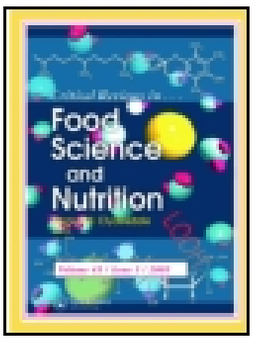

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# BIOACTIVE COMPONENTS AND FUNCTIONAL PROPERTIES OF BIOLOGICALLY ACTIVATED CEREAL GRAINS: A BIBLIOGRAPHIC REVIEW

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**Abstract:**

Whole grains provide energy, nutrients, fibres and bioactive compounds that may synergistically contribute to their protective effects. A wide range of these compounds is affected by germination. While some compounds, such as β-glucans are degraded, others, like antioxidants and total phenolics are increased by means of biological activation of grains. The water and oil absorption capacity as well as emulsion and foaming capacity of biologically activated grains are also improved. Application of biological activation of grains is of emerging interest, which may significantly enhance the nutritional, functional and bioactive content of grains, as well as improve palatability of grain foods in a natural way. Therefore, biological activation of cereals can be a way to produce food grains enriched with health promoting compounds and enhanced functional attributes.

**Keywords**

Biological activation, cereals, bioactive compounds, functional properties

 

## INTRODUCTION

Whole grains are rich sources of fibre, vitamins, minerals and significant amounts of bioactive phytochemicals (phenolics, carotenoids, vitamin E, lignans, β-glucan, inulin, resistant starch, sterols, and phytates), some are considered to be direct free radical scavengers, while others act as cofactors of antioxidant enzymes or indirect antioxidants, which provide desirable health benefits beyond basic nutrition to reduce the risk of chronic diseases due to their additive and synergistic effects **(**Lloyd et al., 2000; Liu et al., 2000; Topping, 2007). Whole grains are made up of the endosperm, the germ and bran of the grain and contains all the essential parts and naturally occurring nutrients of the entire grain seed in their original proportions. The endosperm makes up about 80% of the whole grain, while the germ and bran components vary among different grains. Whole grains are cholesterol free and low in fat, high in dietry fibres and vitamins (especially B vitamins), antioxidant compounds and are good source of minerals (trace elements) (Liu, 2004; Donkor et al., 2012; Rakcejeva et al., 2014; Slavin et al., 2001). Therefore lower energy density due to their fiber content and as a source of bioactive components cereals were repoted to increase satiety, reduce energy intake, enhance the satiating capacity of meals and are inversely associated with body mass index (BMI) and weight gain in diverse populations (Slavin, 2003; Schroeder et al., 2009; Isaksson et al., 2012).

Biological activation of grain or germination is a natural, biological processing techniques and traditional method that can be used to improve the nutritional, functional and sensory properties of cereals grains along with increased the micronutrients (Hefni and Witthoft, 2011). For the increasing of grains nutritive value, germination for several days or biological activation is necessary (Rakcejeva et al., 2014). The minimal environmental conditions needed for grain

activation are optimum humidity, availability of oxygen for aerobic respiration, an adequate temperature and time for the different metabolic processes (Sangronis and Machado 2007).

The biological activation of grains realizes a significant growth of nutritional value by increasing the bioavailability of nutritional compounds, vitamins, bio-elements and other biologically active substances due to the partial hydrolysis of starch, proteins, hemicelluloses and even celluloses. Biological activation triggers the enzymatic activity in grain and dormant hydrolytic enzymes are activated, breaking down starch, fibers and proteins and leading to an increase in the amount of digestible compounds along with improvement of functional properties without any chemical modification. Also, the activity of some anti-nutritional factors (enzyme inhibitors, haema-glutinins, anti-vitamins etc.) decreases or disappears during activation, allowing a complete valorization of biological compounds in grains (Sangronis and Machado, 2007; Donkor et al., 2012; Elkhalifa and Bernhardt, 2010; Tian et al., 2010; Iordan et al., 2013).

The nutritional value of numerous seeds were also improved, through an increase in essential amino acids, protein digestibility, amino acid and vitamins bioavailability and a decrease in some antinutrients, such as phytic acid has also been observed. Flours from germinated cereals have been reported to have better nutritional properties than those of flours from non-germinated cereals **(**Charoenthaikij et al., 2009; Moongngarm and Saetung, 2010; Chanlat et al., 2011; Moongngarm, 2011; Chung et al., 2012**)**. During biological activation endohydrolase enzymes (α and β-amylases), proteolytic enzymes, diphenoloxsydase and catalayse are activated in cereal grains, which enhances the starch degradation, a complex biochemical process and thus lead to the conversion of insoluble granules to soluble starch and dextrin (Prakash et al., 2007; Rakcejeva et al., 2007; Saman et al., 2008**)**.

Biological activation can be used as an alternative to genetic engineering in improving the nutritive values (such as amino acids, vitamins, minerals etc.), functional (temperature and enthalpy, gelatinization, pasting characteristics, swelling, and solubility) and chemical (pH, amylose, total starch etc.) properties of grains (Adedeji et al., 2014). Consequently, food materials prepared from biologically activated grains often have modified functional properties. Modifications in protein structure of cereals during germination process have been reported to be largely responsible for functional changes such as foaming, emulsification, nitrogen solubility and water absorption capacity. The swelling power and amylograph viscosity decreased during germination and no changes or only minor ones in amylose content were observed during activation of grains (Noda et al., 2004; Chinma et al., 2009). Numerous studies have been carried out in the past on the influence of germination or biological activation of grains on the antioxidant properties, bio-functional compounds and functional properties of germinated cereal grains. The aim of this paper is to review the existing literature on the effect of germination on cereal grains and to present an overview of changes in quality attributes of cereal grains as affected by processing techniques and conditions.

## EFFECT OF GERMINATION ON BIOACTIVE COMPONENTS OF CEREAL GRAINS

The metabolic activity of dry seed increases as soon as it is hydrated during soaking. Complex biochemical changes occur during germination in various parts of the seed. Because no external nutrients are added during the germination process, only water and oxygen are consumed by the germinating seed, desirable nutritional changes mainly stem from the decomposition of complex compounds into more simple forms, and their transformation into essential constituents as well as the breakdown of nutritionally undesirable constituents (Chavan and Kadam, 1989). Apart

from positive shifting in the level of nutrition, biochemical activities which occur during activation also generate bioactive components of health-promoting activities through the enzymatic actions that are antioxidants in nature, such as ascorbic acid and phenolic compounds, thus resulting in an increase of antioxidant activity. Other compounds generated during grain activation are γ-aminobutyric acid (GABA), inositols, ferulic acid, tocotrienols, γ-oryzanol, minerals, phenolic compounds, sterols, arbinoxylans and prolylendopeptidase inhibitor. Flours from germinated cereals have been reported to have better nutritional properties than those of flours from non-germinated cereals **(**Charoenthaikij et al., 2009; Moongngarm and Saetung, 2010; Chanlat et al., 2011; Chung et al., 2012**)**. In several instances contradictory results were reported and differences are primarily attributed to variation in soaking practices, biological activation times, temperatures and methods of drying the activated grains.

***ANTIOXIDANT ACTIVITY***

Antioxidants protect the cells against oxidative stress caused by oxygen radicals. A whole range of compounds with antioxidant properties have been found in cereals, including vitamins, sterols, and phenolic compounds as well as phytic acid (Peterson, 2001; Fardet et al., 2008). Most of the named compounds were enriched either in the bran or the germ **(**Slavin et al., 2001). They all might contributed to a degree to the antioxidant properties and were affected in different ways by germination. Indirect antioxidant effects were also attributed to some minerals and trace elements, which can act as co-factors to certain enzymes. However, while many effects of antioxidants have been proven in vitro, the exact impact of the relevant compounds in vivo are not completely clear yet **(**Fardet et al., 2008**)**. Some of the compounds might act as synergists or antagonists or, while having antioxidant properties in vitro, might not show these in vivo. The

mixture of powerful antioxidant compounds found in several grain tissues may be a potent protection for human against the pathologies linked to oxidative stress **(**Donker et al., 2012**)**. Therefore, it is important to stress the significance of natural sources that not only supply a series of natural antioxidant compounds, but supply them in natural ratios between themselves **(**Calzuola et al., 2006**)**. The nutritional and physiological relevance of grain sprouts in terms of bioactive compounds are of importance in strengthening antioxidant defence.

Prominent increase in the antioxidant activities of several germinated grains with longer germination time, which are time and temperature dependent, were reported by many researchers (Table 1). Several authors reported that antioxidant activities increased in rough rice **(**Umnajkitikorn et al., 2013**)** and brown rice (Bolivar et al., 2010; Gujral et al., 2012; Cácereset al., 2014; Ti et al., 2014; Tian et al., 2004) as duration of their germination progressed. This effect could be attributed to higher accumulation of compounds with peroxyl-scavenging activity, such as phenolic compounds **(**Andriantsitohaina et al., 2012). Some reports have demonstrated that germinated brown rice display higher antioxidant capacity as hydrolytic enzymes may release free phenolics with more effective antioxidant activities **(**Tian et al., 2004**)**. Moreover, it has also been reported that germination under high temperature induced several radical scavenging enzymes such as superoxide dismutases, glutathione S-transferase, catalase, peroxidases, and enzymes in the ascorbate--glutathione cycle which keep a balance of redox homeostasis **(**Gupta et al., 2013). Cáceres et al. (2014**)** observed that among all of the sprouted brown rice, 96 h germinated brown rice produced at 34 $^{o}$C showed the highest antioxidant activity then those produced at 28 $^{o}$C (Table 1). With regards to antioxidant activity, it is worth noting that germination brought about an enhancement of the antioxidant potential of brown rice.

A recent study demonstrated that GBR supplementation increases antioxidant enzyme activity and reduces lipid peroxidation in hypercholesterolemic rabbits (Esa et al., 2013**)**.

Salinity in soaking water was reported to promote some antioxidant compounds and antioxidant capacity in rice. Umnajkitikorn et al. (2013) stated that the antioxidant capacities of rice seeds germinated on agar supplemented with NaCl increased continuously with germination time, and reached maximum at day 5, in which the antioxidant capacities were 1.79 times higher than those of native rice. Increase of 19% and 28.2% as well as 65% and 163% in free and bound antioxidant activities of germinated brown rice were reported by Ti et al. (2014) using the ferric reducing antioxidant power (FRAP) assay and oxygen radical absorbance capacity (ORAC) assay, respectively. The FRAP assay is based on electron transfer and the ORAC assay is based on hydrogen atom transfer. They also concluded that the ORAC assay is chemically more relevant to chain-breaking antioxidant activity, while the FRAP assay is a test to determine the total antioxidant power using antioxidants as reductants in a redox-linked colorimetric method.

Similar results for increase in antiradical power in barley were reported by Maillard et al. (1996); Dvorakova et al. (2008) and Sharma and Gujral (2010) which could possibly be due to the development of Maillard products during malt kilning and due to the synthesis of compounds like vitamin C and tocopherols which are responsible for antioxidant activity (Dicko et al., 2005). Sharma and Gujral (2010) also reported that when the duration of germination was increased from to 12 h to24 h, the antioxidant activity increased in different fractions of eight cultivars of germinated barley. In contrast to the total phenolic content the antioxidant activity continuously increased in whole flour, bran and refined flour of all the cultivars as duration of their germination progressed. During germination the hydrolytic enzymes modify the endosperm

and may liberate some of the bound components which play a role in antioxidant activity (Doblado et al., 2007). Bran is a rich source of free and bound phenolic compounds therefore the bound phenolic compounds are released during germination and increase the antioxidant activity. Comparable results for increases in antioxidant activities were also reported in wheat by Yang et al. (2001); Hung et al. (2011) and in tartary and common buckwheat sprouts by Ren and Sun (2014) with increasing germination time (Table 1). They observed that the antioxidant compounds such as vitamin C and tocopherols also increased with the length of germination, which might also increase the antioxidant activity of the sprouted wheat flours. Thus, the sprouted wheat was shown to have more desirable nutritional values than the un-germinated wheat and could be used to blend with commercial wheat flour to increase both nutritional value and texture of bread (Morad and Rubenthaler, 1983; Ranhotra et al., 1977).

However, Karki and Kharel (2012) reported decrease in antioxidant activity of four finger millet varieties and Ramadan et al. (2012) observed decrease in antioxidant activities of wheat, corn and sorghum with increment in the germination time (Table 1). The antioxidant activity of native millet was exponentially related to its total phenolic content however, this relationship was not apparent in malted millet. These decreases may be attributed to increase the activity of polyphenol oxidase and other catabolic enzymes as observed by for wheat.

***TOTAL PHENOLIC COMPOUNDS AND PHENOLIC ACIDS***

Phenolic compounds are often cited as the most important contributors to the antioxidant capacity of cereal grains (Zielinski and Koslowska, 2008; Dykes and Rooney, 2007). Phenolic acids are present in cereals either free or bound to cell wall components. Free acids are mainly located in the pericarp and can be extracted with organic solvents (Mattila et al., 2005). During

the germination process, enzyme synthesis and kernel modification take place, which results in the enhancement of intrinsic phenolic compounds and antioxidant activity (Kaukovirta-Norja et al., 2004). Polyphenols found in wheat sprouts may be of benefit associated with a particular group of population as they appear to improve glucose metabolism (Hanhineva et al., 2010) and counteract inflammation and oxidative stress associated with obesity (Detopoulou et al., 2010).

Table. 1, illustrates the total phenolic content profile of different cereal grains in relation to germination time and temperature. Researchers found that the content of many phenolic acids decreased in the early stages of the malting process, i.e., steeping and the earliest period of germination (Lu et al., 2007). Germination brought about a noticeable increase in total phenolic content (TPC). Studies reported that TPC increased in brown rice (Bishnoi et al., 1994; Moongngarm and Saetung, 2010; Donkor et al., 2012; Gujral et al., 2012; Cáceres et al., 2014; Ti et al., 2014) and rough rice (Moongngarm and Saetung, 2010) upon germination and optimum germination conditions gave rise to greater TPC content. The change of TPC was also dependent on the type of phenolic compounds, which dominated in the different rice cultivars. In addition, the different germination time or the procedural differences may also lead to the significant differences in phenolic content, such as the temperatures and soaking times used regardless of cultivars (Moongngarm and Saetung, 2010; He et al., 2011; Cáceres et al., 2014).

During germination of rice induced saccharolytic enzymes breakdown endosperm while carbohydrase enzymes hydrolysed the starch to release the bound phenolic compounds which results in increasing the TPC (Tian et al., 2004; Gujral et al., 2012). The total phenolic content also increased could be due to increases in the activity of enzymes responsible for the oxidation of endogenous phenolic compounds and phenolic-containing biomolecules, such polyphenol

oxidases and peroxidases (Cáceres et al., 2014).The increase in phenolic compounds in germinated brown rice could also be due to the increase in the free phenolics forms due to dismantling of the cell wall during germination (Shibuya, 1984; Gujral et al., 2012). The germination induces enzyme expression/activation of the phenylpropanoid pathway and hydrolysis of cell wall polysaccharides that cause the release of cell wall-bound phenolics which results in increased phenolic compounds in brown rice (He et al., 2011). This is supported by Tian et al. (2004) that showed an increase in free phenolic acids (ferulic, p-coumaric and sinapic acids) and hydrolysable phenolic compounds, as well as decreases in the hydroxycinnamate sucrose esters in GBR.

Most of the brown rice phenolics were distributed in free forms. Ti et al. (2014) observed 77% and 45% increase in free and bound phenolics respectively, after 48 h of brown rice germination. The increase in free and bound phenolic contents by germination may be partly explained by the production of enzymes to break down cell walls surrounding compounds during germination (Kaukovirta-Norja et al., 2004). In contrast, the results from the study of Hung et al. (2011) suggest that the free phenolic acids in wheat increased during germination, whereas the bound phenolic acids decreased. During the 24 h soaking period before germination in a previous study by Bishnoi et al. (1994) increases of total phenolic compounds were observed in brown rice, whereas inversely, all identified compounds underwent a drastic decrease in beans, peas, and lentils. The rise of the free phenolic content coincided with a decline in the bound phenolic content, which indicate that the increased free phenolics come from the liberation of the bound phenolics as some enzymes were synthesised to degrade storage macromolecules that can

liberate bound phenolics and by the synthesis of phenolics in response to the germination treatment (Ti et al., 2014).

The increase of the bound phenolics may be explained by the polymerisation and oxidation of phenolics and by certain changes in enzymes involved in the synthesis and degradation of free or bound phenolics. The bound phenolics cannot be directly digested by human enzymes, thus the bound phenolics may be absorbed slowly and continuously released into the lower gastrointestinal tract by the simultaneous action of β-glucosidases and esterases of the microflora in the colon (Vitaglione et al., 2008). Studies reported that phenolics from the cell wall had antimutagenic properties and that this physiological activity could have significance in the preventative activity of the diet against cancer. Therefore, the increase of bound phenolics during germination may exert beneficial health effects throughout the digestive tract after absorption and may reduce mutations (Ti et al., 2014).

The predominant phenolic acids in brown rice were *p*-coumaric, ferulic acids and caffeic acid however; the phenolic composition of brown rice may vary among genotypes (Zohu et al., 2004; Huang and Ng 2012). Most of the ferulic and coumaric acids were present in bound forms, whereas less, or trace amounts, of other compounds were detected in bound forms, which was reported by Zohu et al. (2004). Authors also observed that upon germination, phenolic compounds like protocatechuic acid, caffeic acid, syringic acid, ferulic acid and coumaric acid were reported to increase by 72.4%, 2231.7%, 453%, 245% and 190.1%, while no changes were observed in chlorogenic acid after 48 hrs of brown rice germination (Zohu et al., 2004; Tian et al., 2004). They also reported that during germination, free phenolic acid content increased significantly; the ferulic acid content of brown rice also increased and became the most abundant

phenolic compound in germinated brown rice. In germinated wheat, Yang et al. (2001) observed a slight decrease or constant contents of ferulic and vanillic acid in the early stages of germination which was followed by a significant increase in later stages. During the germination process, the ferulic acid was accumulated due to the phenolic biosynthesis and hydrolysis of polyphenolic compounds bound to cell walls.

The changes observed in the germination process could be partly explained by the action of the endogenous esterases or all these simple phenylpropanoids are produced from cinnamate, which is synthesised from phenylalanine by the action of phenylalanine ammonia-lyase via a series of hydroxylation, methylation and dehydration reactions (Dixon and Paiva, 1995). Some authors reported that the increased activity of phenylalanine ammonia-lyase during germination could catalyse the synthesis of phenolics, which partly explain the increase of free phenolic forms during the germination process (Walton. 1968). However, Tian et al. (2004) found that 6-O-feruloylsucrose and 6-O-sinapoylsucrose, the major soluble phenolic compounds in brown rice significantly decreased during germination, while the levels of free ferulic and sinapinic acids increased because of the conversion (polymerisation) from free phenolics. However, authors also reported that, the protocatechuic acid first decreased and then increased and chlorogenic acid initially disappeared and then increased to the same level after germination when compared with their raw brown rice grains. The disappearance of chlorogenic acid may be attributed to the production of complex phenolic acids.

Sorghum is especially rich in phenolic compounds and the effect of malting on the phenolic compounds depends on the variety used. Some varieties showed increased contents (Dicko et al., 2005) of phenolic compounds after germination, while others lost phenolic compounds in the

same time (Ramadan et al., 2012). However, in most varieties the content of condensed tannins decreased which is a possible explanation for a loss of these compounds. Hung et al. (2011) showed that the TPC extracted with alkaline decreased during the steeping process of grain but increased later on during germination. Yang et al. (2001) also showed increased phenolic content during and after germination of wheat while Ramadan et al. (2012) reported decrease total phenolic content of wheat and corn, which was due to increase the activity of polyphenol oxidase and other catabolic enzymes. However, Sharma and Gujral (2010) observed that the total phenolic content decreased in all the eight cultivars of barley upon germination for 12 h after soaking for 24 hrs whereas, when the duration of germination increased to 24 h the total phenolic content increased for all the cultivars of barley. The decrease in total phenolic content after germination for 12 h may be attributed to the phenolic compounds being metabolized to other compounds, their leaching into the steeping water or due to the formation of insoluble complexes with proteins that hinder their extraction (Beta et al., 1999; Dicko et al., 2005). The increase in TPC upon germination for 24 h could be attributed to the bound phenolic compounds becoming free by the action of enhanced hydrolytic enzyme activity (Maillard et al., 1996).

Increase in phenolic compound contents in the oat seeds after germination was observed by Tian et al. (2010). The increase could be attributed to the better extractability of phenolic compounds from the kernel structures after germination. Avenanthramides are a group of phenolic compounds with high bioactivities such as anti-inflammatory, antiatherogenic and antioxidants, which exist exclusively in oat seeds (Dimberg et al., 1993). The processes of steeping and germination resulted in increased levels of avenanthramides phenolic compounds exclusively found in oats (Skoglund et al., 2008). Similar results were also reported by Ren and Sun (2014)

in both common buckwheat and tartary buckwheat and by Karki and Kharel (2012) in five Nepalese finger millet varieties. Increase in total phenolics during germination was expected as a result of loss of dry matter as well as hydrolysis of condensed tannins due to germination.

Furthermore, it was anticipated that during germination, different enzymes were produced and contributed to the modification of grain composition resulting in the release of bound phenolics and facilitating more extraction of phenolics than that of native grain (Karki and Kharel, 2012). According to Maillard and Berset (1995), increase in total phenolics on malting may be due to enzymatic release of bound phenolic compounds during seed germination. Maillard et al. (1996) reported that polyphenols in millet occur both in free and bound forms. Increase in malt total phenolics may be due to the action of induced esterase activity on bound phenolics, which act on various phenolic acid esters linked either to arabinoxylans or other non-strach polysaccharides. In contrats, Subba Rao and Muralikrishna (2002) found that during the course of malting of finger millet, the amount of total free phenolic acids decreased from the native kernel up to 3 days of malting and afterwards slightly increased after 4 days of malting. The amount of bound phenolic acids steadily decreased.



***STEROLS***

Sterols are hydrophobic steroid alcohols which are mainly found in the cell membranes, are typically associated with the lipid fraction in plants with significant biological function (Kaukovirta-Norja et al., 2004; Hübner and Arendt, 2013). In cereals, sterols occur as free sterols, steryl esters and steryl glycosides. Andersson et al. (2004) stated that the main health benefit of sterols in the diet is seen in the lowering of blood cholesterol levels in human beings. In spite of their health benefits, only very limited material on the influence of germination on

sterols in cereals is known. However, studies reported increased in sterol content in germinated grains in comparison to the unmalted material. Increase in sterol content was reported in oats (Wilhelmson et al., 2001; Kaukovirta-Norja et al., 2004) (Table 2), maize (Kemp et al., 1967; Izzo et al., 1994) and rye (Liukkonen et al., 2003) during germination. Sitostanol was found to be synthesized during germination. Oat sterols were found to be heat stable by Kaukovirta-Norja et al. (2004) when germinated oats were dried at different temperatures.



***FLAVONOIDS***

Flavonoids are reactive compounds with no steric inhibition due to additional side chains; therefore, many flavonoids more easily form polymers in bound forms. Studies of Ti et al. (2014) stated that the distribution of flavonoids in free and bound forms before and after germination did not change, which indicated a stable transformation between free and bound flavonoids. Total flavanoid content increased in brown rice (Ti et al., 2014), common buckwheat and tartary buckwheat (Ren and Sun, 2014) and finger millet (Karki and Kharel, 2012) (Table 2). The synthesised flavonoid pathway may be activated during germination by the phenylpropanoid metabolic pathway, during which the intermediates may further generate acetyl coenzyme A esters that are converted to flavonoids (Ti et al., 2014).

The changes in the flavonoid content during germination could be explained by various types of key enzymes or cofactors being synthesised, which leads to the production of the flavonoids. Similarly, rutin and total free phenylalanine levels were reported to increase during germination however quercetin content decreased gradually from 15.2 mg/g (1-day sprouts) to 0 mg/g (7-day sprouts), probably because more quercetin was used for the synthesis of rutin, Ren and Sun (2014). The highly active PLA and sufficient quantity of free phenylalanine could promote the

biosynthesis process for phenol and flavonoid compounds in buckwheat sprouts. However, no quercetin can be detected in common buckwheat flour probably because the metabolisms in two different buckwheat varieties are different. Ren and Sun (2014) showed that sunlight, temperature, and calcium ion water had a great effect on the flavonoid content of buckwheat sprouts. Long exposure to sunlight, reasonable temperature, and calcium ion water can promote flavonoid synthesis in buckwheat sprouts (Sun, 2008).



***γ-AMINOBUTYRIC ACID***

γ-aminobutyric acid (GABA) is a non protein amino acid widely distributed in nature, produced primarily by the decarboxylation of L-glutamic acid, catalyzed by the enzyme, glutamate decarboxylase (GAD) (Manyam et al., 1981; Mayer et al., 1990). GABA has several physiological functions such as neurotransmission and induction of hypotensive effects, diuretic effects, and tranquilizes effects (Omori et al., 1987; Jakobs et al., 1993; Okada et al., 2000; Xu et al., 2001), inhibited cancer cell proliferation (Oh and Oh, 2004), accelerate the metabolism of the brain (Kayahara et al., 2001). Kayahara et al. (2001); Hagiwara et al. (2004) found that GABA from PGBR might be effective in preventing headaches, relieving constipation, regulates blood sugar levels, ischemic heart disease and an increase in blood glucose concentration. It also reduces the risk of developing some cancers such as colon cancer and the risk of Alzheimer's disease.

An increase in γ--aminobutyric acid content of germinated wheat was reported by Singkhornart et al. (2014) indicating that various enzymes degrade seed storage components such as starch and protein to provide energy, amino acids and vitamins for a new plant during germination (Table 2). Similar results were also reported by Donker et al. (2012) in germinated barley, sorghum, rye,

and sorghum then ungerminated grains. Their analysis further showed that the GABA content in barley and rye were significantly higher than that of the other examined grains.

Many reports have demonstrated that brown rice contains higher levels of GABA than does white rice. Ohtsubo et al. (2005) observed that the GABA content in brown rice is 3.5 times higher than that in white rice. Similarly, the results of Iwaki and Kitada (2007) reported that, the GABA content in a half-milled rice sample was higher than that in a well-milled one, and after being cooked, the content in the former was 1.5 times that in the latter. Xi et al. (2009) reported that the GABA contents in different parts of rice decrease in the following order: rice germ > rice husk >brown rice >white rice. Change in the GABA content is enhanced in the germination state, so allowing time for germination during processing can help improve rice quality. GABA is one of the most interesting compounds in germinated rice. Studies reported that, the concentration of GABA also remarkably increased, in germinated brown rice (Saikusa et al., 1994; Oh, 2003; Charoenthaikij et al., 2009; Charoenthaikij et al., 2010; Moongngarm and Saetung, 2010; Roohinejad et al., 2011; Kim et al., 2012) and germinated rough rice (Moongngarm and Saetung, 2010; Kim et al., 2012) respectively, compared with that of ungrminated grains.

GABA level is related to the content of glutamic acid and it is synthesised by decarboxylation of glutamic acid (Bak et al., 2006; Lee et al., 2007a; 2007b), however, a small variation, in the GABA obtained, can be varied by several factors, such as cultivar, germination temperature, light intensity and germination time. GABA in rice grains is synthesized by decarboxylation of glutamic acid catalyzed by glutamate decarboxylase (Bown and Shelp, 1997; Lee et al., 2007a). Komatsuzaki et al. 2007 observed that GABA content is related to protease and glutamate decarboxylase (GAD) activity. Amino acids are stored in rice grains as storage proteins that are

decomposed by hydrolysis during germination and converted into transportable amides and supplied to the growing rice seedlings therefore, water absorption during soaking and germination activates GAD enzymes and results in the conversion of glutamic acid to GABA (Singkhornart et al., 2014; Donkor et al., 2012).

Charoenthaikij et al. (2010) found that as the steeping time increased from 24 to 48 h the free GABA content in germinated brown rice flour increased by 105 and 74.3 at both pH 3 and 6.8, respectively after 48 h germination. They also reported that pH 3 was more effective in increasing of the free GABA content compared to pH 6.8 of the steeping water and highest free GABA content (67.0 mg/100 g flour) was observed in GBRF with 48 h of steeping at pH3. Similar results were also reported by Charoenthaikij et al. (2009). They also observed that highest amount of free GABA could be accumulated when brown rice was steeping at pH 3 for 48 h and pH 3 for 24 h as compared to steeping of brown rice at pH 5, 6.8 and 7. This increase was perhaps due to the fact that GABA synthesis increases rapidly in response to a variety of environmental signals, including acidosis condition, resulted in a stimulation of GAD activity which could convert glutamate to GABA via GABA shunt pathway (Scott-Taggart et al., 1999). Komatsuzaki et al. (2007) reported that after soaking for 3 h and gaseous treatment for 21 h at 35 C, the content of γ-aminobutyric acid (GABA) in germinated brown rice (24.9 mg/100 g) was higher than that by the conventional soaking method (10.1 mg/100 g).

Cáceres et al. (2014) reported that germination at 34°C afforded a higher GABA (123.92-139.32mg/100g) accumulation in 96h-germinated brown rice as compared with germination for 48 h at 34°C (44.61-76.66 mg/100g) in different varieties of Ecuadorian brown rice. They observed that GABA accumulation was initiated in the soaking process and continued in a time-

dependent manner during germination in all the cultivars. They explained that the soaking process induces glutamate decarboxylase (GAD) activity which increases with germination time. GAD catalyses the γ-decarboxylation of L-glutamic acid to carbon dioxide and GABA. Sen et al. (2008) compared the GABA contents of 181 varieties of germinated brown rice. Their results showed that the GABA content in germinated brown rice varied with different types of rice; among all of the samples, the highest, lowest, and average GABA contents were 87.88 mg/100 g, 34.62 mg/100 g, and 56.84 mg/100 g, respectively. The authors also suggested that GABA content in early-season rice is significantly higher than that in semilate and late rice and that in *indica* rice, the GABA content is slightly higher than that in *japonica* rice. Oh (2003) also pointed out that germinating brown rice in glutamic acid and chitosan mixture solutions results in greater increases in GABA than when using either additive alone. Moreover, the GABA concentrations in brown rice germinated with the chitosan/glutamic acid solution were 13 times higher than the GABA concentrations in non-germinated brown rice, suggesting that chitosan and glutamic acid have a synergistic effect on GABA synthesis. The combination of high hydrostatic pressure treatment (HPT) and the initial germination of rough rice significantly increased the GABA content (Kim et al., 2015). The highest GABA content was observed after HPT for 48 he, and ranging from 41.48 to 121.21 mg/100 g as compared to 25.76--87.88 mg/100 g for control. Ueno et al. (2010) reported that the GABA content in dry soybean seed was 0.90l mol/g and it increased to 3.20 mol/g after 2 days soaking and HPT. In general, HPT was used to cause a partial degradation of the internal cell structure in rice. Cellular membrane systems were damaged in the pressurized plant cell. Thus, mass transfer in the pressurized plant cell was accelerated compared with that observed in an intact cell, which promoted enzymatic reactions

(Ueno et al., 2010). Therefore, the HPT and initial germination of rough rice caused an increase in the enzymatic activities related to GABA biosynthesis (such as GAD, GABA transaminase, and a-ketoglutarate transaminase). Consequently, metabolic pathways associated with GABA and glutamic acids are accelerated using a combination of germination and HPT.

In addition to chemical contents, the harvesting period also affected the GABA content. Chungcharoen et al. (2014) reported that the higher minerals of germinated paddy provided higher activities of enzymes within the seeds and contained higher levels of bioactive compounds, which led to larger production of GABA. Chungcharoen et al. (2012); (2014) observed that after germination, the GABA content of the shade-dried samples was increased by 5.2--6.5 times as compared to the over dried germinated brown rice. They also stated that the GABA content of germinated paddy was remarkably higher than that of germinated brown rice. The higher content of GABA in germinating paddy is due to the reason that minerals are being accumulated in the hull. The larger amount of GABA in the germinated samples can be explained by the fact that the hydrolytic enzymes, especially α -amylase, decomposed the high-molecular-weight polymers, leading to the generation of bio-functional substances, which resulted in the increase of GABA (Chung et al., 2009). In addition, Chungcharoen et al. (2012) also observed that germination time also affected the GABA content; the GABA content was increased with increasing germination time. However, the germination time over 68 hours led to the decrease of GABA content. Kono and Himeno (2000) stated that the decrease of GABA content is due to the fact that GABA is supplied to the growing parts of the rice seedling. Moreover, the germination time over 68 hours provided a strong fermentation odour, which led subsequently to poor quality of germinated brown rice.

Increases in die temperature, screw speed and injection of $Co_2$ during extrusion significantly reduced γ-aminobutyric acid of extruded germinated wheat. As extrusion led to starch degradation, thus providing reducing sugars, at same time that it modifies protein structure, exposing reactive sites, which favoured the Maillard reaction and might a reason for the decrease in amino acid content (Singkhornart et al., 2014). However, the γ-aminobutyric acid content of extruded germinated wheat was greater than those of extruded non germinated wheat.



***β-GLUCAN CONTENT***

β-glucan,the nonstarchy polysaccharides from the main constituents of dietary fibre undergo structural changes during germination (Mohan et al., 2010). Singkhornart et al. (2014) observed a reduction in β-glucan content of germinated wheat than non germinated wheat (Table 2). The β-glucan decreased presumably by endogenous enzyme activity (Wang et al., 2004). Similarly, Wilhelmson et al. (2001) also reported that the β-glucan content decreased during germination. They reported that the β-glucanase activity was highest in the samples germinated at 15°C which results in the breakdown of β-glucans. After eight days of germination at 15°C, β-glucan was almost completely degrade as the β-glucanase activity rose sharply between four and six days of germination, coinciding with the disappearance of β-glucan. Singkhornart et al. (2014) reported that after extrusion, the β-glucan content decreased and it ranged from 41%58 as extrusion caused physical disruptions of the cell wall material. Nonetheless, part of the insoluble β-glucan is bound to other components of the cell wall and remains in the insoluble fibre fraction. Result of decreasing the β-glucan content for extruded products was that, the insoluble β-glucan was more soluble and released and then becomes water-extractable by high shear force and temperature during the extrusion process (Johansson et al., 2004). Yang et al. (2001) observed

that after steeping for 24 or 48 h, β -carotene content in wheat sprouts was greatly increased during the germination process and reaching the peak on day 8.

***ARABINOXYLANS***

Arabinoxylan (AX), a major fibre component in many cereal grains, are non starcy polysaccharides comprising arabinose side chains attached to a xylose backbone, found as cell wall constituents within dietary fibre (Vinkx et al., 1995; Nelson et al., 2013). The nutritional values of other fibre components in grains, most notably arabinoxylans, have not been investigated to the same extent as those of β-glucans. However, recent studies revealed positive effects of water soluble maize, wheat and rye arabinoxylans on caecal fermentation, production of short-chain fatty acids, reduction of serum cholesterol and improved adsorption of calcium and magnesium. It has been shown to decrease ghrelin, serum insulin, reduced fasting plasma glucose and postprandial glucose in diabetic subjects compared with a control diet and glucose (Lopez et al., 1999; Hopkins et al., 2003; Lu et al., 2004; Garcia et al., 2007). In recent studies, arabinoxylan isolated from rice bran was found to have an immune-enhancing function and anti-tumour activity (Ghaoneum and Abedi, 2004). It is anticipated, therefore, that the health benefits of oats, barley, sorghum, buckwheat and brown rice grains will stimulate interest among food producers and consumers in using them for food purposes.

Increase in soluble arabinoxylans had been reported in wheat by Borght et al. (2005); Backer et al. (2010); Donker et al. (2012) and Singkhornart et al. (2014), in brown rice by Donker et al. (2012), in rough rice by Kim et al. (2015) and in buckwheat and sorghum by Donker et al. (2012) following the germination of grains (Table 2). On the contratry, Donker et al. (2012) also observed that the total arabinoxylans content in germinated barley, oats and rye grains decreased

compared with arabinoxylans content in non-germinated grains. According to Lu and Li (2006), cell wall of ungerminated wheat is not extensively degraded that's limiting the solubilisation of arabinoxylans, as the enzymes that degrade arabinoxylans are often produced late in the germination process (Gupta et al., 2010). During germination and seedling growth, endogenous β- D-xylanase andcell-wall hydrolase enzyme activity was drastically increased (Eom and Lee, 2008; Backer et al., 2010; Kim et al., 2015**)** which resulted an increase in the total arabinoxylan content after germination. Backer et al. (2010) reported the relationship between the extractability of arabinoxylan and β-D-endoxylanase during wheat germination and observed that germination enhanced the total and soluble arabinoxylan in wheat and the highest content found in wheat samples after 24 h of germination.

Extrusion processing was reported to decrease the soluble arabinoxylans in extruded germinated wheat as compared to non extruded wheat (Singkhornart et al., 2014)**.** While extrusion of germinated wheat increased the soluble arabinoxylan content as compared to extrudates compared from non germinated wheat at different extrusion conditions. On the other side, Kim et al. (2015) reported that the total arabinoxylan contents of rough rice which are 6.84% after germination periods of 4 days increased by 9.22% - 10.16% with the high hydrostatic pressure treatment of samples for 24 and 48 hrs, respectively.

***γ-ORYZANOL***

γ-oryzanol, a mixture of 10 esters of triterpene alcohols is mainly composed of esters of trans-ferulic acid (trans-hydroxycinnamic acid) with phytosterols. Among these phytosterols, cycloartenol, β-sitosterol, 24-methylenecycloartenol and campesterol are the major components in γ-oryzanol **(**Xu et al., 2001; Zhimin et al., 2001; Lerma-Garcia et al., 2009). γ-oryzanol is an

antioxidant compound and is associated with decreasing plasma cholesterol, lowering serum cholesterol, decreasing cholesterol absorption and decreasing platelet aggregation (Murase and Iishima, 1963; Sasaki et al., 1990; Guardiola et al., 1996; Rong et al., 1997; Xu et al., 2001). The beneficial effects of γ-oryzanol on human health have generated global interest in developing simple methods for its separation from natural sources, such as crude rice bran oil, rice bran oil soap stock, rice bran acid oil, or biodiesel residue from rice bran (Zullaikah et al., 2009**)**. Rice bran is a rich source of steryl ferulate esters, commonly referred to as oryzanols (Xu and Godber, 1999).

The effect of germination process on γ-oryzanol levels has been studied by several researchers. In brown rice it was reported that γ-oryzanol content increased during germination **(**Ohtsubo et al., 2005; Miura et al., 2006; Sie-Cheong et al., 2009). However, Sie-Cheong et al. (2009) observed that after germination of 24 h, only three cultivars retained or showed slight increases in γ-oryzanol content out of eight cultivars of brow rice studied. The rest of the cultivars showed reduction in γ-oryzanol content compared to pre-germination levels and this may also be due to different water uptake rates by the different rice seeds. They also reported that germination process exhibits diverse effects on the γ-oryzanol accumulation in brown rice and is cultivar-dependent and this process could enhance γ -oryzanol content in certain rice cultivars. This may be attributed to genetic and environmental factors**.** During the process of germination, saccharification occurs, breaking complex carbohydrates into simple sugars and softening the nutritive tissue surrounding the embryo of plants (Ohtsubo et al., 2005; Sie-Cheong et al., 2009). Hydrolytic enzymes are thus activated, which increases the amount of digestible vitamins, oligosaccharides, minerals and amino acids by decomposing starch, non starch polysaccharides

and proteins. The decomposition of the high molecular weight polymers during germination leads to the generation of bio-functional substances.

Moongngarm and Saetung (2010); Kim et al. (2011); Kim et al. (2012); Kim et al. (2015) reported that after germination the γ-oryzanol content of both rough rice and brown rice increased as compared to ungerminated rice. Moongngarm and Saetung (2010) concluded that an increase in γ-oryzanol occurs in the embryo following rough rice germination and it is influenced by site and season (Miller and Engel, 2006). This phenomenon was attributed to the synthesis of γ-oryzanol as a physiological metabolic component before the sprouting and growth of rough rice and its use as a growth accelerator and synergist in the young rice plants (Kim et al., 1997). Kim et al. (2015) observed that γ-oryzanol content significantly increased from 23.19 mg/100 g to 36.20 mg/ 100 g after 5 days of germination and then decreased to 32.93 mg/ 100 g after 6 days of germination. Similar results were also reported by Kim et al. (2011). Kim et al. (2015) also concluded that High Hydrostatic Pressure Treatment (HPT) has positive effect on γ-oryzanol content in germinated rough rice.

**EFFECT OF GERMINATION ON FUNCTIONAL PROPERTIES OF GRAINS**

The functional properties have been defined as those physicochemical properties that affect the processing and behaviour of proteins in food systems as judged by the quality attributes of the final product (Kinsella, 1976). The functionality of protein depends to some extent upon the size and structure of proteins and in part on their interactions with other food components such as carbohydrates and fats and is modified by various treatments (Prakash and Narasinga Rao, 1986). Modified proteins are known to have entirely different functionality as compared with the

parent protein and can be added in small amounts to food products for a specific aspect (Ghavidel and Prakash, 2006; Wu and Inglett, 1974).

Functional properties could be classified according to the mechanism of action on three main groups: (i) properties related with hydration (absorption of water/oil, solubility, thickening, wettability) (ii) properties related with the protein structure and rheological characteristics (viscosity, elasticity, adhesiveness, aggregation and gelification) and (iii) properties related with the protein surface (emulsifying and foaming activities, formation of protein-- lipid films, whippability) (Damodaran, 1997; Moure et al., 2006). Alternatively, the prediction of functional properties as a function of the contributions of the amino acids (hydrophilicity, molecular size, electronic properties, heat formation and energy levels from molecular orbitals calculations) has been reported by Siebert (2003). The importance of the dynamics of water in relation to the protein structure and to the adaptation to protein environment has been reviewed by Mattos (2002).

***PROTEIN SOLUBILITY PROFILE***

Amongst the functional properties of proteins, solubility is probably the most critical because it affects other properties such as emulsification, foaming and gelation (Kinsella, 1976). Protein solubility characteristics are influenced by factors such as origin, processing conditions, pH, ionic strength and the presence of other ingredients (Kinsella, 1976). Increase in germination time increased the protein solubility profile of sorghum (Elkhalifa and Bernhardt, 2010) (Table 3). The highest solubility of the protein for germinated samples occurred at pH 6 and the values increased to reach its maxima in $5^{th}$ day germinated sorghum flour. Elkhalifa and Bernhardt (2010) also reported that all germinated samples had minimum protein solubility at pH 4, which

is the isoelectric pH. Minimum protein solubility of ungerminated sample is relatively broad at pH 2 and 4. The protein of the germinated samples was more soluble at pH 4 than the control. This might be due to the high proteolytic activity during germination, which will lead to an increase in the protein solubility resulting from hydrolysis of the storage proteins. The applicability of germinated flour in food preparations where maximum solubility of proteins is desired looks very promising.



***NITROGEN SOLUBILITY INDEX (NSI)***

Elkhalifa and Bernhardt (2010) reported that nitrogen solubility index increased during the first three days of germination and then there was a slight decrease in the 4th and the 5th day of germination in sorghum grains (Table 3). The increase in NSI during germination can be due to gradual degradation of reserve proteins into amino acids and short peptides caused by increasing the levels of protease enzymes (Elkhalifa and Bernhardt, 2010). This can lead to an increase in the nutritive value of germinated sorghum by increasing its in vitro protein digestibility; as such partially hydrolysed storage proteins may be more easily available for pepsin attack (Bhise et al., 1988). Working with pearl millet, Pelembe et al. (2003) also found that NSI increased with increasing germination time. Similarly, Gamel et al. (2006) reported that flour from germinated amaranth seeds showed higher NSI than that from ungerminated seeds.

***GELATION/LEAST GELATION CONCENTRATION***

A gel can be defined as an intermediate state between solid and liquid. In food systems the liquid is water and the molecular net is formed by proteins, polysaccharides or by a mixture of both. Proteins are more efficient gelling agents than carbohydrates because large molecules are

capable of forming crosslinks in three dimensions (Moure et al., 2006). Gelation is favoured by the protein size, since large molecules form extensive networks by crosslinking in three dimensions, and by the flexibility and ability of the proteins to denature **(**Oakenfull et al., 1997). In order to form gels, partial denaturation is desirable due to which partial gelation occurs in the frontier between aggregation and solubility, since unfolding of the tertiary structure gives long chains without breakage of covalent bonds (Hegg, 1982). Other influencing factors are pH, ionic strength, reducing agents, temperature, the presence of non-protein components and the mechanical forces applied to the system **(**Damodaran, 1997; Sathe, 2002). Two kinds of gels, transparent or coagulant, are formed depending on the type of protein, the amino acid composition and other external factors as pH and ionic strength. Proteins containing non-polar residues tend to form coagulant gels (Shimada and Matsushita, 1980) whereas those containing hydrophilic amino acids form transparent ones. Rheological measurements are useful to obtain information on the nature of the gel. The ability of proteins to form gels, is traditionally measured by the least gelation concentration (LGC), defined as the minimal protein concentration required for inverting a tube without producing sliding of the gel in the walls (Moure et al., 2006).

Gelation is an aggregation of denatured molecules. The least gelation concentration for germinated sorghum was 14 in the first two days of germination and 12% in the last three days of germination, whilst it was 18% for the control sorghum flour (Elkhalifa and Bernhardt, 2010) (Table 3). Similar results were also reported by Chinma et al. (2009) in brown and yellow varities of tingernut. They reported LGC of 12% in 72h ferminated sample and 18% for control sample. Elkhalifa et al. (2005) reported the same value obtained in the study of Elkhalifa and

Bernhardt (2010) for the control, whilst it was 6% for 24 h fermented sorghum flour. Ocheme and Chinma (2008) reported 8% least gelation concentration for germinated millet flour. The variation in least gelation concentration might be due to aggregation of denatured molecules, which increased the protein concentration or solubility causing intermolecular contact during heating (Obalolu and Cole, 2000). This observation may also indicate that amylase released during germination would have interacted with the starch component of the flour leading to increase in its gelation property.

Germination may have denatured the proteins and thus, caused more aggregation than in the ungerminated flour. These results of Elkhalifa and Bernhardt (2010) suggested that flour derived from the three days germinated sorghum would be a good gel-forming or firming agent and would be useful in food systems such as pudding and snacks which require thickening and gelling. Obalolu and Cole (2000) also attributed gelation to high globulin fraction in soybean based blends. The variation observed in the gelling properties of the flour samples might be associated to the relative ratios of different constituents such as protein, carbohydrate and lipids that make up the flour; thus suggesting that the interaction between such components may have a significant role in there functional properties (Chinma et al., 2009). Sathe and Salunkhe (1981) reported that gelation is not only a function of quantity of protein but the type of protein as well as its non-protein components.

***WATER ABSORPTION CAPACITY***

In food applications the water retention capacity is related with the ability to retain water against gravity, and includes bound water, hydrodynamic water, capillary water and physically entrapped water (Moure et al., 2006). The amount of water associated to proteins is closely

related with its amino acids profile and increases with the number of charged residues (Kuntz and Kauzmann, 1974), conformation, hydrophobicity, pH, temperature, ionic strength and protein concentration (Damodaran, 1997**)**. The water absorption capacity of the meals is significantly improved by germination (Moure et al., 2006**)**.

Germination increased the water absorption capacity (WAC) of sorghum flour upto 3 day of germination, while it decreased with further increase in germination time (Elkhalifa and Bernhardt, 2010). Similar results of increase in water absorption capacity were also reported by Adeniyi and Obatolu (2014) in germinated amaranth grain flour**,** Adedeji et al. (2014) in germinated maize and Chinma et al. (2009) in germinated brown and yellow varieties of tingernut (Table 3). In contrast, Gamel et al. (2006) found that the flour of germinated amaranth seed showed lower water absorption values than the raw seed flours. An increase of WAC on germination could be attributed to an increase in protein content and change in the quality of protein upon germination and also breakdown of polysaccharide molecules; hence the sites for interaction with water and holding water would be increased Elkhalifa and Bernhardt (2010). Studies of Adedeji et al. (2014) and Adeniyi and Obatolu (2014) reported that germination produced the samples with highest amount of water-loving, hydrophilic compounds, having good water holding capacity, which may be in form of proteins, carbohydrates such as soluble sugars, gums, starch as well as water-soluble vitamins. According to Okaka and Potter (1997), water holding capacity depends on the water bounding capacities of food components. Furthermore, exposure of the water binding site on the side chain groups of protein units previously blocked in a lipophilic environment might have led to an increase in water absorption capacity of the germinated flour (Uwaegbute et al., 2000; Chinma et al., 2009).

***OIL-ABSORPTION CAPACITY***

Oil absorption capacity has been attributed to the physical entrapment of oil. This is important since fat acts as a flavour retainer and increases the mouth feel of food (Kinsella, 1976). Since the binding of the oil depends on the surface availability of hydrophobic amino acids (Sosulski et al., 1976), the enhancement in oil-absorption capacities of germinated samples could be attributed to an increase in the availability of certain amino acids by unmasking the non-polar residues from the interior protein molecules. Several studies had reported a significant increase in oil absorption capacity of germinated cereal grains and data was presented in Table 3. Giani and Bekebain (1992) reported that germination of grains enhances the oil absorption capacity due to the entrapment of oil related to the non polar side chains of proteins. Oil absorption capacity (OAC) of sorghum flour (Elkhalifa and Bernhardt 2010), millet flour (Akubor and Obiegbuna, 1999), amaranth flour **(**Adeniyi and Obatolu, 2014), maize flour (Adedejiet al., 2014), brown and yellow tigernut flour (Chinma et al., 2009) increased with germination of grains. In sorghum flour, OAC increased upto 3rd day of germination (Elkhalifa and Bernhardt, 2010), whereas further increase in the germination decrease the OAC. The higher oil-binding capacity of sorghum flour suggests that this flour would be useful in formulation of foods where an oil holding property is an important consideration (Elkhalifa et al., 2005). The increase in oil absorption capacities could be attributed to change in the quality of protein upon germination and also its capacity to hold fat globules as the amount of lipophilic protein increases which is also an index of the ability of protein to absorb and retain oil (Chinma et al., 2009). Also decreased fat content of the germinated flour samples might have resulted to its ability to absorb more oil in its structure.



 

***EMULSIFYING ACTIVITY AND STABILITY***

The efficiency of emulsification varies with the type, concentration and solubility of the proteins **(**Achinewhu, 1983**)**. The capacity of proteins to enhance the formation and stabilization of emulsion is important for many applications in cakes, coffee whiteners, and frozen desserts. In these products varying emulsifying and stabilizing capacities are required because of different compositions and stresses to which these products are subjected. Adeniyi and Obatolu. (2014) confirm the fact that germination effects improved functional properties of grains in addition to the improved nutritional value as reported by Paredes-Lopez and Escobedo. (1989).

Table 3, depicts that germination significantly increased the emulsifying activity of sorghum flour (Elkhalifa and Bernhardt 2010), millet flour (Akubor and Obiegbuna 1999), amaranth flour (Adeniyi and Obatolu, 2014), maize flour (Adedejiet al., 2014) and brown and yellow tingernut flours (Chinma et al., 2009). In contradictory to Adeniyi and Obatolu (2014), Gamel et al. (2006) reported a decrease in emulsifying activity of amaranth with increase in germination time. The increase observed in emulsion capacity as a result of increased germination time could be due to an increase in the area of stabilized oil droplet at interface which is a function of the food components, its low fat, high protein content and higher interaction of its protein and fat with other components present in the germinated flour samples. Emulsion capacity of a product depends on its oil content and protein concentration (Nkonge and Balance, 1984; Kato et al., 1985; Chinma et al., 2009; Imtiaz et al., 2011). Germination caused dissociation, partial unfolding and denaturation of polypeptides that expose the hydrophobic sites of amino acids, which aids hydrophobic association of the peptide chains with the lipid droplets, so that the net result was that a much greater volume/ surface area of protein was made available and



 

emulsification capacity was enhanced (Kinsella, 1976; Wang and Kinsella, 1976; Nir et al., 1994). Similarly, the hypothesis of conversion of oligomeric proteins to simple proteins and/or the synthesis of new proteins during germination may have increased the soluble proteins. Soluble proteins are more surface active and are known to promote oil in- water emulsion (Subba Rao and Srinivasan, 1988).

Similarly, emulsion stability was also reported to be significantly increased in germinating millet (Akubor and Obiegbuna, 1999), brown and yellow tingernut (Chinma et al., 2009), sorghum (Elkhalifa and Bernhardt, 2010), amaranth (Adeniyi and Obatolu, 2014) and maize (Adedejiet al., 2014) as compared to native grains with increased germination time (Table 3). A positive correlation had also reported by Yasumatsu et al. (1972) and Wang and Kinsella, (1976) between protein solubility and the Emulsifying activity and Emulsion stability of the protein. Even though germination improved the emulsifying capacity of grain, the emulsion was not noticeably stable (Adeniyi and Obatolu, 2014) and it differs with the temperature of germination (Adedejiet al., 2014).

***FOAMING CAPACITY AND STABILITY***

Owing to a large increase in surface area of liquid/air interphase, proteins denatured and aggregates during whipping and forms stable foams with gas by forming impervious protein films which is an important property for flours to be used in many leavening food products such as baked goods, cakes and biscuits (Belitz and Grosch, 1999; Elkhalifa and Bernhardt, 2010). The foaming capacity of a food material depends on the surface active properties of its protein (Sathe et al., 1982; Udensi and Okoronkwo, 2006).

The values of foam capacity shows that ungerminated grain amaranth flour (Adeniyi and Obatolu, 2014) and sorghum flour (Elkhalifa and Bernhardt, 2010; Elkhalifa et al., 2005) did not show any foaming capacity at all but on germination it increased and keep on increasing with increase in germination time (Table 3). Germinating the grains for more than one day shows some foaming capacity and the value increased with increasing germination time of sorghum (Elkhalifa and Bernhardt, 2010) and tingernut (Chinma et al., 2009) until it reached maximum value at the end of 5 and 3 days of germination period respectively. Germination may have caused surface denaturation of the proteins which increased the amount of solubilised proteins and reduced the surface tension of the air and water interface leading to absorption of soluble protein molecules thereby permitting hydrophobic interactions, resulting in improved foaming capacity (Chinma et al., 2009; Elkhalifa and Bernhardt, 2010). In disparity Adedeji et al. (2014) observed a significant decrease in the foaming capacity with the maize sample that was germinated for 48 h having the least value than the native sample that might have been as a result of denaturation of protein molecules during milling and germination processes. Native protein provides higher foam capacity than denatured protein (Brou et al., 2013). Adeniyi and Obatolu (2014) reported that germination temperature also influenced the foaming capacity. Native grain amaranth did not foam at all but, it increased to 3.99% at 30°C, 7.84% at 34 $^{o}$C to the peak value of 8.45% at 32°C and then to the least value, 0.97% at 40 $^{o}$C after 24 h of germination. This could be attributed to increased protein content, quality and probably due to formation of some alginates (Paredes- Lopez and Mora- Escobedo, 1989).

Foaming stability is important because the usefulness of whipping agents depends on their ability to maintain the whip as long as possible (Lin et al., 1974). Germination also improved the

foaming stability of sorghum flour (Elkhalifa and Bernhardt, 2010) and amaranth flour (Adeniyi and Obatolu, 2014) and it tended to increased with increasing germination time. However, conformational changes taken place during germination of proteins may have an effect on foam stability of the cereal flours (Elkhalifa and Bernhardt, 2010). The increase in foaming stability observed for germinated grains might have been as a result of bioavailability of inherent proteins which were probably bound by antinutritional factors such as phytin in the samples (Brou et al.,. 2013). Singh and Raghuvanshi (2012) reported that antinutritional factors in cereals bind to both exogenous and endogenous proteins including enzymes of the digestive tract affecting utilization of proteins. The foams were not stable at all because the foam stability of most of the samples was close to zero. Hence, Elkhalifa and Bernhardt (2010); Adeniyi and Obatolu (2014) deduce that germinated and ungerminated amaranth flours will not produce an acceptable result where foam production is desirable as in cakes, sponges, ice cream etc. In contrite, it had been observed by Adedeji et al. (2014) that the native maize had higher foaming stability than germinated samples at the same foaming stability time. Brou et al. (2013) also reported higher foaming stability for native proteins and increasing foaming stability with increasing protein content. The reduction in stability observed for sample that germinated could have been due to denaturation of protein. They also observed that ungerminated sample had a higher stability than the germinated samples and that foaming stability of the samples decreased with time.

***PASTE CLARITY***

Paste clarity is related to the state of dispersion and the retrogradation tendency of the starch and hence will influence other technologically important qualities of starch. A fairly transparent paste is desirable in fruit pie fillings, whereas opacity is desirable in salad dressing and instant

desserts. Paste clarity is influenced by many factors like concentration, pH, extent of modification and type of modification. Paste clarity is a requisite parameter in food applications such as fruit pie fillings or canned specialty products, such as Chinese style foods, where clarity has paramount importance so as to maintain the attractive appearance of vegetables; on the other hand, paste used for spoonable salad dressing should be opaque (Elkhalifa and Bernhardt, 2013).

The transmittance (%) or clarity of sorghum flour pastes (Elkhalifa and Bernhardt, 2013) increased with increase in germination time (Table 3). Elkhalifa et al. (2004) reported similar behaviour with starch derived from fermented and unfermented sorghum flour. In contrast to this Teli et al. (2009) and Teli and Sheikh (2011) observed that % transmittance of non-germinated maize starch were higher than that of germinated starch (Table 3). The paste clarity is directly related to the state of dispersion and retrogradation tendency of the starch and if the swelling power of non-germinated starch was higher, its paste clarity was also higher than that of the germinated starch (Teli et al., 2009; Teli and Sheikh, 2011).Whistler et al. (1965) stated that the factors which increase granule swelling and solubilisation, or those factors that inhibit retrogradation increase in the paste clarity.

The %T after 72 h of storage at 4°C was lower than the flour samples stored at room temperature, indicating that the lower temperature favoured starch retrogradation (Elkhalifa and Bernhard,t 2013). Study of Elkhalifa and Bernhardt (2013), reported that, storage of the pastes at low temperature (4°C) had resulted in the formation of less perfect crystallites than storage at room temperature and resulted in a higher rate of aggregation of amylose chains, thus decreasing the %T of the flour pates significantly. Within the same storage temperature and after 24 h of

storage time, flour from germinated sorghum showed an increased %T as compared with flour from ungerminated sorghum.

***FREEZE-THAW STABILITY***

Freeze-thaw stability indicates retrogradation of starch pastes and reflected by defined quality of a typical food product or a class of foods. When starch gels are subjected to freeze-thaw cycling, water used in the preparation of the gels will separate because of the tendency of starch molecules to reassociate, thus forming insoluble aggregates. The gels are characterized as weepy, grainy, or spongy. The stability of starch to freeze-thaw cycling will enhance its suitability for use in food products. Elkhalifa and Bernhardt (2013) reported that flour derived from germinated sorghum presented higher syneresis than that derived from ungerminated sorghum flour and highest syneresis was reported in 72 h germinated sorghum samples (Table 3). This higher syneresis of flour derived from germinated sorghum may be due to starch depolymerisation, as it is well known that depolymerised starch is more prone to syneresis (Elkhalifa and Bernhardt, 2013). Syneresis values were observed over the first three freeze thaw cycles but when the cycle number increased, both flours showed zero syneresis value. Elkhalifa et al. (2004) observed similar behaviour with starch isolated from fermented and unfermented sorghum flours. These results showed that flours derived from sorghum (germinated and ungerminated) are not particularly suitable for frozen food products.

***GEL CONSISTENCY***

The germinated grains produced the thinnest gels as compared to ungerminated grains and the acid gel consistency measured at pH 2.6, increased from 55 to 145mm when the germination

time increased upto 72 h (Elkhalifa and Bernhardt, 2013). A similar trend was observed with neutral gels prepared with distilled water pH 7.5, which showed gel consistency values between 35 and 85 mm. Efficient grain modification during germination due to combined action of cell wall degradation enzymes such as β-glucanase and proteases, help to break down the protein matrix. These enzymes thus exposed the starch granules to amylase attack during mashing (Palmer, 1989), which breakdown starch and hence lowers the viscosity of sorghum gruel which thus produced thinnest gels (Elkhalifa and Bernhardt, 2013). They also indicated that the involvement of protein in limiting starch gelatinization in germinated sorghums produced thinner gels.

***SWELLING POWER***

Swelling is regulated by the degree of crystallinity of the starch granules and the swelling power is determined by the ability of starch granules to swell in the presence of excess water when heated (Musa et al., 2011) and it reflects the interactions between water molecules and starch chains in amorphous and crystalline domains, respectively (Ratnayake et al., 2002). Swelling power of starch depends on the water holding capacity of glucose molecules as determined by hydrogen bonding. Hydrogen bonds which stabilize the double helices in crystallites are lost during gelatinization and replaced with water. Thus, disruption of the crystalline structure weakens the bonding and allows an increase in granule swelling (Lee and Osman, 1991). The major factor that controls the swelling behaviour of starch is the strength and character of the micellar network within the granule, which in turn is dependent on the degree and kind of association. Also at the molecular level, many factors like, ratio of amylose to amylopectin, the characteristics of each fraction in terms of molecular weight and its distribution, degree of

branching, conformation and the length of outer branches of the amylopectin, they all influenced the degree of association, as well as the size, shape, composition and distribution of the miscellar areas in the internal lattice (Whistler et al., 1965; Teli et al., 2009; Teli and Sheikh, 2011).

Biological activation of grains decreased the swelling power of maize (Teli et al., 2009; Teli and Sheikh, 2011; Adedeji et al., 2014), sorghum (Elkhalifa and Bernhardt, 2013) and brown rice (Musa et al., 2011) flour. Germination decreased the swelling power of the samples probably as a result of disruption of hydrogen atoms inherent in maize by amylases and proteases into sugars and amino acid respectively (Okafor, 1987; Egwim and Ademonom, 2009). During germination α-amylase gets activated and catalyses the hydrolysis of α-1,4 glucosidic linkages in starch and gives rise to oligosaccharides of lower molecular weights such as dextrin, maltose and glucose which do not have any swelling power (Whistler et al., 1965). Teli et al. (2009); Teli and Sheikh (2011) reported that during germination the amylose content increased and the starch granules with higher amylose content were better reinforced and thus were more rigid which ultimately causing swelling less freely when heated. In contrats, Phattanakulkaewmorie et al. (2011) observed nearly four times increase in swelling power in germinated sorghum flour at 95°C, while it was lowered until the temperature at 75°C. As per the study of Chung et al. (2008) this was due of the presences of higher protein, lipid, fat and fiber contents and larger amount of amylose--lipid complex in flour that inhibited the swelling of starch granules and when starch dispersions were heated at high temperature, where the swelling of granules and starch polymer solubilization also occur. Starch granules with low amylase content are less rigid and swell more when heated as opposed to granules with high amylose content which are more rigid and swell less (Sandhya Rani and Bhattacharaya, 1989). However, Tester and Morrison (1990) proposed

that amylopectin and not amylose is mainly responsible for the swelling behavior of starches, while amylose acts only as a diluent.

It has been reported by Phattanakulkaewmorie et al. (2011) and Elkhalifa and Bernhardt (2013), that swelling power of biologically activated and raw grains increased with increase in temperature. Sorghum gelatinises at temperatures above 80°C (Palmer, 1989). Ungerminated sorghum flour had lower swelling power at 85°C than at 100°C (Phattanakulkaewmorie et al., 2011; Elkhalifa and Bernhardt, 2013). The general increase in swelling power with higher temperature is presumably due to granule water uptake, which gelatinizes the starch. As the temperature increased, the starch vibrated more vigorously, breaking intermolecular bonds and allowing hydrogen-bonding sites to engage more water molecules (Claver et al., 2010), which indicates that grain flour requires higher temperatures to reach full granule swelling. Germination had not much effect on sorghum flour swelling power at 85°C as the maximum reduction in the swelling power was by 23% after 3 days of germination but at 100°C the swelling power of sorghum flour decreased by 38.75% as the germination time increased to reach its minimum value after 72 h (Elkhalifa and Bernhardt, 2013). This indicates that the starch granules have been substantially degraded after undergoing maximum swelling around their respective gelatinization temperature. The involvement of protein in limiting starch gelatinization is also supported by the differences in water uptake of germinated and ungerminated sorghum flour at temperatures 85 and 100°C (Elkhalifa and Bernhardt, 2013). Other evidence for the involvement of protein in limiting starch gelatinization was obtained by Chandrashekar and Desikachar (1981), who showed that the addition of papain to sorghum flour prior heating resulted in an increased water uptake.

**PRODUCTS FROM GERMINATED GRAINS**

Today, consumers are increasingly interested in food products with high biological value, excellent sensory qualities and increased shelf life (Iordan et al., 2013). Many researchers had highlighted the health potential of biologically activated or germinated grain and if such grain is used in conventional food, it would intensify metabolism, strengthen immunity, compensate deficiency of vitamins and mineral substances, and normalize acid and alkali balance (Rakcejeva et al., 2005; Rakcejeva et al., 2007). During biological activation of grains generation of bio-functional substances leads to the improvement of the organoleptic qualities due to softening of texture and increase of flavour in barley, finger millet, oat and rye, while problems usually associated with the cooking of brown rice have been resolved (Ohtsubo et al., 2005). Table 4 shows the utilization of different germinated cereal grian in various products like bread, cookies, noodles etc.

Utilization of biologically activated grains as additive were found to increase the nutritive value of bread with high vit C, vit E, dietry fibre, β glucan and folate content in wheat and Egyptian piat breads (Watanabe et al., 2004; Rakcejeva et al., 2005; Rakcejeva et al., 2007; Hefni and Witthoft, 2011). Iordan et al. (2013) reported that the use of biologically active preparations such as sprouted wheat (BAW) at 15% level in bread increased the total sensory quality of bread. Similar results were also observed by Rakcejeva et al. (2005). They observed that incorporation of biologically activated wheat, rye and hull less barley increased the vitamin content in the bread as compared to control samples and value of bread baking loss has also decreased. The evaluation of sensory properties demonstrate that application of biologically activated wheat, rye and barley grain as additives in making of what bread improve its flavour and texture with



 

visible influence on colour of bread crumb and porosity and the panelists also preferred the wheat bread with biologically activated wheat and hull-less barley grain to the other bread samples. Oat and quinoa malts were also incorporated in a rice and potato based gluten free formulation and breads (Mäkinen et al., 2013). Hefni and Witthoft (2011; 2012) also reported that consumption of Egyptian pita bread with enhanced folate content would increase the average daily folate intake by approximately 75 µg.

Utilization of germinated brown rice flour (30%) for bread making in wheat-germinated brown rice flour formulations was reported to prepare a more nutritious bread formulation by Charoenthaikij et al. (2010) without compromising sensory quality. They also observed that this type of bread may be sold as frozen bread that would have a longer shelf life, or may be supplied as a food-service product that would be made-to-order or made fresh daily as currently practiced in some major grocery stores. Morita et al. (2007) also utilize pre-germinated brown rice and along with combination of different additives for bread making. Phattanakulkaewmorie et al. (2011) reported that breads containing germinated sorghum (50:50) had better texture (hardness) than those of ungerminated sorghum bread and malted sorghum bread contained higher level of total phenolic compounds. However, the crust and crumbs of gluten free breads made with sorghum blend were harder and less elastic than those of wheat bread; therefore, some modifications will be needed such as an addition of some hydrocolloids and emulsifiers to obtain the best possible characteristics of gluten free bread from sorghum. Chung et al. (2014) reported that substituting wheat flour with germinated brown rice (GBR) flour for utilization in sugar-snap cookies improved their physical properties with lower moisture content and higher spread factor than those containing untreated GBR flour and also retarding moisture loss and hardening

during storage. They also showed that the cookies with acceptable quality and improved nutrition could be prepared by partial or complete replacement of wheat flour with the heat-moisture treated GBR flour. **Bhol and Bosco (2014)** also observed that the bread with 20% malted finger millet exhibited better sensorial characteristics and textural attributes and had improved nutritional characteristics i.e. dietary fiber, protein and mineral content, hence showing the possibility of utilization of millets to increase the nutritional quality of bread.

**Miyake et al. (2006)** observed that germinated buckwheat was an effective, suitable and useful for the production of *natto* (soba natto) and *miso* paste (soba miso paste) with a low- or non-allergenic reaction and that may replace the typical products made from soybean. Adedeji et al. (2014) utilized germinated maize flour in preparation of cookies and observed that germination resulted in cookies with better gelatinization at different baking temperature with sample that germinated for 72 h having the best result. Replacing 20% of the yoghurt with biologically activated wheat grain flakes improved the organoleptic properties along with improved protein and dietary fibre content (Zagorska et al., 2010). It also improved the flavour and texture of product with greater acceptability and palatability compared with the plain yoghurt (control). Therefore, addition of wheat grain flakes can be a good possibility for enriching nutritive value of yoghurt with dietary fibre. Activated grains were malted for the production of weaning foods, opaque beers and other traditional dishes. Various promising foodstuffs, such as rice-balls, rice bread and soups, have been developed using pre germinated brown rice as primary material (Ito and Ishikawa, 2004; Elkhalifa and Bernhardt, 2010). Utilization of heat-moisture treated germinated brown rice (GBR) in noodles substantially improved cooking and textural qualities comparable to the control wheat noodle (Chung et al., 2012). Heat-moisture treatment allowed

the germinated brown rice to be effectively used as a replacement of wheat flour for noodle making with additional health-promoting and nutritive values.

## CONCLUSION

In the coming years, biologically activated grains should gain a lot of popularity and widely accepted as a functional food because of its nutritious and health benefits in several aspects, as biological activation of grains is an economical processing technology which improves the nutritional properties of grains by removing several antinutrients and improving digestibility grains. Cereals can be biologically activated and dried and then milled into flour that can be utilized in novel food products. This process can improve the nutritional functional and sensory properties of the raw material which in turn can result in partially germinated flour that exhibit higher bioactive components. Apart from changing the level of nutrition, biochemical activities which occur during activation, it also generate bioactive components having health-promoting activities through the enzymatic actions and some of these possess antioxidants and phenolic compounds, γ-aminobutyric acid (GABA), γ-oryzanol, sterols and arbinoxylans thus resulting in an increase of antioxidant activity. The biological activation can improved the functional properties of grains and it would be possible to design new foods and to produce a natural healthy product.



 

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**TABLE 1. EFFECT OF GERMINATION ON ANTIOXIDANT ACTIVITY AND TOTAL PHENOLIC CONTENT OF CEREAL GRAINS**

| **Bioactive component** | **Cereal** | **Activation temperature (°C)** | **Activation time (days)** | **Initial value** | **Final value** | **% increased (+) or decreased (-)** | **Reference** |
|---|---|---|---|---|---|---|---|
| Antioxidant activity (AOX) **(**µmol of Trolox equiv /g of DW**)** | Rice | 28 ± 1°C | 5 days | 1.2 | 1.7 | +41.67 | Umnajkitikorn et al., (2013) |
| AOX **(**µmol of Trolox equiv /g of DW**)** | Brown Rice | 20°C | 2 hrs | 38.7 | 72.7 | +87.86 | Ti et al., (2014) |
| AOX (mg TE/100 g d.m.) | Brown Rice | 28 °C | 24 h soaking | 242.67 | 262.05 | +7.98 | Cáceres et al., (2014) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| AOX (mg TE/100 g d.m.) | Brown Rice | 28 °C | 4 days | 242.67 | 729.60 | +200.66 | Cáceres et al., (2014) |
| AOX (mg TE/100 g d.m.) | Brown Rice | 34 °C | 4 days | 242.67 | 1054.68 | +344.61 | Cáceres et al., (2014) |
| AOX (%AOA) | Brown Rice | 25 °C | 2 days | 11.14 | 15.29 | +37.25 | Gujral et al., (2012) |
| AOX (%DPPH scavenging activity) | Barley | 25 °C | 1 day | 17.39 | 33.28 | +91.37 | Sharma and Gujral (2010) |
| AOX (%DPPH scavenging activity) | Wheat | 37 °C | 2 days | 7.8 | 15.4 | +97.44 | Hung et al., (2011) |
| AOX (%DPPH scavenging activity) | Wheat | 21 °C | 24 hr steeping | 7.8 | 12.8 | +64.10 | Hung et al., (2011) |
| AOX (α - tocopherol | Wheat | 16.5 °C | 8 days | 4.37 | 10.92 | +149.89 | Yang et al., (2001) |



 

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| µg/g) | | | | | | | |
| AOX (%DPPH scavenging activity) | Wheat | Room temp | 2 days | 34.44 | 27.0 | -21.6 | Ramadan et al., (2012) |
| AOX (%DPPH scavenging activity) | Corn | Room temp | 2 days | 33.05 | 26.4 | -20.12 | Ramadan et al., (2012) |
| AOX (%DPPH scavenging activity) | Sorghum | Room temp | 2 days | 37.28 | 25.8 | -30.79 | Ramadan et al., (2012) |
| AOX (%DPPH scavenging activity) | Wheat | Room temp | 12 hr soaking | 34.44 | 32.08 | -6.85 | Ramadan et al., (2012) |
| AOX (%DPPH scavenging activity) | Corn | Room temp | 12 hr soaking | 33.05 | 28.59 | -13.49 | Ramadan et al., (2012) |
| AOX | Sorghum | Room temp | 12 hr | 37.28 | 31.0 | -16.85 | Ramadan et al., |



 

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| (%DPPH scavenging activity) | | | soaking | | | | (2012) |
| AOX (%DPPH scavenging activity) | Common Buckwheat | 25 $^{o}$C | 7 days | 13.5 | 98.8 | +631.85 | Ren and Sun (2014) |
| AOX (%DPPH scavenging activity) | Tartary Buckwheat | 25 $^{o}$C | 7 days | 16.8 | 99.7 | +493.45 | Ren and Sun (2014) |
| AOX (% AOA) | Fingermillet | 28±1°C | 2 days | 55.39 | 30.25 | -45.39 | Karki and Kharel (2012) |
| Total Phenolic Content (TPC) (mg GAE /g) | Oats | 16°C | 6 days | 0.20 | 0.91 | +355 | Tian et al., (2010) |
| TPC(mg GAE/100 g) | Brown rice | 28-30 $^{o}$C | 1 days | 70.3 | 84.3 | +19.91 | Moongngarm and Saetung (2010) |
| TPC (mg GAE/100 g) | Rough rice | 28-30 $^{o}$C | 2 days | 70.3 | 98.6 | +40.25 | Moongngarm and Saetung (2010) |



 

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| TPC (mg GAE/100 g) | Brown rice | 28°C | 24 hr soaking | 57.65 | 66.61 | +15.54 | Cáceres et al., (2014) |
| TPC (mg GAE/100 g) | Brown rice | 28°C | 4 days | 57.65 | 252.16 | +337.40 | Cáceres et al., (2014) |
| TPC (mg/g FAE) | Brown rice | 25°C | 2 days | 0.885 | 0.992 | +12.09 | Gujral et al., (2014) |
| TPC (mg/100 g) | Rye | 18°C | 6 days | 340 | 450 | +32.35 | Katina et al., (2007) |
| TPC (mg/100 g) | Brown rice | 20°C | 2 days | 174.0 | 283.9 | +63.16 | Ti et al., (2014) |
| TPC (mg GAE/100 g) | Wheat | Room temp | 12 hr soaking | 381.4 | 323.5 | -15.18 | Ramadan et al., (2012) |
| TPC (mg GAE/100 g) | Corn | Room temp | 12 hr soaking | 371.3 | 288.5 | -22.3 | Ramadan et al., (2012) |
| TPC (mg GAE/100 g) | Sorghum | Room temp | 12 hr soaking | 204 | 173.6 | -14.9 | Ramadan et al., (2012) |
| TPC (mg GAE/100 g) | Wheat | Room temp | 2 days | 381.4 | 224.7 | -41.09 | Ramadan et al., (2012) |
| TPC (mg GAE/100 g) | Corn | Room temp | 2 days | 288.5 | 161.7 | -43.95 | Ramadan et al., (2012) |
| TPC (mg | Sorghum | Room temp | 2 days | 204 | 130.7 | -35.93 | Ramadan et al., |



 

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| GAE/100 g) | | | | | | | (2012) |
| TPC (µg/g FAE) | Barley | 25 $^{o}$C | 1 day | 3070 | 2512 | -18.18 | Sharma and Gujral (2010) |
| TPC (µg/g FAE) | Wheat | 21 $^{o}$C | 24 hr steeping | 2330 | 2009 | -13.78 | Hung et al., (2011) |
| TPC (µg/g FAE) | Wheat | 37 $^{o}$C | 2 days | 1230 | 1763 | +43.33 | Hung et al., (2011) |
| TPC (µg/g FAE) | Wheat | 16.5 $^{o}$C | 8 days | 590 | 932.4 | +58.03 | Yang et al., (2001) |
| TPC | Common Buckwheat | 25 $^{o}$C | 9 days | 31.9 | 406.5 | +1174.3 | Ren and Sun (2014) |
| TPC | Tartary Buckwheat | 25 $^{o}$C | 9 day s | 24.7 | 553.4 | +2148.48 | Ren and Sun (2014) |
| TPC | Finger millet | 28±1°C | 2 days | 60.9 | 135.3 | +122.17 | Karki and Kharel (2012) |



 

**TABLE 2. EFFECT OF GERMINATION ON BIOFUNCTIONAL COMPONENTS OF CEREAL GRAINS**

| **Bio-functional component** | **Cereal** | **Activation temperature (°C)** | **Activation time (days)** | **Initial value** | **Final value** | **% increased (+) or decreased (-)** | **Reference** |
|---|---|---|---|---|---|---|---|
| Sterols (%) | Oat | 15 $^{o}$C | 3 days | 4.15 | 5.0 | +20 | Wilhelmson et al., (2001); Kaukovirta-Norja et al., (2004) |
| Total Flavonoids (mg catechin/100 g) | Brown rice | 20°C | 2 days | 124.9 | 154.4 | +21.22 | Ti et al., (2014) |
| Total Flavonoids (mg/g) | Tartary Buckwheat | 25 $^{o}$C | 9 days | 9.19 | 108.2 | +1077.4 | Ren and Sun (2014) |
| Total Flavonoids (mg/g) | Common Buckwheat | 25 $^{o}$C | 9 days | 11.4 | 77.6 | +580.7 | Ren and Sun (2014) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rutin(mg/g) | Buckwheat | 25 °C | 9 days | 1.36 | 42.24 | +3005.8 | Ren and Sun (2014) |
| Total free phenylalanine (%) | Buckwheat | 25 °C | 9 days | 3.8 | 123 | +3136.8 | Ren and Sun (2014) |
| Total Flavonoids (mg%) | finger millet | 28±1°C | 2 days | 141.7 | 236.3 | +66.76 | Karki and Kharel (2012) |
| β-glucan (%) | Wheat | 25 °C | 3 days | 0.56 | 0.39 | - 30.36 | Singkhornart et al., (2014) |
| β-glucan (%) | Oat | 15 °C | 3 days | 3.2 | 0.2 | -93.75 | Wilhelmson et al., (2001) |
| Arabinoxylans (AX) (%) | Wheat | 25 °C | 3 days | 2.37 | 2.64 | +11.39 | Singkhornart et al., (2014) |
| AX (g/100g) | Wheat | 16.5 °C | 5 days | 0.50 | 0.61 | +22 | Donker et al., (2012) |
| AX (%) | Rough rice | 37 °C | 5 days | 2.97 | 7.50 | +150 | Kim et al.,(2015) |
| AX (g/100g) | Sorghum | 16.5 °C | 5 days | 0.25 | 0.6 | +140 | Donker et al., (2012) |
| AX (g/100g) | Buckwheat | 16.5 °C | 5 days | 0.2 | 0.45 | +125 | Donker et al., (2012) |
| AX (g/100g) | Brown rice | 16.5 °C | 5 days | 0.10 | 0.50 | +400 | Donker et al., (2012) |
| AX (g/100g) | Barley | 16.5 °C | 5 days | 1.15 | 0.9 | -21.74 | Donker et al., (2012) |
| AX (g/100g) | Oats | 16.5 °C | 5 days | 2.55 | 0.25 | -90.20 | Donker et al., (2012) |
| AX (g/100g) | Rye | 16.5 °C | 5 days | 1.25 | 0.75 | -40 | Donker et al., (2012) |



 

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| γ-oryzanol (mg/100 g) | Brown rice | 30 $^{o}$C | 3 days | 48.2 | 50.4 | +4.56 | Ohtsubo et al., (2005) |
| γ-oryzanol (mg/ g) | Brown rice | 25 $^{o}$C | 1 day | 0.103 | 0.132 | +22.30 | Sie-Cheong et al., (2009) |
| γ-oryzanol (mg/ g) | Brown rice | 25 $^{o}$C | 1 day | 0.270 | 0.121 | -55.18 | Sie-Cheong et al., (2009) |
| γ-oryzanol (mg/100 g) | Rough Rice | 37 $^{o}$C | 5 days | 23.19 | 36.20 | +56.10 | Kim et al., (2015) |
| γ-oryzanol (mg/ g) | Brown rice | 15 $^{o}$C | 3 days | 5.80 | 6.90 | +18.97 | Kim et al., (2012) |
| γ-oryzanol (mg/ g) | Rough Rice | 15 $^{o}$C | 3 days | 6.80 | 7.60 | +11.76 | Kim et al., (2012) |
| γ-oryzanol (mg/100 g) | Brown rice | 28-30 $^{o}$C | 1 day | 66.0 | 84.0 | +27.27 | Moongngarm and Saetung (2010) |
| γ-oryzanol (mg/100 g) | Rough Rice | 28-30 $^{o}$C | 2 days | 66.0 | 104 | +57.58 | Moongngarm and Saetung (2010) |
| γ - aminobutyric | Wheat | 25 $^{o}$C | 3 days | 10.04 | 213.2 | +2023.6 | Singkhornart et al., (2014) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| acid (GABA) (mg/100g) | | | | | | | |
| GABA (mg/100g) | Brown rice | 28-30 $^{o}$C | 1 day | 23.8 | 68.4 | +187.4 | Moongngarm and Saetung (2010) |
| GABA (mg/100g) | Brown rice | 35 $^{o}$C | 3 days | 4.2 | 22.8 | +442.9 | Chungcharoen et al., (2012); (2014) |
| GABA (mg/100g) | Brown rice | 25 $^{o}$C | 3 days | 7.22 | 92.42 | +1180 | Kaosaard and Songsermpong (2012) |
| GABA (mg/100g) | Brown rice | 30 $^{o}$C | 4days | 6.04 | 149.0 | +2367.4 | Ohtsubo et al., (2005) |
| GABA (mg/g) | Brown rice | 30 $^{o}$C | 4 days | 0.10 | 1.81 | +1710 | Roohinejad et al., (2011) |
| GABA (mg/100g) | Rough rice | 28-30 $^{o}$C | 2 days | 23.8 | 115 | +383.2 | Moongngarm and Saetung (2010) |
| GABA (mg/100g) | Brown rice | 15 $^{o}$C | 3 days | 11.5 | 28 | +143.5 | Kim et al., (2012) |
| GABA (mg/100g) | Rough rice | 15 $^{o}$C | 3 days | 15 | 32.5 | +116.7 | Kim et al., (2012) |
| GABA (mg/100g) | Rough rice | 37 $^{o}$C | 4 days | 25.76 | 87.88 | +241.1 | Kim et al., (2015) |
| GABA | Brown rice | 35 $^{o}$C | 1 days | 7.3 | 10.1 | +38.6 | Komatsuzaki et al., |



 

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| (mg/100g) | | | | | | | (2007) |
| GABA (mg/100g) | Brown rice | 35 °C | 48 hr steeping | 2.41 | 28.81 | +1095.4 | Charoenthaikij et al., (2009) |
| GABA (mg/100g) | Brown rice | 35 °C | 48 hr steeping | 2.10 | 67.0 | +3090.5 | Charoenthaikij et al., (2010) |
| GABA (mg/100g) | Brown rice | 34 °C | 4 days | 15.21 | 139.3 | +815.8 | Cáceres et al., (2014) |
| GABA (mg/g) | Barley | 16.5 °C | 5 days | 1.8 | 5.2 | +188.8 | Donker et al., (2012) |
| GABA (mg/g) | Buckwheat | 16.5 °C | 5 days | 0.8 | 1.85 | +131.3 | Donker et al., (2012) |
| GABA (mg/g) | Rye | 16.5 °C | 5 days | 0.9 | 7.95 | +783 | Donker et al., (2012) |
| GABA (mg/g) | Sorghum | 16.5 °C | 5 days | 1.0 | 2.5 | +150 | Donker et al., (2012) |



 

**TABLE 3: EFFECT OF GERMINATION ON FUNCTIONAL PROPERTIES OF CEREAL GRAINS**

| **Functional properties** | **Grain** | **Activation temperature (°C)** | **Activation time (days)** | **Initial value** | **Final value** | **% increase (+) or decreased (-)** | **Reference** |
|---|---|---|---|---|---|---|---|
| Protein solubility (%) | Sorghum | 27 ± 2 °C | 5 days | 46.24 | 88.49 | + 47.75 | Elkhalifa and Bernhardt (2010) |
| Nitrogen solubility (%) | Sorghum | 27 ± 2 °C | 3 days | 42.32 | 63.20 | + 34.67<br>+ 33.04 | Elkhalifa and Bernhardt (2010) |
| Nitrogen solubility (%) | Pearl millet | 25 °C | 5 days | 20 | 40 | +50 | Pelembe et al., (2003) |
| Least gelation concentration (LGC) | Sorghum | 27 ± 2 °C | 5 days | 18 | 12 | - 33.33 | Elkhalifa and Bernhardt (2010) |
| LGC | Finger | 32 ± 2 °C | 2 days | 8 | 16 | +100 | Ocheme and |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | millet | | | | | | Chinma (2008) |
| LGC | Tingernut | 27 ± 2 °C | 3 days | 16 | 12 | -25.00 | Chinma et al., (2009) |
| | | | | 18 | 12 | -33.33 | |
| Water absorption capacity (WAC) | Sorghum | 27 ± 2 °C | 3 days | 131.34 | 141.64 | + 7.27 | Elkhalifa and Bernhardt (2010) |
| | | | 3-5 day | 141.64 | 131.35 | -7.26 | |
| WAC | Amaranth | 40 °C | 1 day | 107.58 | 124.94 | + 13.89 | Adeniyi and Obatolu (2014) |
| WAC | Maize | 32±2 °C | 3 days | 0.94 | 2.79 | +66.31 | Adedeji et al., (2014) |
| WAC | Tingernut | 27 ± 2 °C | 3 days | 2.56 | 6.94 | +63.11 | Chinma et al., (2009) |
| | | | | 3.20 | 6.97 | +54.08 | |
| Oil absorption capacity (OAC) | Sorghum | 27 ± 2 °C | 3 days | 90.56 | 108 | + 16.15 | Elkhalifa and Bernhardt (2010) |
| | | | 3-5 day | 108 | 102.32 | - 5.26 | |
| OAC | Amaranthus | 38°C | 1 day | 31.07 | 35.96 | +13.6 | Adeniyi and Obatolu (2014) |
| OAC | Maize | 32±2°C | 3 days | 1.03 | 2.57 | +59.92 | Adedeji et al., |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | (2014) |
| OAC | Tingernut | 27 ± 2 °C | 3 days | 1.14 | 1.78 | +35.95 | Chinma et al., (2009) |
| | | | | 1.17 | 1.69 | +30.77 | |
| Emulsion capacity (%) (EC) | Sorghum | 27 ± 2 °C | 3 days | 38.5 | 51.25 | + 33 | Elkhalifa and Bernhardt (2010) |
| EC | Amaranth | 40°C | 1day | 2.01 | 31.17 | +1450 | Adeniyi and Obatolu (2014) |
| EC | Maize | 32±2 | 3 days | 47.22 | 65.52 | +38.75 | Adedeji et al., (2014) |
| EC | Tingernut | 27 ± 2 °C | 3 days | 16.40 | 20.25 | +23.48 | Chinma et al., (2009) |
| | | | | 14.32 | 19.50 | +36.17 | |
| Emulsion stability (ES) (%) | Sorghum | 27 ± 2 °C | 3 days | 36.75 | 44.5 | + 21 | Elkhalifa and Bernhardt (2010) |
| ES | Amaranth | 36°C | 1 day | 1.20 | 2.31 | +1450 | Adeniyi and Obatolu (2014) |
| Foaming capacity (FC) (%) | Sorghum | 27 ± 2 °C | 5 days | 0.00 | 11.50 | + 100* | Elkhalifa and Bernhardt (2010) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| FC | Maize | 32±2°C | 3 days | 3.10 | 2.50 | -19.35 | Adedeji et al., (2014) |
| FC | Tingernut | 27 ± 2 °C | 3 days | 8.60 | 12.91 | +50.12 | Chinma et al., (2009) |
| | | | | 7.75 | 11.40 | +47.1 | |
| FC | Amaranth | 32°C | 1 day | 0.00 | 8.45 | +100* | Adeniyi and Obatolu (2014) |
| Foaming stability (FS) | Sorghum | 27 ± 2 °C | 5 days | 0.00 | 82.55 | + 100* | Elkhalifa and Bernhardt (2010) |
| FS | Maize | 32±2°C | 3 days | 15 | 10 | -33.33 | Adedeji et al., (2014) |
| FS | Amaranth | 32°C | 1 day | 0.00 | 6.24 | +100* | Adeniyi and Obatolu (2014) |
| Paste clarity (PC) (% transmittence) | Sorghum | 27 ± 2 °C | 3 day | 32 | 80 | + 150 | Elkhalifa and Bernhardt (2013) |
| PC | Maize | Room temp | 1 day | 2.83 | 2.13 | -24.7 | Teli et al., (2009); Teli and Sheikh (2011) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Freeze-thaw stability (% syneresis) | Sorghum | 27 ± 2 °C | 3 days | 12 | 40 | + 233 | Elkhalifa and Bernhardt (2013) |
| Gel consistency (mm) | Sorghum | 27 ± 2 °C | 3 days | 35 | 85 | + 142 | Elkhalifa and Bernhardt (2013) |
| Swelling power (SP) (g/g) | Sorghum | 27 ± 2 °C | 3 days | 8 | 4.9 | -38.75 | Elkhalifa and Bernhardt (2013) |
| SP | Maize | 25°C | 1 day | 9.07 | 3.57 | -60.64 | Teli et al.,(2009) |
| SP | Maize | 25 °C | 1 day | 9.64 | 6.55 | -32.1 | Teli and Sheikh (2011) |
| SP | Maize | 32±2 °C | 3 days | 19.81 | 15.0 | -24.28 | Adedeji et al. (2014) |
| SP | Sorghum | 27°C | 2 days | 0.16 | 0.20 | +25 | Phattanakulkaewmorie et al., (2011) |
| SP | Brown rice | _ | _ | 1.76 | 1.70 | -3.41 | Musa et al., (2011) |

**TABLE 4: PRODUCTS PREPARED FROM GERMINATED CEREAL GRAINS**

| **Germinated grain** | **Product in which grains are incorporated** | **Reference** |
|---|---|---|
| Wheat | Bread | Hefni and Witthoft (2011; 2012); Iordanet al., (2013), |
| Wheat, Rye, Barley | Bread | Rakcejeva et al., (2005) |
| Oat and quinoa | Bread | Mäkinen et al., (2013) |
| Brown rice | Bread | Watanabe et al., (2004); Morita et al., (2007); Charoenthaikij et al., (2010b) |
| Oat | Bread | Rakcejeva et al., (2007) |
| Sorghum | Bread | Phattanakulkaewmorie et al., (2011) |
| Finger millet | Bread | Bhol and Bosco (2014) |
| Buckwheat | *Natto* and *Miso* paste | Miyake et al.,(2006) |
| Wheat | Yoghurt | Zagorska et al.,(2010) |
| Maize | Cookies | Adedeji et al., (2014) |
| Brown rice | Cookies | Chung et al., (2014) |
| Brown rice | Noodles | Chung et al., (2012) |



 