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Effect of primary processing of cereals and legumes on its nutritional quality: A comprehensive review

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Abstract: Cereals and legumes are important part of dietaries and contribute substantially to nutrient intake of human beings. They are significant source of energy, protein, dietary fiber, vitamins, minerals, and phytochemicals. Primary processing of cereals and legumes is an essential component of their preparation before use. For some grains, dehusking is an essential step, whereas for others, it could be milling the grain into flour. Grains are subjected to certain processing treatments to impart special characteristics and improve organoleptic properties such as expanded cereals. All these treatments result in alteration of their nutritional quality which could either be reduction in nutrients, phytochemicals and antinutrients or an improvement in digestibility or availability of nutrients. It is important to understand these changes occurring in grain nutritional quality on account of pre-processing treatments to select appropriate techniques to obtain maximum nutritional and health benefits. This review attempts to throw light on nutritional alterations occurring in grains due to pre-processing treatments.

Subjects: Breads, Cereals & Dough; Food Analysis; Processing

Keywords: milling; sieving; flaking; nutritional composition; phytochemicals; nutrient digestibility

ABOUT THE AUTHOR

The first author was a graduate student of the Institution, who worked for his PhD thesis on cereal grains and legumes. A very sincere and committed worker, he completed his thesis on a very comprehensive research topic related to food matrix and *in vitro* bioavailability of nutrients and bioactive components with reference to dietary fiber in selected foods. The work dealt with the effects of different processing treatments on nutritional quality of many cereal grains and legumes. The senior author was the research advisor and is an experienced faculty at the University. Her main research interests are nutritional composition of processed foods, functional properties of foods, product development, and sensory evaluation. In addition, she has also contributed significantly in the area of nutrient digestibility/bioaccessibility and antioxidant properties of foods. She is a prolific writer with many research and review papers to her credit.

PUBLIC INTEREST STATEMENT

Cereals and legumes are important part of human diets and a large variety are grown for edible purposes. They contribute significantly towards energy, protein, vitamins, minerals, dietary fiber, and phytochemical intakes. All grains undergo different types and levels of processing to make them edible and palatable. Pre-processing of grains is essential to prepare them for further processing and involves simple operations such as dehusking, milling, sieving, parboiling, germination, etc. Any kind of processing alters the nutritional quality of grains depending upon type and severity. Since the distribution of constituents in grain is not uniform, the milling processes can greatly influence the composition of resultant grain or flour. This review discusses the effects of pre-processing treatments on the nutrients, antinutrients, and phytochemical contents, and their digestibility and bioavailability in common cereals and legumes. This information will help us to understand the relative nutritional quality of pre-processed food grains.

1. Introduction

Cereals and legumes are major staple foods, specifically in Asian dietaries. They are rich sources of nutrients especially when used as whole grains. However, most grains are processed further after cleaning and grading to yield end products useful for industry. These pre-processing operations such as dehulling, milling, refining, polishing, etc. alter the nutritional composition of resultant product to varying degrees. These could also modify the matrices, the surrounding in which nutrients are embedded in a grain, which in turn influences the nutrient availability *in vivo*. While some cereal grains like rice or legumes are consumed as whole grains, most cereals are converted to flour before usage.

Milling is defined as an act or process of grinding, especially grinding grain into flour or meal (Bender, 2006). It is an important and intermediate step in post-production of grain. The basic objective of milling process is to remove the husk and sometimes the bran layers, and produce an edible portion that is free of impurities and in the form of a powder with varying particle size. The concentration of essential nutrients decrease with the degree of milling with minor alteration in energy density of pre- and post-meal (Ramberg & McAnalley, 2002). Structurally, all grains are composed of endosperm, germ, and bran. The endosperm comprises < 80% of the whole grain, whereas the percentages accounted for the germ and bran components vary among different grains. Milling process can be of two kinds, (1) wherein the whole grain is converted into flour without abstracting any parts or, (2) it could undergo differential milling to separate the grain into different parts. For example, wheat could be milled as whole wheat flour or undergo roller milling to yield multiple products as refined wheat flour, bran, germ, semolina, etc.

Nutrients and phytonutrients are not evenly distributed throughout the grain; most of nutrient's concentration is higher in outer part of the grain, so differential milling or refining results in reduced nutrient content except starch (Slavin, Martini, Jacobs, & Marquart, 1999). The grade of milling and refining can produce very fine flour that has different amount of nutrients in comparison to its original sources. Usually outer layer of cereals and pulses are rich in antinutrients that can be reduced by dehulling. The major compositional difference between whole grains and their milled form is reduction of all nutrients that are stored in external layer, dietary fiber, and the components associated with fibers including phytic acid, tannin, polyphenol, and some enzyme inhibitors like trypsin inhibitor, as well as minerals and some vitamins (García-Estepa, Guerra-Hernández, & García-Villanova, 1999). In most of the studies, reduction of phytate, tannin, and phenolic elements lead to improved availability of minerals and digestibility of protein and carbohydrates, however, these components also exhibit strong antioxidant properties which may stop free radical activity and reduce oxidative stress in human body (Harland & Morris, 1995). These are also subject to loss while refining. Whole rice grain after dehusking retains all the nutrients prior to the polishing step, however, polished rice grains lose many nutrients and phytochemicals depending upon the degree of polishing, the higher the degree, more would be the loss. Germination and malting of grains, on the other hand, is associated with an improvement in the nutrient content as well as decrease in antinutrients, thereby increasing the digestibility and availability.

This review aims to discuss the effects of primary processing on carbohydrate, protein, minerals, and phytochemical content and their digestibility/bioaccessibility among cereals and pulses.

2. Primary processing of cereals and legumes and nutrients

Cereals are the most important sources of food, and cereal-based foods are a major source of energy, protein, B vitamins, and minerals for the population of the world. Many scientific studies support the observation that consumption of whole grain cereals can protect against diabetes, obesity, constipation, cardiovascular disease, and other lifestyle disorders (Anderson, 2003; Fardet, 2010; McKevith, 2004; Priebe, van Binsbergen, de Vos, & Vonk, 2008). The changes in composition and matrix of grain due to milling process can explain why whole grain consumption can be advisable. Elements in whole grain associated with health status include lignans, tocotrienols, phenolic compounds, and antinutrients including phytic acid, tannins, and enzyme inhibitors. In the process of refining grain, the bran is separated, resulting in the loss of dietary fiber, vitamins, minerals, lignans, phytoestrogens, phenolic compounds, and phytic acid. Thus refined grains are more concentrated in starch since most of the bran and some of the germ is removed in the refining process. The phytochemicals are involved in health-improving activities which are very important for stressful life. So using whole grain or milled flour without sieving and separating different portion can be beneficial for health (Schatzkin et al., 2007; Slavin, 2004).

Nearly all wheat grown in the world is subjected to milling and used for production of many staple foods, primarily different kinds of bread (Edwards, 2007). The nutritional composition of whole and refined wheat flour differs markedly and studies indicate that through refining process, most of the bran and some of the germ are removed, resulting in loss of dietary fiber, vitamins, minerals, lignans, phytoestrogens, phenolic compounds, and phytic acid. Refined grains have a higher starch content than whole grains. Most vitamins and minerals (44.45%) are found in the germ and bran portion of grains. Milling of grains results in major losses (in descending order) of thiamine, biotin, vitamin B_6, folic acid, riboflavin, niacin, and pantothenic acid; there are also substantial losses of calcium, iron, and magnesium (Fardet, 2010; Truswell, 2002). An amazing 70–80% of the original vitamins are lost when grains are milled. The larger the portion of the grain removed, the greater is the nutrients loss. When wheat is milled into wheat flour, there is an approximate 70% loss of vitamins and minerals (range 25–90%) and fiber, 25% loss of protein, 90% loss of manganese, 85% loss of zinc and linoleic acid, and 80% loss of magnesium, potassium, copper, and vitamin B_6 (Ramberg & McAnalley, 2002; Redy & Love, 1999). Table 1 shows the effect of milling processes on the chemical composition of wheat, finger millet (*Eleucine coracana*), and some legumes as reported in different studies.

Refining decreases the contents of almost all nutrients in wheat flour. As observed by Oghbaei and Prakash (2013) refining decreased protein, fat, ash, calcium, iron, and zinc in wheat flour. The decrease in soluble and insoluble dietary fiber was found to be significant after refining. The isolated wheat bran during differential milling, in contrast, was richer in all these constituents. The losses in thiamine, riboflavin, and tannin content during refining of wheat flour were reported to be 48, 38, and 67%, respectively. In contrast, the increase in these constituent in wheat bran was 36, 110, and 51%, respectively, in comparison to whole wheat flour. Simple process of sieving a whole flour can also alter the nutrient content with decreased nutritional constituents in sieved flour as can be seen for finger millet (Table 1).

Majzoobi, Pashangeh, Farahnaky, Eskandari, and Jamalian (2014) studied the effect of particle size reduction, hydrothermal treatment, and fermentation on phytic acid contents of wheat bran and reported various levels of reduction in different treatments. Phytic acid content decreased from 50.1 mg/g to 21.6, 32.8 and 43.9 mg/g after particle size reduction, hydrothermal treatment, and fermentation. A combination of hydrothermal and fermentation treatment along with particle size reduction further reduced phytic acid content up to 74.4 and 57.3%, respectively.

Prodanov, Sierra, and Vidal-Valverde (2004) studied influence of soaking on vitamin contents of faba beans, chick pea, and lentils and found that, in general, there were losses of thiamine (6.2–17.1%), riboflavin (2.5–34.2%), and niacin (2.0–61.2%) to varying extent in soaked legumes. Losses were higher when beans were soaked in alkaline media than in acidic media or water alone. This loss was obviously due to leaching of water soluble vitamins in soaking media.

Pelgrom, Wang, Boom, and Schutyser (2015) used air classification after pre-treatment of pea and lupin legumes to obtain a protein-rich flour fraction. They reported that the finer faction of flour in all pre-treatments had a much higher protein content than coarser faction. Soaking and freezing as pre-treatment did not improve the protein content of fine fraction in comparison to control, however, defatted lupin flour had higher protein (Table 1). Aguilera et al. (2009) determined protein and fiber contents of chick pea, white bean, and pink-mottled cream bean after soaking and dehydration and found that soaked chick pea had 22.3% lower protein content than raw grains, whereas for other legumes differences were negligible. The soluble fiber content of all soaked legumes was much higher. Insoluble fiber did not alter for white bean, though for others there was a slight reduction (Table 1).

Table 1. Effect of milling processes on chemical composition of wheat, finger millet, and legumes (per 100 g)

Components	Differential milling					Sieving	
	Wheat flour		Wheat flour		Wheat bran	Finger millet flour	
	Whole	Refined	Whole	Refined		Whole	Sieved
	Thompson (1992)		Oghbaei and Prakash (2013)			Oghbaei and Prakash (2012)	
Protein (g)	19.45	14.0	14.28	11.66	19.45	7.15	6.33
Fat (g)	5.25	2.70	2.50	1.54	5.25	1.78	1.29
Starch (g)	21.91	70.00	64.77	80.16	21.91	66.10	69.53
Ash (g)	5.71	1.80	1.89	0.78	5.71	2.21	1.80
Soluble dietary fiber (g)	4.45	1.10	0.51	0.27	4.45	1.55	1.79
Insoluble dietary fiber (g)	42.47	11.50	12.45	3.39	42.47	20.23	12.15
Iron (mg)	12.90	3.50	7.54	3.24	12.90	6.52	3.29
Zinc (mg)	4.70	2.90	1.62	0.70	4.70	2.50	1.98
Calcium (mg)	–	–	50.75	34.20	87.76	404.3	294.8
Thiamine (mg)	–	–	0.64	0.33	0.87	0.552	0.342
Riboflavin (mg)	–	–	0.21	0.13	0.44	0.243	0.196
Phytates (mg)	290.0	10.0	604.0	396.5	3396.0	628.2	432.0
Tannins (mg)	–	–	385.7	127.8	584.2	851.2	563.9

Air classification of legume flours after pre-treatments (Pelgrom et al., 2015)

Protein (g)	Pea				Lupine			
	Control	Defatted	Soaked	Frozen	Control	Defatted	Soaked	Frozen
Fine	43.9	41.6	34.6	39.7	45.1	56.9	43.2	43.0
Coarse	11.4	11.4	13.5	12.7	29.0	39.7	37.8	34.8

Soaking and dehydration (Aguilera et al., 2009)

Legume	Chick pea		White bean		Pink mottled cream bean	
Treatment	Raw	Soaked	Raw	Soaked	Raw	Soaked
Protein (g)	22.4	17.4	19.8	19.4	18.8	18.7
Soluble dietary fiber (g)	9.6	12.8	58.2	65.8	54.3	64.4
Insoluble dietary fiber (g)	20.5	19.8	21.1	21.2	16.4	14.8

The process of parboiling, puffing, and flaking causes alteration in nutrient content of rice grain. Rice can be flaked to different degree of thickness following a process of soaking paddy in hot water and roller pressing. Flaked rice can be eaten as such or used in preparation of other rice-based snacks or other culinary items. Flaking altered the phosphorus, phytin phosphorus, and dietary fiber content of flaked rice with a decrease in proportion to thickness of flakes, the lesser the thickness, the lower was the constituent, whereas the iron and calcium contents were not affected (Suma, Sheetal, Jyothi, & Prakash, 2007).

Yasmin, Zeb, Khalil, Paracha, and Khattak (2008) studied effect of soaking and germination on antinutritional factors of red kidney bean (*Phaseolus vulgaris*) and reported various levels of reduction in cyanide content on soaking in water (7.7%), in citric acid added water (8.7%), in sodium carbonate added water (13.9%), and on germination (20.8%). Germination reduced tannins (68.6%), polyphenols (54.5%), and phytic acid (42.6%) to various extents. Such reduction in antinutrients increases the bioavailability of minerals in germinated legumes.

3. Effect on carbohydrates and its digestibility

Carbohydrates are major part of cereals and pulses and main source of energy in human body. The process of dehulling and milling improves the starch content of grain and its digestibility (Kerr, Ward, McWatters, & Resurreccion, 2000; Oghbaei & Prakash, 2012, 2013; Raghuvanshi, Singh, Bisht, & Singh, 2011). Method of milling and particle size are related to the starch content of flour. It has been shown that as the size of screen used for milling decreases, the starch content increases (Kerr et al., 2000).This could be possibly due to the fact that as the size of mesh decreases, more of fiber portion is separated and finer flour with higher starch content passes through sieve. As fiber is difficult to pulverize in comparison to endosperm with higher starch content, it is separated as coarse fraction. It is observed that reduction in bran during milling leads to improved starch digestibility. Oghbaei and Prakash (2013) reported 42 and 51% *in vitro* starch digestibility in whole and refined wheat flour, respectively. Bran includes large amount of insoluble dietary fiber and antinutrients like tannin and phytate which are able to bind enzymes and proteins and reduce their activity. In rice flakes, the percent starch digestibility varied from 78.1 to 84.1% in flakes of different thickness (Madhu, Gupta, & Prakash, 2007). Degree of flaking in rice did not influence starch digestibility significantly.

Home practices such as soaking, dehulling, fermentation, germination, and cooking effectively improve the nutritional value of legumes. Ghavidel and Prakash (2007) reported that germination and dehulling of green gram (*Phaseolus aureus Roxb*.), cowpea (*Vigna catjang*), lentil (*Lens esculanta*), and chickpea (*Cicer arietinum*) improved starch digestibility significantly (36.3–39.2%). Reduction in antinutrients content and activity of amylase could explain the improved starch digestibility and reduction of total starch, respectively. Due to dehulling, the soluble and insoluble dietary fiber, phytic acid, and tannin decreased significantly. According to Egounlety and Aworh (2003) the combined effect of soaking, dehulling, and cooking affected the level of oligosaccharides to a greater extent. About 50% of raffinose and more than 55–60% of sucrose and stachyose were lost, showing the importance of these treatments in bean processing.

Kaur, Sandhu, Ahlawat, and Sharma (2015) reported effects of processing of Mung bean (*Vigna radiata*) on starch digestibility and reported hydrolysis and glycemic index of 17 and 49.1% for raw, 19.1, and 50.2% for soaked, and 26.8 and 54.4% for germinated grains, respectively. Sinha and Kawatra (2003) studied effect of soaking and dehulling on cow pea (*Vigna unguiculata*) and reported that the phytic acid content decreased by 16.3 and 30.1% in soaked and dehulled pulses. The control sample had 836 mg phytic acid per 100 g of grains. On germination of grains, a decrease of 47.8% was observed after 72. The grains were also analyzed for polyphenols and the content per 100 g was 517 mg in untreated, 476 mg in soaked, 254 mg in dehulled, and 349 mg in germinated samples. Dehulling showed a maximum reduction in polyphenols indicating that whole grains have a higher content of antioxidant components.

4. Effect on protein and its digestibility

Cereals and pulses are major sources of protein, especially for many low income group populations. Both protein content and digestibility besides protein quality are important factors to be satisfied in daily protein requirement. Outer layers of grain are rich source of components like phytate and polyphenol that bind minerals which are necessary as cofactors, thus interfering with several essential metabolic processes, especially the utilization of protein (Landete, 2012). Phenolic compounds with higher molecular weight structures are usually designated as tannins, which refers to their ability to interact with proteins and render them unavailable for absorption by the human body. Tannins are defined as water-soluble polymeric phenolics that precipitate proteins (Reed, 1995).

Different varieties of rice after dehusking undergo different degree of milling; highly milled rice has lesser moisture, protein, lipid, and ash contents in comparison to rice milled to a lesser degree (Juliano, 1993). It can be due to removal of the caryopsis coat, aleurone, and subaleurone layers, which have high ash, lipid, and fiber contents (Kim, Noh, & Lee, 1994; Park, Kim, & Kim, 2001). In preprocessed expanded rice products such as puffed rice, popped rice, and rice flakes, the starch digestibility was higher than raw milled rice. Parboiled rice also exhibits higher starch digestibility than raw rice, however, it was lower than ready-to-eat expanded products (Chitra, Singh, & Ali, 2010). Kamaraddi and Prakash (2015) studied the effect of varietal differences of rice on nutritional characteristics of expanded rice and reported a range of 69.7–76.2% of protein digestibility and 80.3–82.8% of starch digestibility. Rice with higher degree of polishing carry better cooking quality because of textural changes which is due to the removal of dietary fiber and reduction of protein contents (Park et al., 2001), the digestibility of carbohydrate, and protein is higher in refined rice than in brown or semi-refined rice. As reported by Pedersen and Eggum (1983), highly refined rice had a lower protein content, though the amino acid coposition and net protein utilization were not affected. In rice flakes, the degree of flaking influences the percent protein digestibility with thick flakes being the lowest, (39.2%) followed by medium (43.2%), thin (55.3%), and very thin (66.2%) flakes (Madhu et al., 2007).

Soaking is a common pre-processing technique for whole legumes to facilitate decortication or cooking. The effect of soaking and fermentation on *in vitro* protein digestibility (IVPD) of some common legumes, as reported by different authors is compiled in Table 2. Khattab, Arntfield, and Nyachoti (2009) analyzed two varieties of cowpeas, kidney beans, and peas and showed an increase in IVPD of all soaked and fermented legumes. Torres, Rutherfurd, Muñoz, Peters, and Montoya (2016) stated that protein digestibility depended on the cultivar of the legume and reported an increase in soaked *Lablab purpurens* and red variety of *Vigna unguiculata* and a decrease in *Canavalia brasiliensis*, and pink and white variety of *Vigna unguiculata*. Abd El-Hady and Habiba (2003) found slight alteration in percent IVPD of soaked faba beans, peas, chick pea, and kidney beans. Hence, it can be said that soaking did not show any significant change in IVPD of legumes. Rasane, Jha, Sabikhi, Kumar, and Unnikrishnan (2015a) reviewed nutritional advantages of oats and opportunities for its processing as value-added foods and observed that germination improved protein quality of oats, though the content of β-glucan reduced in germinated grains.

It was observed that protein content of cowpea flour (24%) sieved through smallest sieve size was more than unsieved flour and that of flour sieved through larger sieve. The changes in protein content were not significant (Kerr et al., 2000). The average *in vitro* protein digestibility of three cultivars of mung bean improved from 68.22 to 74.72% following dehulling and frying the grains (Raghuvanshi et al., 2011). Plahar, Annan, and Nti (1997) analyzed *in vitro* protein digestibility of four cultivars of dehulled cowpea and did not find a major difference in whole (75.5–78%) or dehulled cowpea (77.4–78.4%), though there was a significant reduction in tannin content of dehulled grains. Both protein and its digestibility increased significantly following dehulling of green gram, cowpea, lentil, and

Table 2. Effect of soaking and fermentation on *in vitro* protein digestibility (%) of some legumes

Treatment	Legumes						Reference
	C.Cowpea	**C.Kidney bean**	**C.Pea**	**E.Cowpea**	**E.Kidney bean**	**E.Pea**	
Raw	82.3	70.5	78.4	81.6	78.0	80.1	Khattab et al. (2009)
Soaked	87.5	76.0	83.7	86.7	83.2	85.5	
Fermented	85.1	73.4	81.4	84.3	80.9	82.9	
	Canavalia brasiliensis	***Lablab purpurens***	***Vigna unguiculata***				Torres et al. (2016)
			Pink	Red	White	–	
Unsoaked	45.3	18.0	35.5	37.1	58.6	–	
Soaked	31.3	33.3	34.9	44.0	54.4	–	
	Faba beans	**Peas**	**Chick pea**	**Kidney bean**	–	–	Abd El-Hady and Habiba (2003)
Raw	75.4	74.5	74.0	70.6	–	–	
Soaked	76.0	75.2	74.8	70.2	–	–	

Notes: C.: Canadian, E.: Egyptian.

chickpea in range of 2.2–5.1 and 13.2–16.7%, respectively (Ghavidel & Prakash, 2007). Endosperm is a rich source of protein so removing hull portion can increase protein contents, and a reduction in tannin and phytate which bind protein and enzyme required for protein digestion result in higher protein digestibility. Blessing and Gregory (2010) also reported that the protein content in undehulled green gram was 4.3% higher than dehulled sample which was significant.

Khattab et al. (2009) evaluated the effect of water soaking and fermentation on the protein quality of Canadian and Egyptian cow pea, kidney beans, and peas using protein efficiency ratio (PER) and essential amino acid index (EAAI). While major differences in differently treated legumes were not observed, soaked cowpea of both variety had a higher PER in comparison to control (2.69 and 2.59 vs. 2.65 and 2.35, respectively). Soaked kidney beans and Canadian pea exhibited lower PER but higher EAAI. Pre-treated Egyptian pea had both higher PER and EAAI.

5. Effect on minerals and their availability/bioaccessibility

Milling is the critical process affecting the concentrations of inorganic elements in cereals, grains, and food products prepared from them. As the outer parts of the kernel, especially the aleurone layer and the germ, are richer in minerals when compared to the starchy endosperm, conventional milling reduces their content in flour and concentrates them in the milling residues. Differences in the mineral content is likely to exist even between the outer endosperm and the inner endosperm (Brondi, Ciardi, & Cubadda, 1984). The grain shape and texture and the technical conditions of milling, principally the extraction rate, are important in determining the extent of mineral loss. However, when all these variables are fixed, the distribution of the mineral in the various milling fractions finally depends on how the element is unequally distributed within the kernel. While milling reduces the mineral content, their availability is improved due to reduction in antinutrient contents (Oghbaei & Prakash, 2013).

Phytic acid is the major storage form of phosphorus in cereals and legumes which chelates minerals and prevents their intestinal absorption; several pre-processing treatments such as soaking, fermentation, germination, treatment of grains with phytase enzyme reduce the phytic acid content in grains (Gupta, Gangoliya, & Singh, 2015; Rasane et al., 2015a; Rasane, Jha, Kumar, & Sharma, 2015b). Polyphenols have the potential to bind positively charged proteins, amino acids and/or multivalent cations or minerals such as iron, zinc, and calcium in foods (Gilani, Cockell, & Sepehr, 2005). They thus reduce the bioavailability of essential minerals and a reduction in their content may result in improved absorption of these nutrients.

Luo and Xie (2014) studied the iron and zinc availability in soaked and sprouted green and white faba beans (*Vicia faba L.*) and reported an increase in iron availability in green beans on soaking and sprouting (50.5–51.2%) in comparison to control (32.2%). In white beans, the corresponding values were 58.8 and 58.9% in soaked and sprouted grains in comparison to 28.6% of control. In zinc availability the percent increase observed was 38.4 and 49.3% in green bean and 44.2 and 58.7% in white bean on soaking and sprouting in comparison to control values of 31.6 and 33.4%, respectively.

Differential milling of grains can also be applied to green gram to obtain protein and fiber-rich fractions as reported by Indrani, Milind, Sakhare, and Inamdar (2015). Whole green gram was milled to obtain straight run flour, protein-rich fraction, fiber-rich fraction and protein + fiber-rich fractions which were subsequently used for bread formulations. While the protein content of straight run flour was 25.7%, that of protein-rich fraction increased to 29.8%. Similarly the fiber content of straight run flour was 8.2% and increased to 68.5% in fiber-rich fractions. Hence differential milling can be used to separate specific constituents of grains as desired which in turn can be used for product formulations.

Cubadda, Aureli, Raggi, and Carcea (2009) reported various degrees of mineral loss in milling durum wheat grains for pasta. At least six groups of elements could be distinguished on the basis of their concentration decrease upon milling. Selenium had the highest retention with concentrations in semolina equal to 77–85% of that in grain (dry weight basis), followed by calcium (54–60%), copper (49–53%), potassium, phosphorous (42–47%), iron (36–38%), magnesium, and zinc (32–36%). Steadman, Burgoon, Lewis, Edwardson, and Obendorf (2001) milled buckwheat (*Fagopyrum esculentum*) to different fractions through roller milling and sieving the particles into flour (mainly central endosperm), grits (hard chunk of endosperm), and bran. Among different portions, mineral content of bran was found to be highest followed by flour and chunk.

Iron bioavailability from unpolished, polished, and bran fraction of five rice genotypes was studied by Prom-u-thai et al. (2006) and it was found that in all five genotypes polished samples followed by unpolished and bran portion had highest availability of iron. Iron availability was significantly correlated with the level of total extractable phenol in unpolished rice grain and bran portion but not in polished grain. In the highly refined white rice, the zinc content was reduced to half and the mineral content to 23% of corresponding levels in brown rice. Rats fed with rough, brown, and lightly milled rice were unable to maintain their femur zinc concentration; deposition of calcium and phosphorus also appeared to be affected. Factors present in the outer part of the rice kernel interfere strongly with zinc utilization. Phytate and/or fiber were not solely responsible for this effect. Unless rice was milled into highly refined white rice, zinc status of rats was negatively affected. The results suggest that zinc might be a limiting factor in rice-based diets (Pedersen & Eggum, 1983).

Percent losses of different nutrients on 5 and 10% milling of 16 varieties of raw rice, respectively, were: total ash 40, 62; iron 51, 67; magnesium 40, 64; calcium 36, 57; iron 54, 64; copper 26, 45; manganese 48, 56; molybdenum 24, 34; chromium 57, 69; and zinc only 2.8, 4.6. Zinc in rice grain was uniformly distributed and a major portion of other nutrients was concentrated in the outermost 2.5% surface layers of the grain (Doesthale, Devara, Rao, & Belavady, 1979). The milling of white rice from brown rice results in loss of certain vitamins and minerals particularly zinc, iron, niacin, and biotin. When corn is degermed, the majority of the germ and bran is removed. Degerming of corn significantly reduces fiber, lysine and tryptophan, and minerals (70%). Production of refined cornmeal significantly reduces levels of calcium, zinc, iron, niacin, and biotin (Redy & Love, 1999). Milling of barley reduces minerals by 60% and also causes significant loss of protein and lysine. Milling of sorghum and rye causes high mineral losses (Lachance & Bauernfeind, 1991).

The average iron and calcium content of raw mung bean grains was 5.29 and 249.0 mg/100 g which was reduced to 3.68 and 154.3 mg/100 g after dehusking followed by frying (Raghuvanshi et al., 2011). Mubarak (2005) also reported 4% decrease in calcium content of raw mung bean after dehulling. Ionizable iron at pH 7.5 expressed as the index of *in vitro* iron bioavailability was improved from 2.35% in raw grain to 22.95% in dehulled fried grains (Raghuvanshi et al., 2011). The highly significant increase in *in vitro* iron bioavailability can be attributed to fact that most of the tannin resides in the seed coat of legume. Rao and Prabhavathi (1982) reported 16.2% ionizable iron at pH 7.5 in decorticated green gram in comparison to 2.6% ionizable iron in whole green gram. Lestienne, Icard-Vernière, Mouquet, Picq, and Trèche (2005) reported that soaking of whole grains such as millet, maize, sorghum, rice, soybean, cowpea, and mung bean reduced iron and zinc contents in all grains, the effect was said to be due to the leaching of minerals in soak water.

The activity of antinutritional factors like trypsin inhibitor, hemamagglutinin activity, tannins, and phytic acid were reported to be reduced by 7.59, 32.6, 33.3, and 20.7%, respectively, after dehulling of mung bean seed (Mubarak, 2005). The effect of different processing methods (soaking, milling, cooking, fermentation, and germination) on phytate content of grain was studied and it was reported that milling process after enzymatic methods (fermentation and germination) was the most efficient method in reducing phytate content (García-Estepa et al., 1999). In another study, reduction of ash, iron, calcium, and phosphorous content after dehulling in selected pulses was attributed to high concentration of mentioned elements in hull portion. The availability of iron (17.4–21.9%) and calcium (13.1–16.6%) significantly improved in dehulled samples. The significant rise was attributed to reduction of antinutrients which bound minerals and reduced their availability in whole grains (Ghavidel & Prakash, 2007).

6. Effect on phytochemicals

Phytochemicals are components that contribute to antioxidant activity and health benefits of plant foods. Some are common in many plant foods and some, exclusive to grain products (Miller, Prakash, & Decker, 2002). Whole grains are specifically rich in phytochemicals and some of these occur with dietary fiber. During the process of digestion they are released from the fiber complex due to action of enzymes (Siddiqui & Prakash, 2014). Digestive enzyme-treated fiber-rich fractions of cereal and millet flours exhibited higher antioxidant components and activity than untreated counterparts indicating that cereals and millets may have fiber-bound phenolics which are released during digestion (Siddiq & Prakash, 2015). Milling and refining can improve the availability of antioxidant compound and their activity because milling breaks cell wall and grain matrix and improves accessibility of digestion enzymes to components that are bound with food matrix (Liukkonen et al., 2003; Nagah & Seal, 2005; Parada & Aguilera, 2007; Prom-u-thai et al., 2006).

Phytic acid, the content of which is high in cereal bran, was considered an antinutrient all along, however, recent studies show its beneficial effect for health. It is said to be effective in prevention of coronary disease and has anticarcinogenic effects. It is shown to prevent the generation of superoxide and boost the immune system. It is being recognized for potential health benefits due to its ability to prevent colon cancer, liver cancer, lung cancer, skin cancer, etc. (Kayahara, 2004). Polyphenols have been recognized as the most abundant source of antioxidants in our diet (Thomasset et al., 2007). The quantity and quality of polyphenols present in plant foods can vary greatly due to factors such as plant genetics, soil composition and growing conditions, state of maturity and post-harvest conditions (Faller & Fialho, 2009). The profiles and quantities of polyphenols and tannins in foods are affected by processing due to their highly reactive nature, which may affect their antioxidant activity and the nutritional value of foods (Dlamini, Dykes, Rooney, Waniska, & Taylor, 2009). Polyphenols are not evenly distributed in plant tissues, and food fractionation during processing may result in a loss or enrichment of some phenolic compounds. Polyphenols in wheat grain are principally contained in the outer layers (aleurone cells, seed coat) and are lost during the refining of flour. Rice and oat (*Avena byzantina*) flours contain approximately the same quantity of phenolic acids as wheat flour (63 mg/kg), although the content in maize flour is about three times as high (Shahidi & Naczk, 1995).

The consumption of cereal products contributes to the phenolic acid intake only when whole grains are used for their manufacture (Scalbert & Williamson, 2000). Ferulic acid is linked with dietary fiber and is connected through ester bonds to hemicelluloses (Kroon, Faulds, Ryden, Robertson, & Williamson, 1997). Ferulic acid has the capability to prevent the generation of superoxide, controlling the aggregation of blood platelets (Kayahara, 2004), and cholesterol-lowering properties, as well as for their antioxidant capacity (Nyström, Achrenius, Lampi, Moreau, & Piironen, 2007). Ferulic acid is the most abundant phenolic compound found in cereal grains, which constitute its main dietary source. The ferulic acid content of wheat grain is 8–20 mg/100 g dry weight, which may represent up to 90% of total polyphenols (Lempereur, Surget, & Rouau, 1998). Ferulic acid is found chiefly in the outer parts of the grain. The aleurone layer and the pericarp of wheat grain contain 98% of the total ferulic acid. The ferulic acid content of different wheat flours is thus directly related to levels of sieving, and bran is the main source of polyphenols (Hatcher & Kruger, 1997). Only10% of ferulic acid is found in soluble free form in wheat bran (Lempereur et al., 1998). The nutritional and other components in brown rice such as dietary fibers, phytic acid, vitamin E, vitamin B, and γ-aminobutyric acid (GABA), are more than the ordinary milled rice. These biofunctional components are present mainly in the germ and bran portion; most of which are removed by polishing or milling. Unfortunately, brown rice takes longer to cook and cooked brown rice is harder to chew and not as tasty as white rice (Champagne, Wood, Juliano, & Bechtel, 2004).

The fractions produced during milling of rye were as follows: bran 48%, shorts 16%, and inner flour 35%. The outer layer was found to contain 3.3–4.0-fold-fold higher alkaline –extractable total phenolic and 1.6–2.1-fold-fold more sterol, folate, tocoferol, tocotrienol, lignin than whole rye. Bran portion showed markedly stronger antiscavenging activity. It can be seen that in addition to dietary fiber, most of bioactive constituents are concentrated in the outer layer of grain, signifying the negative effect of refining and importance of using whole grain (Liukkonen et al., 2003).

The concentration of tannin in hull portion of cowpea, soybean, and ground bean is much higher than whole grain. Dehulling raw cow pea, ground bean, and soya bean reduced their tannin content from 223, 152, and 68 mg/100 g to not detectable level (Egounlety & Aworh, 2003). Tajoddin, Shinde, and Lalitha (2011) analyzed polyphenol contents of 10 varieties of mung bean with different seed coat color. Total polyphenol was in range of 280–356 mg/100 g in whole grains and yellow variations relatively had higher polyphenol content with one exception of green colour variety which contained highest polyphenols among others.

Table 3. Compilation of selected studies on effects of pre-processing treatments on phytochemicals/antinutrients of food grains

1.	Effect of soaking on antinutrients of whole legume meals (Abd El-Hady & Habiba, 2003).							
	Constituents (% decrease)				**Faba beans**	**Peas**	**Chick pea**	**Kidney bean**
	Phytic acid				4.7	5.2	2.6	9.8
	Tannins				1.4	18.4	19.2	1.7
	Total phenols				4.7	14.6	6.8	4.5
	Trypsin inhibitor activity				19.9	15.4	9.2	1.5
2.	Effect of soaking whole grains on phytate content (Lestienne et al., 2005).							
	Phytic acid (% decrease)	**Millet**	**Maize**	**Sorghum**	**Rice**	**Soybean**	**Cowpea**	**Mung bean**
		27.8	20.6	4.6	16.6	22.8	11.6	4.7
3.	Effect of different degree of soaking on total phenolic compounds of legumes (Xu & Chang, 2008).							
	Total phenolic compounds (% decrease)			**Treatments**	**Green pea**	**Yellow pea**	**Chick pea**	**Lentil**
				Soaking −50%	–	–	–	9.5
				Soaking −70%	11.5	11.6	9.0	12.6
				Soaking −85%	9.8	5.1	9.0	21.5
				Soaking −100%	4.9	2.2	2.77	37.8
4.	Effect of pre-dehulling treatments on total phenolics and phytic acid of navy bean and pinto bean. Treatments: Conditioning the legume with water to 14% and 28% moisture, or soaking followed by freeze drying (FD) or heat drying (HD), (Anton et al., 2008).							
	Constituents (% change)	**Legumes**	**FD-14%**	**FD-28%**	**HT-14%**	**HT-28%**	**FD-Soaked**	**HD-Soaked**
	Total phenolics	Navy bean	+11.9	+81.0	+7.1	+102	+9.5	+97.6
	Phytic acid	Navy bean	−1.8	−0.5	−3.0	−2.7	+0.4	+4.3
	Total phenolics	Pinto bean	−11.5	+20.8	+0.9	+89.0	−1.6	+88.0
	Phytic acid	Pinto bean	−3.4	−2.9	−1.1	−6.0	−4.4	+2.3
5.	Effect of soaking and fermentation on anti-nutritional factors of legumes (Khattab & Arntfield, 2009).							
	Constituents (% decrease)	**Treatments**	**C. Cowpea**	**E. Cowpea**	**C. Kidney bean**	**E. Kidney bean**	**C. Pea**	**E. Pea**
	Phytic acid	Soaked	42.8	44.0	48.9	47.6	43.8	45.2
		Fermented	66.9	66.9	68.9	66.8	67.5	66.9
	Trypsin inhibitor activity	Soaked	10.2	18.2	13.0	19.4	19.8	17.0
		Fermented	47.08	39.1	38.0	42.8	41.6	41.0
	Oligosaccharides	Soaked	48.7	35.9	36.7	36.3	35.9	36.5
		Fermented	70.6	71.2	71.6	71.0	71.6	71.6
6.	Impact of germination on phenolic profiles of small millets (Pradeep & Sreerama, 2015).							
	Total phenols (% increase)	**Barnyard**	**Foxtail**	**Proso**	**Total flavonoids**	**Barnyard**	**Foxtail**	**Proso**
		208	134	220		22.4	80.0	78.9

Notes: All values are computed as percent decrease or increase from original papers. C.: Canadian, E.: Egyptian.

The effect of pre-milling treatments on phytochemicals/antinutrients of some legumes and cereals as reported in different studies are compiled in Table 3. The overall observations can be summarized as follows: soaking reduces the phytic acid, tannins, total phenols, and trypsin inhibitor activity of many legumes, cereals, and millets (Abd El-Hady & Habiba, 2003; Lestienne et al., 2005; Xu & Chang, 2008). Fermentation also showed a decrease in phytic acid, trypsin inhibitor activity and oligosaccharides in legumes (Khattab & Arntfield, 2009). Germination of millets increases total phenolic contents (Pradeep & Sreerama, 2015). Soaking followed by dehydration by freeze drying or heat drying increased total phenolics and decreased phytic acid in navy and pinto beans (Anton, Ross, Beta, Gary Fulcher, & Arntfield, 2008).

7. Conclusion

Cereals and legumes undergo different types of primary processing to enable their further use for product manufacture or cooking. Some of the primary processed products are also in ready-to-eat form such as expanded rice products. Generally processing alters the grain quality. As long as the whole grain is used, all nutrients and phytochemicals are retained, however, abstraction of any part of the grain results in reduced nutrients. The distribution of nutrients and phytochemicals in any grain is not uniform with the outer portion containing more nutrients and fiber contents. Milling has mutual effects on nutritional quality. It results in breakage of cell wall and improves availability of nutrients which are bound in nutrient matrix. On the other side, during milling outer layer of grains which are very rich source of nutrient except starch are separated. Separation of bran/husk decreases nutrients but improves digestibility and/or bioaccessibility. Separation of bran portion by mechanical means such as sieving of flour can also reduce the nutrient content of sieved flour. Processes like soaking and germination reduce the antinutrient content and also increase the availability of nutrients, in particular of minerals. Finally, it can be said that nutritional quality of grains is influenced by pre-processing treatments and processes which retain all parts of whole grains as beneficial for health and consumption of highly refined products should be discouraged.

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