grain food intake elevates serum enterolactone. Br J Nutr 88: 111-116.
25. Ross AB, Kamal-Eldin A, Lundin EA, Zhang JX, Hallmans G, et al. (2003) Cereal alkylresorcinols are absorbed by humans. J Nutr 133: 2222-2224.
26. Andreasen MF, Kroon PA, Williamson G, Garcia-Conesa MT (2001) Intestinal release and uptake of phenolic antioxidant diferulic acids. Free Radic Biol Med 31: 304-314.
27. Tighe P, Duthie G, Vaughan N, Brittenden J, Simpson WG, et al. (2010) Effect of increased consumption of whole-grain foods on blood pressure and other cardiovascular risk markers in healthy middle-aged persons: a randomized controlled trial. Am J Clin Nutr 92: 733-740.
28. Chatenoud L, La Vecchia C, Franceschi S, Tavani A, Jacobs DR Jr, et al. (1999) Refined-cereal intake and risk of selected cancers in italy. Am J Clin Nutr 70: 1107-1110.
29. Fardet A (2010) New hypotheses for the health-protective mechanisms of

whole-grain cereals: what is beyond fibre? Nutr Res Rev 23: 65-134.

30. Jensen MK, Koh-Banerjee P, Franz M, Sampson L, Grønbaek M, et al. (2006) Whole grains, bran, and germ in relation to homocysteine and markers of glycemic control, lipids, and inflammation 1. Am J Clin Nutr 83: 275-283.

31. Liu RH (2007) Whole-grain phytochemicals and health. J Cereal Sci 46: 207-219.

32. Adom KK, Liu RH (2002) Antioxidant activity of grains. J Agric Food Chem 50: 6182-6187.

33. Zieli Å, Ki H, Koz Å, owska H (2000) Antioxidant activity and total phenolics in selected cereal grains and their different morphological fractions. J Agric Food Chem 48: 2008-2016.

34. Harborne JB, Williams CA (2000) Advances in flavonoid research since 1992. Phytochemistry 55: 481-504.

35. Rhodes MJ, Price KR (1997) Identification and analysis of plant phenolic antioxidants. Eur J Cancer Prev 6: 518-521.

36. Williams RJ, Spencer JP, Rice-Evans C (2004) Flavonoids: antioxidants or signalling molecules? Free Radic Biol Med 36: 838-849.

37. Sies H, Schewe T, Heiss C, Kelm M (2005) Cocoa polyphenols and inflammatory mediators. Am J Clin Nutr 81: 304S-312S.

38. Ramos S (2008) Cancer chemoprevention and chemotherapy: dietary polyphenols and signalling pathways. Mol Nutr Food Res 52: 507-526.

39. Vitaglione P, Napolitano A, Foliano V (2008) Cereal dietary fiber, a natural functional ingredient to deliver phenolic compounds in the gut. Trends Food Sci Technol 19: 451-461.

40. Saura-Calixto F (2011) Dietary fiber as a carrier of dietary antioxidants: an essential physiological function. J Agric Food Chem 59: 43-49.

41. Duthie GG, Duthie SJ, Kyle JAM (2000) Plant polyphenols in cancer and heart disease: implications as nutritional antioxidants. Nutrition Research Reviews 13: 79-106.

42. Weichselbaum E, Buttriss JL (2010) Polyphenols in the diet. Nutrition Bulletin 35: 157-164.

43. British Heart Foundation (2011).

44. Adom KK, Sorrells ME, Liu RH (2005) Phytochemicals and antioxidant activity of milled fractions of different wheat varieties. J Agric Food Chem 53: 2297-2306.

45. Hahn DH, Faubion JM, Rooney LW (1983) Sorghum phenolic acids, their high performance liquid chromatography separation and their relation to fungal resistance. Cereal chem 60:255.

46. Sosulski F, Krzyrlof K, Hogge L (1982) Free, esterified, and insoluble-bound phenolic acids.3. composition of phenolic acids in cereal and potato flours. J Agric Food Chem 30: 337-340.

47. Subba Rao MV, Muralikrishna G (2002) Evaluation of the antioxidant properties of free and bound phenolic acids from native and malted finger millet (ragi, Eleusine coracana Indaf-15). J Agric Food Chem 50: 889-892.

48. Kim KH, Tsao R, Yang R, Cui SW (2006) Phenolic acid profiles and antioxidant activities of wheat bran extracts and the effect of hydrolysis conditions. Food Chem 95:466-473.

49. Robbins RJ (2003) Phenolic acids in foods: an overview of analytical methodology. J Agric Food Chem 51: 2866-2887.

50. Holtekjølen AK, Kinitz C, Knutsen SH (2006) Flavanol and bound phenolic acid contents in different barley varieties. J Agric Food Chem 54: 2253-2260.

51. Dewanto V, Wu X, Liu RH (2002) Processed sweet corn has higher antioxidant activity. J Agric Food Chem 50: 4959-4964.

52. Lempereur I, Rouau X, Abecassis J (1997) Genetic and agronomic variation in arabinoxylan and ferulic acid contents of durum wheat (Triticum durum L.) grain and its milling fractions. J Cereal Sci 25: 103-110.

53. Arnason JT, Gale J, Conilh de Beyssac B, Sen A, Miller SS, et al. (1992) Role of phenolics in resistance of maize grain to stored grain insects, Prostphanus truncatus (Horn) and Sitophilus zeamais (Motsch). J Stored Prod Res 28: 119-126.

54. Thompson LU (1994) Antioxidants and hormone-mediated health benefits of whole grains. Crit Rev Food Sci Nutr 34: 473-497.

55. Garrait G, Jarrige JF, Blanquet S, Beyssac E, Cardot JM, et al. (2006) Gastrointestinal absorption and urinary excretion of trans-cinnamic and p-coumaric acids in rats. J Agric Food Chem 54: 2944-2950.

56. Hegde S, Kavitha S, Varadaraj MC, Muralikrishna G (2006) Degradation of cereal bran polysaccharide-phenolic acid complexes by Aspergillus niger CFR 1105. Food Chem 96: 14-19.

57. Madhujith T, Izydorczyk M, Shahidi F (2006) Antioxidant properties of pearled barley fractions. J Agric Food Chem 54: 3283-3289.

58. Awika JM, Rooney LW (2004) Sorghum phytochemicals and their potential impact on human health. Phytochemistry 65: 1199-1221.

59. Mateos R, Goya L, Bravo L (2006) Uptake and metabolism of hydroxycinnamic acids (chlorogenic, caffeic, and ferulic acids) by HepG2 cells as a model of the human liver. J Agric Food Chem 54: 8724-8732.

60. Ferguson LR, Zhu ST, Harris PJ (2005) Antioxidant and antigenotoxic effects of plant cell wall hydroxycinnamic acids in cultured HT-29 cells. Mol Nutr Food Res 49: 585-593.

61. Yao LH, Jiang YM, Shi J, Tomas-Barberán FA, Datta N, et al. (2004) Flavonoids in food and their health benefits. Plant Foods Hum Nutr 59: 113-122.

62. Rice-Evans CA, Miller NJ, Paganga G (1997) Antioxidant properties of phenolic compounds. Trends Plant Sci 2: 152-159.

63. McMurough I, Baert T (1994) Identification of proanthocyanidins in Beer and their direct Measurement with a Dual Electrode Electrochemical Detector. J Inst Brew 100: 409-414.

64. Cook NC, Sammans S (1996) Flavonoids- chemistry, metabolism, Cardioprotective effects and dietary sources. Nutr Biochem 7: 66-1996.

65. Collins FW (1989) Oats Phenolics: Avenanthramides, Novel Substituted N Cinnamoylanthranilate Alkaloids from Oats Groats and Hull. J Agric Food Chem 37: 60-66.

66. Peterson DM (2001) Oat antioxidants. J Cereal Sci 33: 115-129.

67. Bratt K, Sunnerheim K, Bryngelsson S, Fagerlund A, Engman L, et al. (2003) Avenanthramides in oats (Avena sativa L.) and structure-antioxidant activity relationships. J Agric Food Chem 51: 594-600.

68. Chen CY, Milbury PE, Kwak HK, Collins FW, Samuel P, et al. (2004) Avenanthramides and phenolic acids from oats are bioavailable and act synergistically with vitamin C to enhance hamster and human LDL resistance to oxidation. J Nutr 134: 1459-1466.

69. Peterson DM, Hahn MJ, Emmons CL (2002) Oat avenanthramides exhibit antioxidant activities in vitro. Food Chem 79: 473-478.

70. Thompson LU, Robb P, Serraino M, Cheung F (1991) Mammalian lignan production from various foods. Nutr Cancer 16: 43-52.

71. Hooper L, Cassidy A (2006) A reviews of the health care potential of bioactive compounds. J Sci Food Agric 86: 1805-2006.

72. Thompson LU, Seidl MM, Rickard SE, Orcheson LJ, Fong HH (1996) Antitumorigenic effect of a mammalian lignan precursor from flaxseed. Nutr Cancer 26: 159-165.

73. Wang C, Mäkelä T, Hase T, Adlercreutz H, Kurzer MS (1994) Lignans and flavonoids inhibit aromatase enzyme in human preadipocytes. J Steroid Biochem Mol Biol 50: 205-212.

74. Adlercreutz H, Mazur W (1997) Phyto-oestrogens and Western diseases. Ann Med 29: 95-120.

75. Johnsen NF, Hausner H, Olsen A, Tetens I, Christensen J, et al. (2004) Intake of whole grains and vegetables determines the plasma enterolactone concentration of Danish women. J Nutr 134: 2691-2697.

76. Qu H, Madl RL, Takemoto DJ, Baybutt RC, Wang W (2005) Lignans are involved in the antitumor activity of wheat bran in colon cancer SW480 cells. J Nutr 135: 598-602.

77. Vanharanta M, Voutilainen S, Rissanen TH, Adlercreutz H, Salonen JT (2003) Risk of cardiovascular disease-related and all-cause death according to serum concentrations of enterolactone: Kuopio Ischaemic Heart Disease Risk Factor Study. Arch Intern Med 163: 1099-1104.

78. Ross AB, Chen Y, Frank J, Swanson JE, Parker RS, et al. (2004) Cereal alkylresorcinols elevate gamma-tocopherol levels in rats and inhibit gamma-tocopherol metabolism in vitro. J Nutr 134: 506-510.

79. Tsuge N, Mizokami M, Imai S, Shimazu A, Seto H (1992) Adipostatins A and B, new inhibitors of glycerol-3-phosphate dehydrogenase. J Antibiot (Tokyo) 45: 886-891.

80. Kozubek A, Tyman JH (1999) Resorcinolic Lipids, the Natural Non-isoprenoid Phenolic Amphiphiles and Their Biological Activity. Chem Rev 99: 1-26.

81. Ross JA, Kasum CM (2002) Dietary flavonoids: bioavailability, metabolic effects, and safety. Annu Rev Nutr 22: 19-34.

82. Kamal-Eldin A, Pouru A, Eliasson C, Aman P (2001) Alkylresorcinols as antioxidants: hydrogen donation and peroxyl radical-scavenging effects. J Sci Food Agric 81: 353-356.

83. Alanko J, Riutta A, Mucha I, Vapaatalo H, Metsa ketela T, et al. (1993) Modulation of aracidonic acid metabolism by phenols: relation to positions of hydroxyl groups and peroxyl radical scavenging properties. Free Radio Biol Med 14: 19-25.

84. Kozubek A, Nienartowicz B (1995) Cereal grain resorcinolic lipids inhibit H2O2-induced peroxidation of biological membranes. Acta Biochim Pol 42: 309-315.

85. Gasiorowski K, Szyba K, Brokos B, Kozubek A (1996) Antimutagenic activity of alkylresorcinols from cereal grains. Cancer Lett 106: 109-115.

86. Britton G (1995) Structure and properties of carotenoids in relation to function. FASEB J 9: 1551-1558.

87. Saikia D, Deka S (2011) Cereals: from staple food to neutraceuticals. Intl Food Res J 18: 21-30.

88. Panfili G, Fratianni A, Irano M (2004) Improved normal-phase high-performance liquid chromatography procedure for the determination of carotenoids in cereals. J Agric Food Chem 52: 6373-6377.

89. Konopka I, Kozirok W, Rotkiewicz D (2004) Lipids and carotenoids of wheat grain and flour and attempt of correlating them with digital image analysis of kernel surface and cross-sections. Food Res Int 37: 429-438.

90. Vucenik I, Shamsuddin AM (2006) Protection against cancer by dietary IP6 and inositol. Nutr Cancer 55: 109-125.

91. Fox CH, Eberl M (2002) Phytic acid (IP6), novel broad spectrum anti-neoplastic agent: a systematic review. Complement Ther Med 10: 229-234.

92. Zhou JR, Erdman JW Jr (1995) Phytic acid in health and disease. Crit Rev Food Sci Nutr 35: 495-508.

93. Zielinski H, Michalska A, Ceglinska A, Lamparski G (2008) Antioxidant properties and sensory quality of traditional rye bread as affected by the incorporation of flour with different extraction rates in the formulation. Eur Food Res Technol 226: 671-680.

94. Febles CI, Arias A, Hardisson A, Rodriquez-Alvarez C, Sierra A (2002) Phytic acid level in wheat flours. J Cereal Sci 36: 19-23.

95. Lopez HW, Leenhardt F, Coudray C (2002) Minerals and phytic acid interactions: is it a real problem for human nutrition? Int J Food Sci Technol 37: 727-739.

96. Graf E, Eaton JW (1990) Antioxidant functions of phytic acid. Free Radic Biol Med 8: 61-69.

97. Graf E, Empson KL, Eaton JW (1987) Phytic acid. A natural antioxidant. J Biol Chem 262: 11647-11650.

98. Muraoka S, Miura T (2004) Inhibition of xanthine oxidase by phytic acid and its antioxidative action. Life Sci 74: 1691-1700.

99. Battelli MG, Corte ED, Stirpe F (1972) Xanthine oxidase type D (dehydrogenase) in the intestine and other organs of the rat. Biochem J 126: 747-749.

100. Seitz LM (1989) Stanol and Sterol esters of ferulic and P-Coumaric acids in wheat, corn, rye and triticals. J Agric Food chem 37: 662-667.

101. Toivo J, Maataa K, Lampi AM, Piironen V (1999) Free, esterified and glycosilated sterols in finnish cereals.Pages 509-512 in: Functional foods-A new challenge for the food chemists: R Lasztity, WP fannhauser, L Simon-Sakardi, S Tomoskozi eds Technical university Budapest.

102. Weihrauch JL, Gardner JM (1978) Sterol content of foods of plant origin. J Am Diet Assoc 73: 39-47.

103. Dutta PC, Appelquist LA (1996) Saturated sterols (stanols) in unhydrogenated and hydrogenated edible vegetable oils and cereal lipids. J S Food Agric 71: 383-391.

104. Normén L, Johnsson M, Andersson H, van Gameren Y, Dutta P (1999) Plant sterols in vegetables and fruits commonly consumed in Sweden. Eur J Nutr 38: 84-89.

105. Miettinen TA, Puska P, Gylling H, Vanhanen H, Vartiainen E (1995) Reduction of serum cholesterol with sitostanol-ester margarine in a mildly hypercholesterolemic population. N Engl J Med 333: 1308-1312.

106. Hendriks HF, Weststrate JA, Van Vliet T, Meijer GW (1999) Spreads enriched with three different levels of vegetable oil sterols and the degree of cholesterol lowering in normocholesterolaemic and mildly hypercholesterolaemic subjects. Eur J Clin Nutr 53: 319-327.

107. Hallikainen MA, Sarkkinen ES, Uusitupa MI (2000) Plant stanol esters affect serum cholesterol concentrations of hypercholesterolemic men and women in a dose-dependent manner. J Nutr 130: 767-776.

108. Jones PJ, Raeini-Sarjaz M, Ntanios FY, Vanstone CA, Feng JY, et al. (2000) Modulation of plasma lipid levels and cholesterol kinetics by phytosterol versus phytostanol esters. J Lipid Res 41: 697-705.

109. Rao AV, Janezic SA (1992) The role of dietary phytosterols in colon carcinogenesis. Nutr Cancer 18: 43-52.

110. Awad AB, von Holtz RL, Cone JP, Fink CS, Chen YC (1998) beta-Sitosterol inhibits growth of HT-29 human colon cancer cells by activating the sphingomyelin cycle. Anticancer Res 18: 471-473.

111. Nissinen M, Gylling H, Vuoristo M, Miettinen TA (2002) Micellar distribution of cholesterol and phytosterols after duodenal plant stanol ester infusion. Am J Physiol Gastrointest Liver Physiol 282: G1009-1015.

112. Nielson MM, Hansen A (2008) Rapid high-performance liquid chromatography determination of tocopherols and tocotrienols in cereals. Cereal chem 85: 248-251.

113. Cahoon EB, Hall SE, Ripp KG, Ganzke TS, Hitz WD, et al. (2003) Metabolic redesign of vitamin E biosynthesis in plants for tocotrienol production and increased antioxidant content. Nat Biotechnol 21: 1082-1087.

114. Fardet A, Rock E, Remesy C (2008) Is the *in vitro* antioxidant potential of whole-grain cereals and cereal products well reflected in vivo? J Cereal Sci 48: 258-276.

115. Finocchiaro F, Ferrari B, Gianinetti A, Dall'Asta C, Galaverna G, et al. (2007) Characterization of antioxidant compounds of red and white rice and changes in total antioxidant capacity during processing. Mol Nutr Food Res 51: 1006-1019.

116. Panfili G, Fratianni A, Irano M (2003) Normal phase high performance liquid chromatography method for the determination of tocopherols and tocotrienols in cereals. J Agric Food Chem 51: 3940-3944.

117. Tucker JM, Townsend DM (2005) Alpha-tocopherol: roles in prevention and therapy of human disease. Biomed Pharmacother 59: 380-387.

118. Panfili G, Fratianni A, Di Criscio T, Marconi E (2008) Tocol and b-glucan levels in barley varieties and in pearling by-products. Food Chem 107: 84-91.

119. Sheppard AJ, Pennington JAT, Weihrauch JL (1993) Analysis and distribution of vitamin E in vegetable oils and foods. In L Packer, J Fuchs (Eds.) Vitamin E in health and disease. New York Marcel-Dekker Inc.

120. Lampi AM, Nurmi T, Ollilainen V, Piironen V (2008) Tocopherols and Tocotrienols in wheat genotypes in the HEALTH GRAIN Diversity Screen. J Agric Food Chem 56: 9716-9721.

121. Qureshi AA, Bradlow BA, Brace L, Manganello J, Peterson DM, et al. (1995) Response of hypercholesterolemic subjects to administration of tocotrienols. Lipids 30: 1171-1177.

122. Theriault A, Chao JT, Wang Q, Gapor A, Adeli K (1999) Tocotrienol: a review of its therapeutic potential. Clin Biochem 32: 309-319.

123. Jialal I, Devaraj S (2005) Scientific evidence to support a vitamin E and heart disease health claim: research needs. J Nutr 135: 348-353.

124. Kaimal TBN (1999) γ -oryzanol from rice bran oil. J oil Technol Assoc India, 31: 83-93.

125. Britz SJ, Prasad PV, Moreau RA, Allen LH Jr, Kremer DF, et al. (2007) Influence of growth temperature on the amounts of tocopherols, tocotrienols, and gamma-oryzanol in brown rice. J Agric Food Chem 55: 7559-7565.

126. Yu S, Nehus ZT, Badger TM, Fang N (2007) Quantification of vitamin E and gamma-oryzanol components in rice germ and bran. J Agric Food Chem 55: 7308-7313.

127. Juliano C, Cossu M, Alamanni MC, Piu L (2005) Antioxidant activity of gamma-oryzanol: mechanism of action and its effect on oxidative stability of pharmaceutical oils. Int J Pharm 299: 146-154.

128. Suh MH, Yoo SH, Chang PS, Lee HG (2005) Antioxidative activity of microencapsulated gamma-oryzanol on high cholesterol-fed rats. J Agric Food Chem 53: 9747-9750.

129. Yoshino G, Kazumi T, Amano M, Tateiwa M, Yamasakin T, et al. (1989) Effects of gamma-oryzanol and probucol on hyperlipidemia. Curr Ther Res 45: 975.

130. Gerhardt AL, Gallo NB (1998) Full-fat rice bran and oat bran similarly reduce hypercholesterolemia in humans. J Nutr 128: 865-869.

131. Seetharamaiah GS, Krishnakantha TP, Chandrasekhara N (1990) Influence of oryzanol on platelet aggregation in rats. J Nutr Sci Vitaminol (Tokyo) 36: 291-297.

132. Nakayama S, Manabe A, Suzuki J, Sakamoto K, Inagaki T (1987) Comparative effects of two forms of gamma-oryzanol in different sterol compositions on hyperlipidemia induced by cholesterol diet in rats. Jpn J Pharmacol 44: 135-143.

133. Murase Y, Iishima H (1963) Clinical Studies of oral administration of gamma-oryzanol on climacteric complaints and its syndrome. Obstet Gynecol Prac 12: 147-149.

134. Bonner B, Warren B, Bucci L (1990) Influence of ferulate supplementation on post exercise stress hormone levels after repeated exercise stress. J Appl Sports Sci Res 4-10.

135. Bhatty RS (1993) Non-malting uses of barley, In MacGregor, AW and Bhatty RS (Eds).

136. Wood PJ (1992) Aspects of the chemistry and nutritional effects of non starch polysaccharides of cereals, In: Alexander R J Zobel HF, Eds. Developments in Carbohydrate Chemistry, American Association of Cereal Chemistry.

137. Naumann E, van Rees AB, Onning G, Oste R, Wydra M, et al. (2006) Beta-glucan incorporated into a fruit drink effectively lowers serum LDL-cholesterol concentrations. Am J Clin Nutr 83: 601-605.

138. AbuMweis SS, Jew S, Ames NP (2010) Î²-glucan from barley and its lipid-lowering capacity: a meta-analysis of randomized, controlled trials. Eur J Clin Nutr 64: 1472-1480.

139. Behall KM, Scholfield DJ, Hallfrisch JG, Liljeberg-Elmståhl HG (2006) Consumption of both resistant starch and beta-glucan improves postprandial plasma glucose and insulin in women. Diabetes Care 29: 976-981.

140. Smith KN, Queenan KM, Thomas W, Fulcher RG, Slavin JL (2008) Physiological effects of concentrated barley beta-glucan in mildly hypercholesterolemic adults. J Am Coll Nutr 27: 434-440.

141. Thondre PS, Henry CJ (2009) High-molecular-weight barley beta-glucan in chapatis (unleavened Indian flatbread) lowers glycemic index. Nutr Res 29: 480-486.

142. Bell S, Goldman VM, Bistrian BR, Arnold AH, Ostroff G, et al. (1999) Effect of beta-glucan from oats and yeast on serum lipids. Crit Rev Food Sci Nutr 39: 189-202.

143. Braaten JT, Wood PJ, Scott FW, Wolynetz MS, Lowe MK, et al. (1994) Oat beta-glucan reduces blood cholesterol concentration in hypercholesterolemic subjects. Eur J Clin Nutr 48: 465-474.

144. Davidson MH, Dugan LD, Burns JH, Bova J, Story K, et al. (1991) The hypocholesterolemic effects of beta-glucan in oatmeal and oat bran. A dose-controlled study. JAMA 265: 1833-1839.

145. Wood PJ (1990) Physicochemical properties and physiological effects of the (1----3)(1----4)-beta-D-glucan from oats. Adv Exp Med Biol 270: 119-127.

146. FDA (Food and Drug Administration) (1997) Food labeling: Health claims; Oats and coronary heart disease; Rules and regulations. Federal Register 62: 3584-3601.

147. Peter J Wood (2007) Cereal Beta-glucan in diet and health. J of cereal Sc 46: 230-238.

148. Pick ME, Hawrysh ZJ, Gee MI, Toth E, Garg ML, et al. (1996) Oat bran concentrate bread products improve long-term control of diabetes: a pilot study. J Am Diet Assoc 96: 1254-1261.

149. Koh-Banerjee P, Franz M, Sampson L, Liu S, Jacobs DR Jr, et al. (2004) Changes in whole-grain, bran, and cereal fiber consumption in relation to 8-y weight gain among men. Am J Clin Nutr 80: 1237-1245.

150. Martínez-Tome M, Murcia MA, Frega N, Ruggieri S, Jiménez AM, et al. (2004) Evaluation of antioxidant capacity of cereal brans. J Agric Food Chem 52: 4690-4699.

151. Miller HE, Rigelhof F, Marquart L, Prakash A, Kanter M (2000) Antioxidant content of whole grain breakfast cereals, fruits and vegetables. J Am Coll Nutr 19: 312S-319S.

152. Pérez-Jiménez J, Saura-Calixto F (2005) Literature data may underestimate the actual antioxidant capacity of cereals. J Agric Food Chem 53: 5036-5040.

153. Andersson A, Tengblad S, Karlström B, Kamal-Eldin A, Landberg R, et al. (2007) Whole-grain foods do not affect insulin sensitivity or markers of lipid peroxidation and inflammation in healthy, moderately overweight subjects. J Nutr 137: 1401-1407.

154. Chen CY, Milbury PE, Collins FW, Blumberg JB (2007) Avenanthramides are bioavailable and have antioxidant activity in humans after acute consumption of an enriched mixture from oats. J Nutr 137: 1375-1382.

155. Kim JY, Kim JH, Lee da H, Kim SH, Lee SS (2008) Meal replacement with mixed rice is more effective than white rice in weight control, while improving antioxidant enzyme activity in obese women. Nutr Res 28: 66-71.

156. Bryngelsson S, Dimberg LH, Kamal-Eldin A (2002) Effects of commercial processing on levels of antioxidants in oats (*Avena sativa L.*). J Agric Food Chem 50: 1890-1896.

157. Ryan L, Petit S (2010) Addition of whole, semi skimmed, and skimmed bovine milk reduces the total antioxidant capacity of black tea. Nutr Res 30: 14-20.

158. Ryan L, Prescott SL (2010) Stability of the antioxidant capacity of twenty-five commercially available fruit juices subjected to an in vitro digestion. Int J Food Sci Technol 45: 1191-1197.

159. Daniels DGH, Martin HF (1967) Antioxidant in oats: mono-esters of caffeic and ferulic acids. J Sci Food Agric 18: 589-595.

160. Rondini L, Peyrat-Maillard MN, Marsset-Baglieri A, Fromentin G, Durand P, et al. (2004) Bound ferulic acid from bran is more bioavailable than the free compound in rat. J Agric Food Chem 52: 4338-4343.

161. Parikka K, Rowland IR, Welch RW, Wähälä K (2006) In vitro antioxidant activity and antigenotoxicity of 5-n-alkylresorcinols. J Agric Food Chem 54: 1646-1650.

162. Yu L, Haley S, Perret J, Harris M, Wilson J, et al. (2002) Free radical scavenging properties of wheat extracts. J Agric Food Chem 50: 1619-1624.

163. Yu L, Zhou k, Parry Jw (2005) Inhibitory effects of wheat bran extracts on human LDL oxidation and free radicals. LWT 38: 463-470.

164. Zhou K, Su L, Yu LL (2004) Phytochemicals and antioxidant properties in wheat bran. J Agric Food Chem 52: 6108-6114.

165. Xu Z, Hua N, Godber JS (2001) Antioxidant activity of tocopherols, tocotrienols, and gamma-oryzanol components from rice bran against cholesterol oxidation accelerated by 2, 20-azo bis (2-methylpropionamidine) dihydrochloride. J Agric Food Chem 49: 2077-2081.

166. Hu C, Zawistowski J, Ling W, Kitts DD (2003) Black rice (Oryza sativa L. indica) pigmented fraction suppresses both reactive oxygen species and nitric oxide in chemical and biological model systems. J Agric Food Chem 51: 5271-5277.

167. Oki T, Masuda M, Kobayashi M, Nishiba Y, Furuta S, et al. (2002) Polymeric procyanidins as radical-scavenging components in red-hulled rice. J Agric Food Chem 50: 7524-7529.

168. Krawinkel MB (2007) What we know and don't know about Golden Rice. Nat Biotechnol 25: 623.

169. Bunzel M, Ralph J, Martia JM, Hatfield RD, Steinhart H (2001) Diferulates as structural components in soluble and insoluble cereal dietary fiber. J Sci Food Agric 81: 653-660.

170. Mateo Anson N, Van den Berg R, Havenor R, Aalt Bastb, Guido RMM Haenen (2009) Bioavalibility of ferulic acid is determined by its bioaccesibility. J Cereal Sci 49: 296-300.

171. Adam A, Crespy V, Levrat-Verny MA, Leenhardt F, Leuillet M, et al. (2002) The bioavailability of ferulic acid is governed primarily by the food matrix rather than its metabolism in intestine and liver in rats. J Nutr 132: 1962-1968.

172. Barley: Chemistry and technology, p 355–417, American Association of Cereal Chemistry.

173. Brown JP (1980) A review of the genetic effects of naturally occurring flavonoids, anthraquinones and related compounds. Mutat Res 75: 243-277.

174. Caton PW, Pothecary MR, Lees DM, Khan NQ, Wood EG, et al. (2010) Regulation of vascular endothelial function by procyanidin-rich foods and beverages. J Agric Food Chem 58: 4008-4013.

175. Emmons CL, Peterson DM, Paul GL (1999) Antioxidant capacity of oat (Avena sativa L.) extracts. 2. In vitro antioxidant activity and contents of phenolic and tocol antioxidants. J Agric Food Chem 47: 4894-4898.

176. FAO (Food and Agriculture Organisation) (1991) Cereal and Grain legume seed processing Technical guide. FAO plant production and protection Series No 21 FAO, Rome.

177. Jacobs DR, Andersen LF, Blomhoff R (2007) Wholegrain consumption is associated with a reduced risk of noncardiovascular, noncancer death attributed to inflammatory diseases in the Iowa Women's Health Study. Am J Clin Nutr 85: 1606-1614.

178. Jiang Q, Christen S, Shigenaga MK, Ames BN (2001) gamma-tocopherol, the major form of vitamin E in the US diet, deserves more attention. Am J Clin Nutr 74: 714-722.

179. Kent NL, Evers AD (1994) Kent's Technology of Cereals (4th Edn.) Elsevier, Oxford.

180. Lloyd BJ, Siebenmorgen TJ, Beers KW (2000) Effect of commercial processing on antioxidants in rice bran. Cereal Chem 77: 551-555.

181. Maillard MN, Berset C (1995) Evolution of antioxidant activity during kilning: role of insoluble bound phenolic acids of barley and malt. J Agric Food Chem 43: 1789-1793.

182. Ross AB, Kamal-Eldin A, Aman P (2004) Dietary alkylresorcinols: absorption, bioactivities, and possible use as biomarkers of whole-grain wheat- and rye-rich foods. Nutr Rev 62: 81-95.

183. Ross AB, Shepherd MJ, Schüpphaus M, Sinclair V, Alfaro B, et al. (2003) Alkylresorcinols in cereals and cereal products. J Agric Food Chem 51: 4111-4118.

184. Ryynanen M, Lampi AM, Salo-Vaananen P, Ollilainen V, Piironen V (2004) A small-scale sample preparation method with HPLC analysis for determination of tocopherols and tocotrienols in cereals. J Food Compos Anal 17: 749-765.

185. Shahidi F, Naczk M (1995) Food Phenolics: sources, Chemistry, Effects, Applications. Technomic Pub Co Inc USA.

186. Slavin JL, Martini MC, Jacobs DR Jr, Marquart L (1999) Plausible mechanisms for the protectiveness of whole grains. Am J Clin Nutr 70: 459S-463S.

187. Truswell AS (2002) Cereal grains and coronary heart disease. Eur J Clin Nutr 56: 1-14.