NUTRITIONAL AND BIOACTIVE COMPOSITION OF GERMINATED CEREALS AND LEGUMES: A REVIEW

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Abstract
Cereals and legumes are rich source of nutrients and bioactive compounds. However, they also contain several antinutrients such as phytates, lectins, trypsin inhibitors etc which binds with minerals and other nutrients thus reducing their bioavailability. Germination is an inexpensive technique to not only reduce these antinutrients but also improve the nutritional and phytochemical profile of cereals and legumes. Germination process involves activation of endogenous enzymes such as phytases, proteases and amylases and is also associated with biosynthesis of vitamins, polyphenols etc. This review summarizes the literature on how germination impacts the nutrients, vitamins, minerals and antinutrients in cereal and legumes. Further, the impact of germination on polyphenolic compounds and antioxidant activity has also been discussed.

Keywords: *germination, antioxidant activity, total phenolic content, nutritional composition, antinutrients.*

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1. INTRODUCTION

Cereals and pulses are one of the major sources of macronutrients in human diet. Cereals are mainly rich in carbohydrates, dietary fibers while legumes are rich source of proteins, fats and dietary fibers. Apart from these nutrients these grains also contain several vitamins, pigments, polyphenolic compounds and other bioactive compounds which offers several health benefits such as antidiabetic, anticancer antioxidant etc (Verspreet et al., 2015). However, they also contain antinutritional factors such as phytates, trypsin inhibitors, lectins, tannins etc which interferes with the absorption and bio-accessibilities of nutrients such as proteins, carbohydrates and minerals. (Khandelwal et al., 2010). Various processing methods such as roasting, dehulling, milling, germination, cooking etc to reduces these antinutritional factors as well as improve the nutritional values of these grains before consumption (Aguilera et al., 2013).
Germination process begins with steeping grains in water followed to exposure of drained grains to humid environment and it completes with the elongation of embryonic axis. Germination breaks seeds dormancy and is associated with bioaccumulation of phenolics and other bioactives(López-Martínez et al., 2017). The process of germination is associated with activation of several endogenous enzymes such as amylase, phytase and proteases which brings about changes in nutritional, physiochemical and sensory properties of grains (Zhang et al., 2015; Cornejo et al., 2015).The present paper reviews the literature on the impact of germination on nutrients, vitamins, minerals and antinutrients in cereal and legumes. Further, changes in polyphenolic compounds and antioxidant activity upon germination has also been discussed.

2. CARBOHYDRATES

The impact of germination process on carbohydrates of cereals and legumes is presented in Table 1. Germination results in activation of endogenous hydrolytic andamylolytic enzymes which acts on carbohydrates and convert them into simple sugars (Oghbaei & Prakash, 2016) thereby improving their digestibility.

Table 1. Effect of germination on nutritional composition of cereals and legumes

Cereal/Legume	Germination condition	Findings	Reference
White sorghum, red sorghum, pearl millet	S: 24 hr at 25°C G: 72 hr at 25°C	polyphenols, tannin, and phytates ↓ in protein digestibility ↑	Onyango et al. (2013)
Foxtail millet, wheat, and chickpea	S: lime solution (0.05%) for 12–48 hr at 20°C, G: 3–5 days	↑ in protein content	Laxmi et al. (2015)
White sorghum	S: 8–48 hr G: 24–96 hr)	↓ in protein content ↓ in carbohydrates ↑ in sodium, potassium, phosphorous, calcium, magnesium	Ogbonna et al. (2012)
Rice	24 hr, 28–30°C)	↑ crude proteins, niacin, free amino acids, and α-tocopherol Ash, crude fat, and carbohydrate were unchanged	Moongngarm & Saetung (2010)
Green gram, cowpea, lentil, chickpea	S: 12 hr at 22–25°C G: 24 hr at 22–25°C,	↑ in protein ↓ in antinutrients: oxalate, tannin, trypsin inhibitor, and phytates ↓ in iron, calcium, and phosphorous ↑ starch and protein digestibility	Ghavidel and Prakash (2007)
Red kidney beans	S: hr at room temperature G: 4 days at 22°C)	↓ in cyanide, tannins, polyphenols, and phytic acid	Yasmin et al. (2008)
Kidney, mung beans, soybean, and peanuts	S: 6 hr G: emergence of radical at maximum 5 mm	↑ in total sugars ↑ in total dietary fibers	Megat et al. (2016)
Lentils and faba beans	6 days, 20 °C	↓ thiamine amounts	Wang et al. (2014)

Where: S, soaking conditions; G: germination conditions

Ghavidel and Prakash (2007) reported 53 to 62% increase in invitro starch digestibility in legumes such as chickpea, lentil and cowpea upon germination. Nirmala et al. (2000) reported significant decrease in total carbohydrate (81%) and starch (58%) for finger millet germinated for 96 h (total carbohydrate, 58%; starch, 43%). Significant improvement (14-26%) in total sugars content was documented in various beans such as mung bean, kidney bean, soybean and peanuts by Megat et al. (2016).Germination has been found to be a suitable method for preparation of infant or complementary foods owing to the improved digestibility of germinated cereals or leagumes (Desai et al., 2010). Various factors influence the efficacy of germination process with germination time being a cruicle one. Several studies have reported germination duration of 48 to 72 hr results in maximum starch hydrolysis owing to the peak amylase activity (Tian et al., 2010;Guzmán-Ortizm et al., 2019). Zhang et al. (2015) studied the impact of germination time on the reducing sugar content of various cereals and legumes.They reported that no significant difference was observed in the reducing sugar content of sample upto 12 h of germination but 20 fold increase in the sugar content was observed when germinated for longer period of time. This increase in reducing sugar content was ascribed to the enhanced α-amylase activity.

The impact of germination on fiber content of various cereals and legumes have been studied by various researchers. Germination process improves the fiber content of lupin by 456% and peas by 100% (Rumiyati et al., 2012). The increase in fiber content may be dueto the increase in cellular structure forming components such as cellulose, hemicellulose and lignin upon germination (Benítez et al., 2013). Further, the increase dietary fiber content forms gels and decreases release of glucose from foods which is good for patients of diabetes (Yu et al., 2014).

3. PROTEINS

The impact of germination on protein content of cereals or legumes have contradicting results (Table 1). In some studies protein content was reported to increase post germination which was ascribed to the loss of dry weight as well as synthesis of amino acids during germination process (Nimbalkar et al., 2020;Jan et al., 2017). On the other hand, Bhathal and Kaur (2015) documented decrease in total protein content which simultaneous increase in amino acids such as methionine, lysine, and tryptophan in germinated quinoa. This decrease in protein content can be ascribed to the protein degradation by proteases (Sibian et al., 2017).Zhang et al. (2015) reported significant increase in protein content of buckwheat germinated for 72 h. Further, significant increase (14 to 18%) in invitro protein digestibility of various legumes such as green gram, chickpea, lentil and cowpea were reported by Ghavidel and Prakash (2007). Similar trend was observed in finger millet whereby a 64% increase in protein digestibility was observed in germinated samples. The enhanced protein digestibility was ascribed to the hydrolysis and partial solubilization of proteins which was confirmed by significant increase in free amino acid content and water soluble proteins during germination process (Hejazi et al., 2016). However, Ogbonna et al. (2012) documented decline in protein content of white sorghum upon germination which may be due to variation in steeping and germination conditions.

4. FATS

Significant variations in results have been observed for germination effect on fat content (Table 1). Several studies documented decrease in fat content in beans or cereals upon germination (Chauhan et al., 2013;Jan et al., 2017) which was ascribed to the breakdown of fats which are used as energy source for seed growth during germination (Chinma et al.,2015). On the other hand, increase in crude lipids as well as fatty acids such as linoleic acid, oleic acid content of rice upon germination was recorded by Kim et al. (2012). This variation in trend may be due to differences in the germination conditions and variety of rice under study.

5. VITAMINS

The impact of germination on vitamin content of various cereals and legumes was studied by Kim et al. (2012). They reported significant increase in vitamin E, vitamin B2 and vitamin B3 content. This increase in vitamins was ascribed to synthesis of vitamins during germination. However, significant decrease in vitamin B1 content was observed in germinated rice which may be due to leaching out of water-soluble vitamins (Moongngarm & Saetung, 2010). In another study by Prodanov et al. (1997) increase in Vitamin B2 and niacin content while decrease in thiamine was observed in lentil and faba beans samples germinated for a period of 6 days at 20°C. Several researchers reported significant increase in vitamin C content of cereals (ragi, wheat) and legumes (mung bean, chickpea) upon germination (Guo et al., 2012; Desai et al., 2010). This increase in vitamin C content may be due to increased hydrolysis of starch into glucose which is a precursor for vitamin C synthesis.

6. MINERALS AND ANTINUTRIENTS

Cereals and legumes apart from their rich nutritional profile also contains several antinutrients such as phytic acid, trypsin inhibitors lectins, tannin which binds with minerals and interferes with digestion and absorption of nutrients as well as minerals (Yasmin et al. 2008). Traditional processing methods such as soaking, germination, fermentation, roasting have been found to be effective in reducing or eliminating these antinutrients. Zhang et al. (2015) reported significant decrease in phytic acid with the rise in germination duration. This reduction was due to the activation of phytase enzyme upon germination which breakdown phytic acid into phosphoric acid and myoinositol thrby increasing mineral bioavailability (Liang et al., 2008). Further, the mineral bioavailability depends upon the grain type with highest iron availability in wheat, manganese in case of rice while calcium for soybean and faba beans (Luo et al., 2014). The variation in mineral bioavailability among different cereals or legumes can be ascribed to the variation in phytate content, phytase enzyme activity as well as the binding of minerals within the food matrix. Ogbonna et al. (2012) documented increase in iron content of all the studied samples viz wheat, chickpea and foxtail millet upon germination. The release of iron was higher in foxtail millet and chickpea as compared to wheat which can be correlated to their higher phytate content as compared to wheat as well as the leaching of these antinutrients during germination (Idris et al., 2007; Luo et al., 2014).

7. POLYPHENOLIC COMPOUNDS

Polyphenols are plant secondary metabolites widely distributed in fruits, vegetables, flowers, nuts, seeds and barks. They are structurally characterised by atleast one phenol unit and exists in free and bound form. They are synthesized in intracellular endoplasmic reticulum and in some cases are found conjugated with cell wall marcomolecules (cellulose, proteins). Several recent studies have shown that germination can result in change in polyphenolic composition of germinated cereals and legumes (Agati et al., 2012). The impact of germination on total phenolic content of various cereals and legumes is summarized in Table 2.

Table 2. Effect of germination on total phenolic content of cereals and legumes

Cereal/Legume	Germination duration	Unit	Ungerminated	Germinated	Reference
Wheat (Triticum aestivum)	2 day	mg FE/g DW	1230	1763	Hung et al. (2011)
Wheat (Triticumaestivum)	5 day	mg GAE/kg DW	1431	1627	Zilic et al.(2014)
Brown rice(Oryza sativa)	17-48 h	mg GAE/100 g	100	159-188	Ti et al.(2014)
Black soybean (Glycine max (L.) Merr)	1-4 day	mg GAE/100 g	~70	~60 -100	Wu et al. (2012)
Lentil (Lensculinaris)	3-8 day	mg GAE/100 g	~450	~130 - 250	Aguilera et al.(2014)
Kidney bean (Phaseolus vulgaris L)	3-8 day	mg GAE/100 g	~370	~110 - 420	Aguilera et al.(2014)
Soybean (Glycine max L.)	2-10 day	mg GAE/100 g	~220	~120 - 150	Shohag et al.(2012)
Jack bean (Canavalia ensiformis L.)	4 day	mg GAE/g DW	2.3	3.6	Aguilera et al. (2013)
Sword bean (Canavalia gladiate)	1-4 day	mg GAE/100 g	~40	~30 - 58	Wu et al. (2012)
Mung bean (Vigna radiata)	2-10 day	mg GAE/100 g	~150	~75 - 120	Shohag et al.(2012)
Cowpea (Vigna unguiculata)	1-4 day	mg GAE/100 g	~58	~45-70	Wu et al. (2012)

Gan et al. (2016) reported 5 to 5.5 times increase in phenolic content of mung bean subjected to germination for 5 days which was ascribed to the biosynthesis and transformation of polyphenolic compounds during germination process (Wu et al., 2011; Tang et al., 2014). However, somestudies have reported contradictory results whereby the total phenolic content decreased post germination. This decrease in phenolic content might be due to the expression of results on dry or wet weight basis. Further, previous studies documented that bound phenolic initially decrease and then increase upon germination (Hung et al., 2012; Aguilera et al., 2014). The explanation for observed trend was release of phenolics from cell wall material during initial stage of germination which involves hydrolysis of carbohydrates and proteins and release of simple compounds such as sugars and amino acids (Liu et al., 2011). During later stages of germination new cell wall molecules are formed which conjugate the phenolics.

8. ANTIOXIDANT ACTIVITY

Several researchers have investigated the effect of germination on the antioxidant activity of cereals and legumes (Table 3). Several methods are usually employed to evaluate the antioxidative potential and the results indicated that germination significantly improves the antioxidant capacity of germinated cereals and legumes as compared to their ungerminated counterpart. This rise in antioxidant potential may be due to the increased amount of antioxidant components such as vitamins and other polyphenolic compounds upon germination. On the other hand, there are studies which documented a decline in antioxidant capacity of cereals and legumes post germination (Guajardo-Flores et al., 2013). This decrease may be due to the difference in expression of results or dry or fresh weight basis. Ti et al. (2014) reported significant increase in antioxidant activity as compared to raw seeds. Similar trend was also reported for wheat germinated for 5 days (Zilic et al., 2014).

9. CONCLUSION AND FUTURE SCOPE

Germination has been found to be an effective strategy to improve the nutritional and bioactive composition of cereals and legumes. Germination improves the nutritional profile of cereal and legumes due to activation of endogenous enzymes which breakdown macromolecules into simpler forms as well as antinutrients. This enhances the digestibility and bioavailability of macro and micronutrients. Germination results in bioaccumulation of polyphenolic compounds and vitamins thereby improving the antioxidative potential of the grains. Germinated grains with improved nutritional profile can be used to improve human health and prevent malnutrition. Further studies can be taken up regarding utilization of germinated flour for development of functional foods and nutraceuticals. More research needs to be carried out towards bioactive compounds of germinated cereals and legumes in treatment of chronic diseases.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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Table 3. Effect of germination on antioxidant activity of cereals and legumes

Cereal/ Legume	Germination duration	Antioxidant Activity Assay	Unit	Ungerminated	Germinated	References
Brown rice (Oryza sativa)	17-48 h	FRAP	mg TE/100 g DW	108	112-139	Ti et al.(2014)
		ORAC	mmol TE/g DW	29.4	32.1-48.5	Ti et al. (2014)
Wheat (Triticum aestivum L.)	5 day	ABTS	mmol TE/kg DW	22.5	23.5	Zilic et al. (2014)
		DPPH	mg TE/100 g DW	44.1	73.7	Alvarez-Jubete et al.(2010)
Jack bean (Canavalia ensiformis L.)	4 day	DPPH	mmol TE/g DW	~1.50	~1.70	Aguilera et al.(2013)
		FRAP	mmol TE/g DW	~2.00	~3.00	Aguilera et al. (2013)
Soy bean (Glycine max)	2-4 day	ABTS	mmol TE/g DW	37.3	40.2-41.9	Fernandez-Orozco et al. (2008)
Soybean sprout (Glycine max)	2-10 day	FRAP	mmol Fe(II)/ 100 g FW	~0.50-0.79	~1.16	Shohag et al.(2012)
kidney bean (Phaseolus vulgaris L.)	1-4 day	ORAC	mmol TE/100 g FW	~900	~900-1700	Wu et al.(2012)
Mung bean (Vigna radiata L.)	5 day	ABTS	mg TE/g DW	0.86	11.3	Pajak et al. (2014)
		FRAP	mmol Fe(II)/ 100 g DW	0.13	1.20	Pajak et al. (2014)
Cowpea (Vigna unguiculata L.)	4 day	DPPH	mmol TE/g DW	~4.90	~8.30	Aguilera et al. (2013)
		FRAP	mmol TE/g DW	~9.00	~17.0	Aguilera et al.(2013)
		ORAC	mmol TE/100 g FW	~1100	~950-2300	Wu et al. (2012)
Sword bean (Canavalia gladiate)	1-4 day	ORAC	mmol TE/100 g FW	~600	~800-1600	Wu et al. (2012)
Lentil (Lens culinaris L.)	3-8 day	ORAC	mmol TE/g DW	~20.0	~20.0-53.0	Aguilera et al. (2014)

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