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Review Article

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Phytochemicals in Cereals and their Potential Health Benefits-A Review

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Abstract

Edible seeds of Poaceae are referred to as cereals. A lot of cereals have been the staple food for human populations from time immemorial and have been a significant source of energy and nutrients. Their consumption has always been linked to a wide array of health benefits that could be attributed to the rich amount of phytochemicals harbored in them. This review attempts to present a summary of the various phytochemicals present in cereals and their potential health benefits. This review has been compiled using information from various sources including scientific publications. Citations have been provided to credit the sources.

Introduction

Cereals belong to the family Poaceae and are cultivated for their nutritionally beneficial seeds referred to as grains that are used for human consumption directly as well as indirectly via livestock feed [1, 2]. The type of cereal consumed varies according to geographical regions. They are consumed either as raw grains or as components of food substances and whole grain cereals are abundant in vitamins, minerals, carbohydrates, fats, oils and protein [3].

Cereal grains consumption contributes to greater than 50% of global everyday caloric intake [4]. Wheat, rice, maize and oats occupy top position in US diet. Whole grains such as these abound in nutrients and phytochemicals that promote health [5]. Figure 1 shows a cereal plant. Grain is derived following fertilization of the flowers in the inflorescence

This article aims to provide a comprehensive review on phytochemicals in cereals and their potential health benefits. Information presented here has been compiled from existing published articles.

Composition of Whole Grain Cereals:

The different layers of grain are shown in Figure 2.
The endosperm being the largest portion contains carbohydrates, proteins, vitamins, and minerals. The germ has vitamins, some protein, minerals, and fats. The outer most layer, bran protects the other two layers and contains phenolic compounds, vitamins, and minerals [6].

Figure 1: A cereal plant from our garden showing the formation of grains

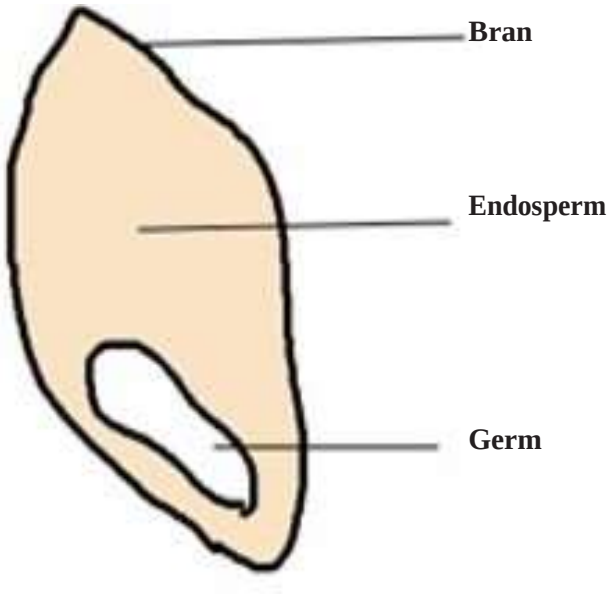

Figure 2: Grain - Structure

When all three layers of the grain are present, it is referred to as the whole grain and is copious in essential vitamins, minerals and phytochemicals. The process of refining removes most of the bran and some of the germ leading to loss of dietary fiber and other important compounds from whole grains. Therefore, in comparison to whole grains, refined grains contain a higher starch content [3, 7, 8]. Whole grains contain high concentrations of B vitamins, minerals, tocol, arginine, lysine and a variety of phytochemicals including phytates, phenolic compounds, avenanthramides, avenalumic acid that confer them with high antioxidant potential [8,90].

Cereals are able to exercise varying metabolic effects because of the presence of both soluble and insoluble fibres [9]. Barley, oats, apples, pears and most legumes are the major sources of soluble fibre [91]. In a review of clinical trials related to health benefits of cereals, Smith and Tucker throw light on how intervention trials have revealed improved glucose and lipid metabolism with soluble fibre [9]. Borneo and Leon, in their review on functional components of cereals, list dietary fiber, inulin, beta-glucan, resistant starch, carotenoids, phenolics, tocotrienols, and tocopherols as the most predominant phytochemicals that are responsible for the health enhancing properties of cereals [10]. Cereals are also a good source of proteins. When they are consumed along with legumes, there is a complementation of amino acids resulting in higher protein quality. There is a variation in protein content among cereals [11]. Maize, rice, and wheat are quite popular [12]. According to Morrison, starches from cereal endosperm may be unique due to elevated levels of monoacyl lipids within the starch granules [13].

Health Benefits

Health benefits from cereals are attributed to the presence of various vitamins, minerals and phytochemicals in them. According to Hollaender et al, a diet rich in whole grains lowers LDL cholesterol and total cholesterol. They also point out that the most effective whole grain for lowering cholesterol is whole-grain oat [14]. Studies carried out by Heather et al demonstrate the effect of whole grain diet in lowering total, LDL and HDL cholesterol. They also reported that a diet rich in whole grains decreased cardiovascular risk factors [15]. Giglio et al. conducted studies to demonstrate the cardio protective functions of polyphenols [16]. The presence of polyphenols in cereals has been well documented [17, 18, 38]. Whole grains help lower blood pressure, which in turn is an important risk factor for heart disease. A lower risk of hypertension among males who had a higher intake of whole grain breakfast cereal has been reported by Kochar et al [19].

In a recent review on the effect of intact cereal grain fiber on gut microbiota composition, Angie and Katie reported increased microbiota diversity as a consequence of intact cereal fiber consumption [20]. The authors recommend increasing cereal fiber consumption for general good health and for promoting gut microbiota diversity. Also, the beneficial effects of dietary fibers in bowel movements are quite well known.

Diets rich in whole grains are correlated with a 20-30% reduction of risk in the onset of type-2 diabetes. This is due to the presence of dietary fiber, vitamins, minerals and phytochemicals in wholegrains. A majority of phytochemicals act as antioxidants *in vitro* and alleviate oxidative stress and inflammation that are involved in the pathogenesis of type-2 diabetes [21].

Studies indicate that consumption of whole grains has a correlation to reduced obesity risk and weight gain [22]. Studies have also pointed out that an increased intake of dietary carbohydrates through ready-to-eat cereals aids in weight reduction [23, 24]. The beneficial effect of whole grains on body weight can be attributed to their higher fiber content [25]. Eating whole grains can help cut down on the amount of body fat and decrease waist circumference [15].

The role of cereals in combating cancer is being researched. These properties are attributed to the fibers and germ of the cereal [26, 27]. According to Makarem et al, whole grains and cereal fiber might have a protective effect against gastrointestinal cancers [28].

Ferulic acid present in whole-wheat grain or wheat bran may be responsible for its anti-inflammatory properties [29]. Small particle size wheat bran fraction may help manage inflammatory disorders outside the gut [30]. Lopes et al. observed that a combination of whole sorghum breakfast cereal and unfermented probiotic milk decreased the serum levels of C-reactive protein and malondialdehyde and increased superoxide dismutase and total antioxidant potential in individuals with chronic kidney disease [31]. Whole grains can contribute to an increased life span. Numerous studies have reported the correlation between increased intake of whole grains and reduced risk of mortality [32-35; 92].

Phytochemistry of Cereals

The wide variety of phytochemicals harbored in cereals give credence to the array health benefits conferred by them. Prominent phytochemical compounds in whole-grain cereals include phenolic compounds, carotenoids, phytic acid, phytosterols, tocols, gamma-oryzanol, beta-glucan, vitamins and minerals [5,8, 37, 90, 96].

Phenolic Compounds: Phenolic compounds are a group of secondary metabolites in plants including flavonoids, phenolic acids, tannins, lignans, and coumarins [36]. Phenolic compounds in cereals include Phenolic acid, Flavonoids, Avenanthramides, Lignans, and

Alkylresorcinols [37]. A review by Rao et al indicated that whole grain pigmented cereals contained anthocyanins, proanthocyanidins, and their derivatives which conferred them a higher antioxidant potential. Geographical locations and variations in levels of salinity, water, and temperature also influenced the phenolic content [17]. Pasha et al. assessed the antioxidant activity and analysed phenolic acids in sorghum and millet. Total phenolic content was in the range of 0.166-0.362 mg gallic acid equivalent and 0.275-0.305 mg in sorghum and millet respectively. Chlorogenic acid was the major phenolic acid in sorghum while it was m-coumaric acid in millet. The results showed that sorghum possessed higher antioxidant activities and phenolic acids as compared to millet [39].

Rao et al. characterized polyphenols and assessed the antioxidant potential of seven barley varieties from Australia. It was observed that Prodelphinidin B3 possessed the most antioxidant activity. Other polyphenols that exhibited antioxidant activity included procyanidin, glycosides of catechin and flavan-3-ols. The results of the study emphasized the merits of consuming whole grain barley [38].

It was revealed that integrating classical chemotherapy with nutrients and polyphenols from dietary sources might increase potency and decrease adverse side effects of the antineoplastic drug [40]. Saharan et al. observed that rice and wheat had the highest levels of polyphenols and antioxidants followed by sorghum, oat and maize because of fermentation. They also demonstrated the antioxidant activity was related to total phenol and flavonoid content [18]. Cereals are abundant in free phenolic acids like ferulic, sinapic, pcoumaric, 2-hydroxycinnamic, 2, 4-dihydroxybenzoic, caffeic, syringic and vanillic acid [41,42,93]. It has been reported that soluble phenolic acids are responsible for the flavor of cereal foods [43].

Smeds et al. analyzed lignins from cereals and reported the dominant presence of 7-Hydroxymatairesinol, in wheat, triticale, oat, barley, millet, corn bran, and amaranth whole grain. They also reported the occurrence of Syringaresinol, a cereal lignin [44].

Other lignans like buddlenol derivatives and hedyotisol lignans have been reported in rye bran [45]. Lignans are abundant in the bran fraction [43, 46, 47]. In the order of total lignin content cereals have been listed as rye, wheat, triticale, oat, spelt wheat, wild rice, barley, quinoa, red rice, brown rice by Smeds et al [44].

Stasiuk and Kozubek presented a review including the antimicrobial and antiparasitic activity of Alkylresorcinols (phenolic lipids) [48]. Activity exhibited by barley seeds against *Aspergillus niger* and *Penicillium crysogenum* has been attributed to the presence of alkylresorcinols in them [49]. It has also been reported that alkylresorcinols from rye bran inhibits the growth of *Penicillium expansum* and *Neofabraea perennans* [50, 51].

Flavonoids are a category of phenolic compounds and they could potentially halt the progression of certain chronic diseases [52]. Major cereal crops produce biologically active and stable to hydrolyze flavone-C-glycosides [53]. Zieliński et al. and Michalska et al. reported the amount of total flavonoid content in wholegrain rye [54,55]. According to Ivanišova et al. the flavonoid content in coarse and fine rye bran fractions was 1910 and 2390 mg/kg quercetin equivalents respectively [56]. Michalska et al. reported that there is a 46 % distribution of flavonoids in bran [55]. Evidences point out that dietary flavonoids contribute to the reduction of various diseases [57, 58]. Studies in oat groats by Peterson et al. demonstrated that avenanthramides are evenly distributed in the outer groat mass and their concentration is much lower in the starchy endosperm [65].

Benzoxazinoid: Katina et al. reported the presence of benzoxazinoid in rye grains and Pedersen et al. presented a detailed study on the content of benzoxazinoids in rye flours and rye bread [59, 60]. Quantitative data on benzoxazinoid content in wheat and rye fractions was published by Tanwir et al, [61]. They reported that the benzoxazinoids were concentrated in rye bran as DIBOA-diglucoside. Aneugenic effects of benzoxazinoids on human-derived liver cells was reported by Buchmann et al, [62]. Adhikari et al. presented a review on the presumptive health effects of benzoxazinoids and their conversion products. These compounds were reported to posses anti-inflammatory, anticancer, antimicrobial, and stimulatory effects on central nervous system and reproductive system [63]. Steffensen et al. presented the effect of benzoxazinoids from rye in prostrate cancer patients [64].

Carotenoids: Ndolo and Beta attempted to compare the distribution of carotenoids in endosperm, germ and aleurone fractions in different types of grains [66]. A significant variation in the concentrations of carotenoids was observed even though the cereal carotenoid composition was similar. In germ fractions, concentration of lutein and zeaxanthin were higher in non-corn cereals while in the endosperms, lutein and zeaxanthin contents were lower. In the aleurone layer, zeaxanthin levels were higher than lutein [66]. El sayed evaluated carotenoid composition and studied the effect of genotype and environment on lutein utilization on wheat species. It was observed that *Triticum monococcum* possessed high levels of all-trans-lutein [67].

Phytic Acid: Phosphorous in grains and oil seeds is stored in the form of phytic acid or inositol hexaphosphate [94]. 50-80% of the total phosphorus in various cereals is accounted for by phytic acid and is incorporated in the seed during ripening [68]. Phytic acid is capable of chelating ions like zinc, calcium and iron leading to low bioavailability of minerals [95].

Phytosterols: Phytosterols are a class of sterols mostly present in cell walls and membranes of plant. Earlier studies have reported that phytosterols from diet can reduce intestinal cholesterol absorption there by lowering serum LDL and total cholesterol concentrations [69-73]. Analysis of the sterol profiles of extracted lipids from rice bran, wheat bran, wheat germ, durum wheat, oat bran, oat hull, and corn fine fiber by Jiang and Wang showed that rice bran contained the maximum amount of lipids while the least amount of lipids were found in corn fine fiber. The dominant phytosterols were sitosterol, campesterol, and stigmasterol. Brassicasterol was found only in wheat samples, while appreciable quantities of cycloartenol and 24-methylenecycloartanol was found in rice bran oil [74].

Tocols: Tocols are naturally occurring antioxidants in plant based food including cereal grains [75]. Tocols include tocopherols and tocotrienols [76]. These compounds are present in noticeable quantities in most cereal grains including barley, oats, wheat, rye, rice [77-79].

Beta-glucan: β-glucan consists of D-glucose monomers linked with

glycosidic bonds at β (1 -3), (1-4), β (1-6) and is a major component of endosperm and aleurone cell walls of oat, barley, rye and wheat [80-82]. Havrlentová and Kraic reported that barley and oat had the highest content of β-D-glucan and are suitable sources of β-D-glucan that is beneficial for health [83]. The nutritional value of β-glucan is influenced by its tendency to be water soluble by virtue of its irregular structure. Soluble fiber confers protection against cardiovascular diseases [80]. β-glucan from cereals is capable of lowering LDL, total cholesterol and serum triglyceride levels [84].

Minerals and vitamins: In a recent study on polish population; Laskowski et al reported that cereals and cereal products contributed 64.1% manganese to the average Polish diet. This was followed by iron 34.1% and copper 31.3%; 20–30% zinc and phosphorus; 10–20% sodium, potassium and calcium. They also supplied 33.6% folate, 20-30% thiamin , 10-20% riboflavin, niacin and vitamin B6 [85].

Aminoacids and Proteins: Cereals abound in their aminoacids and proteins content. Excepting oats and rice, prolamins are the major endosperm storage proteins of all cereal grains [86, 87]. Majority of storage proteins in rice are glutelins and rice protein has elevated lysine levels. Sorghum contains mainly prolamins and gluten proteins in wheat confer the unique properties of dough formation. Oats are high in glutamine and asparagine and are mildly insufficient in cysteine and methionine [88]. Oats accumulate significant amounts of globulins and prolamins. A higher accumulation of globulins increases their protein quality [89].

Conclusion

From time immemorial, the human diet has been comprised of cereals. These magic grains have been our source of energy and have provided us with the necessary nutrients. Consuming cereals in the right quantities and in the right form could help alleviate numerous health issues. Research focusing on deducing the properties of phytochemicals from whole grains is imperative for the formulation of cereal-based products that can potentially promote health of human populations.

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