Effects of Processing on Phytonutrient and Nutritional Composition of Finger Millet (*Eleusine coracana*): The Neglected Crop of Africa

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Abstract

Millets are termed as nutricereals since they are nutritionally superior to major cereals with respect to protein, energy, vitamins and minerals. The aim of this research was to investigate the effects of processing techniques on the proximate composition and reduction of phytonutrients in finger millet grains. Germination (72hrs) and natural fermentation (24hrs) process of finger millet seeds improved crude protein. A significant ($p<0.05$) variation was noticed within 72hrs of germination in the total amount of calcium, iron and phosphorous due to the transfer of nutrients from the seed material to the growing embryo. The flour was extruded at a temperature of 110 $^{\circ}$C and 130°C, a screw speed of 200 and 250 rpm, and 17 and 21 feed moisture content. The highest expansion ratio and lowest bulk density was obtained at temperature of 130 $^{\circ}$C, screw speed of 250 rpm and 17% moisture content. A significance difference was observed during extrusion processing on elimination of phytate as compared to germination and fermentation. Fermentation (48 hrs) and extrusion (130 $^{\circ}$C) were found to be the best process methods for the reduction of the phytate and tannins, respectively. The improved physical properties of extrudates and level of reduction of phytonutreints indicate the possibility of diversifying utilization of finger millet in the form different indigenous community based added value products and novel commercial value added products at manufacturing industry level.

Key words: Extrusion cooking, extrudates, finger millet, phytonutrients, processing methods

Introduction

Among the millets of the world, finger millet (*Eleusine coracana* sub species *coracana*) ranks fourth in importance after sorghum, pearl millet and foxtail millet (Upadhyaya *et al*., 2007). Grains of finger millet are consumed as unleavened bread, porridge, and making beer (Desai *et al*., 2010). Finger millet is African native originated in the highlands of Ethiopia and Uganda, where subsistence farmers have been growing it for thousands of years. In parts of Eastern

and Southern African countries including Mozambique, Zambia, Uganda, Southern Sudan and Ethiopia finger millet is the principal cereal grain.

Africa produces two million tons which is 44% of the World finger millet grain production. For all its importance, however, finger millet is unacceptably neglected both scientifically and internationally (National Research Council, 1996). Finger millet (*Eleusine coracana*) is hardly "lost." Indeed, it is one of the few special species that currently support the World's food supplies. Compared to the research lavished on wheat, rice, and maize, for instance, it receives almost none. Most of the World has never heard of it, and even many countries that grow it have left it to languish in the limbo of a "poor person's crop," a "famine food," or, even worse, a "birdseed" (National Research Council, 1996). The World's attitude towards finger millet must be reversed. Of all major cereals, this crop is one of the most nutritious. Indeed, some varieties appear to have high levels of methionine, an amino acid lacking in the diets of hundreds of millions of the poor who live on starchy foods such as cassava and plantain. Taylor *et al* (2006) stated that millet is underutilized crop in most developed countries. In developing countries, the commercial processing of these locally grown grains into value-added food and beverage products is an important driver for socio-economic development.

Many African countries including Ethiopia that grow finger millet have left somehow as one of the neglected crops of Africa (National Research Council, 1996). Finger millet (*Degussa*) occupies on average 5% (228,000 ha) of the total area devoted to cereal production and accounts for 4% of total cereal yield annually in Ethiopia. It is an important crop in parts of Gojjam, Gonder, Wlollega, Illubabur, Gamo-Gofa, Easter Haraghe and Northern Tigray. Finger millet also becomes an important crop in parts of the Ethiopian central rift valley including Arsi Negelle, Shashemene and Siraro areas (Erenso Degu *et al*., 2009). The agricultural research institutes, food research centers, manufacturing food industries, nutrition and health institutes are not giving much passion for the large scale production, processing, utilization and commercialization of finger millet based products in either in modern marketing channels or house hold consumption and industrial manufacturing which in turn contributes for food security in the East and central African countries context.

Of all major cereals, finger millet grain is one of the most nutritious and has high biological value, with good amounts of essential amino acids. All of these are crucial to human health and growth and are deficient in most cereals. Millets contain good sources

of dietary fiber, minerals and phytochemicals with antioxidant activity (Anubha et al., 2015). Phytochemicals (phenolic compounds and phytates) are responsible for higher antioxidant activity in whole grain foods (Sridevi *et al*., 2008). Millet has been shown to be helpful in prevention of type 2 diabetes mellitus, cardiovascular disease and cancer due to its low glycemic index and antioxidant activity. The hypoglycemic effect of millets with their high crude fiber, dietary fiber, antioxidant, low carbohydrate content, low digestibility and also have ß-glucans, which are water soluble gums helpful in impairing glucose metabolism (Itagi *et al*., 2012).

Finger millet described as nutritious millet and has received far less research and development attention than other crops with regard to crop improvement, processing, product commercialization and utilization. It is the main source of protein and minerals in the daily diets of tribal and very low income generating community who are living in remote rural areas. Millets contain water soluble fiber and this property may be utilized for maintaining or lowering blood glucose response among diabetic and CVD (cardiovascular disease) patients.

Finger millet has numerous utilization aspects such as porridge, bread, malt, beverages. Much finger millet in Africa is used to make beer. Its amylase enzymes readily convert starch to sugar. Indeed, finger millet has much more of this "saccharifying" power than does sorghum or maize; only barley, the world's premier beer grain, surpasses it. In Ethiopia, finger millet is also used to make “arake”, a powerful distilled liquor. This high-methionine grain might also be beneficial for use in weaning foods. This is a versatile grain that can probably be used in dozens of types of foods, including many that are quite unlike its traditional ones. For this reason alone, finger millet is important preventative against malnutrition. The essential amino-acids are of special benefit, notably for those who depend on plant foods for their protein. Finger millet is also rich sources of minerals (iron and calcium). High-methionine finger millet grain composition is beneficial for use in weaning foods and excellent malting qualities, increasing its use in food processing. Processing of finger millet-based value added products in the African context is very crucial to give substantial momentum towards food and nutrition security. Finger millet value added products include processing of high-methionine weaning foods, beverages, porridge, bread/cookies, malt, extruded, parboiled, popped products and puffed products (Malleshi, 1986).

Finger millet is one of the future crops which can make a significant contribution in reducing protein-energy malnutrition problem in the African region and manufacturing of

gluten free food products. Finger millet is valued for its versatility as a staple food, its excellent storage quality, adapted to various agro-climatic conditions, and can be stored for up to two years without harmful pesticides, acting as a food reserve during the lean season. Finger millet also has a short harvesting time and thus can be grown more than once a year in certain regions (Barbeau *et al*., 1993).

Cereals and legumes contain significant amounts of phenolic compounds, and also have been reported in finger millet (Anubha et al., 2015). Phytate has long been recognized as one of phytonutrients, affecting the bioavailability of some minerals such as Ca^{2+} and Mg^{2+} and trace elements such as $Zn^{2+,}$ Fe^{2+}, Cu^{2+} and Mn^{2+} (Mbithi-Mwikya *et al*., 2000). Other phytonutrients that cause reduction of proteins and carbohydrates availability by binding these nutrients in finger millet are tannins (Siwela *et al*., 2007). Among millets, finger millet was reported to contain high amounts of tannins (Shashi *et al*., 2007), ranging from 0.04 to 3.47 % catachin equivalent.

Renewing one of the lost crops of Africa-Finger millet that the grains still hold promise via value addition is expecting to contribute for food and nutrition security to the welfare of nations around the world specifically to Africa towards preeminent economic and social development opportunities. Finger millet based value added products processing can emerge business solutions to poverty reduction. Finger millet being a nutricereal can be used to develop Ready-To-Eat snack food products through processing of composite mixes. The purpose of this research paper was to examine the effects of processing methods (extrusion cooking, hydration, germination and fermentation) on the nutrient composition and reduction of phytonutrients concentration of finger millet seeds grown in Ethiopia.

Materials and Methods

Sample Collection and Preparation

The finger millet varieties *Padet* and *Dibates* in this study were grown at Melkassa and Pawe agricultural research center, respectively. The Black type of finger millet grains were obtained from local markets of Addis Ababa (*Ehil Berenda, Mesalemia*, Addis Ababa). Finger millet varieties are selected based on seed color, potential nutritional and phytonutrient compositions. The test samples were cleaned manually to remove husks, damaged grains, stones, dust, light materials, glumes, stalks, undersized and immature grains and other extraneous materials. All samples were ground using cyclone mill and then packed in airtight dark brown polyethylene plastic bags until further analyses took place.

Processing Methods

The conventional processing methods used for the reduction/elimination of phytonutrients were hydration, germination and fermentation. Finger millet seeds were soaked for 8hrs in a volume of water 3 times (3:1) the weight of seeds on dry weight bases and germinated for 48 and 72hrs using household germination practices at 30^{o}C in incubator. Soaked and germinated grains were made dry using air circulating oven at temperature of 65 ^{0}C. Dry samples were milled using sample mill and made to pass through 0.71mm mesh size sieve. The milled flour was then fermented in glass containers at a concentration of 1:2 w/v grain to H_2O at 30^{o}C in an incubator for 24 and 48hrs (Ali *et al*., 2009). Following each processing method phytonutrient and proximate compositions were analyzed.

Extrusion process of finely ground seeds were performed in laboratory scale twin screw extruder (Clextral X-5, model BC 45, F-42100, Made in France). The finger millet flour samples for the reduction of phytonutreinst were extruded at a barrel temperature of 110^{o}C and 130^{o}C, screw speed of 200 and 250 rpm, and 17 and 21 feed moisture content. Moisture, temperature and screw speeds are chosen from pre-test experiments. The extruded products were placed on a table and allowed to cool for 30 min at room temperature for the measurement of weight, length and diameter. Extruded products were size reduced and then packed in airtight dark brown plastic bags until further analyses (Ibanoglu, *et al*., 2005).

Physical Properties of Extruded Finger Millet Products

Specific Length and Degree of Expansion: Sample products were extruded as straight ropes for a time interval of ten seconds. Length was measured by a pocket size steel tape of 1mm accuracy. The diameter of the extrudates were measured by a Vernier Caliper having 0.05mm precision. Weight was measured by a digital balance (ADAM, AFP 1200, South Africa) of 0.01 sensitivity. The expansion ratio is defined as the ratio of the diameter of the extrudates to the diameter of the die hole (Mason and Hoseney, 1986). The specific length of the extrudates is defined as the length (cm) of the extrudates per unit weight (g).

Bulk Density: From the measurements of weight, length and diameter as stated above, immediately after extrusion, the bulk density of the extrudates was calculated (Mason and Hoseney, 1986).

$$\rho = \frac{4w}{\pi d^2 * L}$$

Where: ρ-Bulk density (g/cm^3)

d-Diameter of extrudate (cm)
L-Length of extrudate (cm)
W-Weight of extrudate (g)

Experimental Analysis of Nutrient Composition

Proximate Composition: Fat, protein, ash and fiber contents of the flour was determined by the methods of Association of Official Analytical Chemists (AOAC, 1990) on dry matter basis. Ash and fiber were also evaluated. Total carbohydrates were calculated by differences.

Mineral Composition: The mineral contents were determined by AOAC (1984). Calcium, iron and zinc were determined using an Atomic Absorption Spectrophotometer. Phosphorous was determined by calorimetric method using ammonium molybdate.

Analysis Methods for Phytonutrients

Phytic Acid: Phytic acid analysis was determined by using Latta and Eskin (1980) as modified by Vaintraub and Lapteva (1988). The phytate of samples were extracted from about 5 mg of dry sample with 100ml, 2.4% HCl for 1hr at an ambient temperature and centrifuged (3000 rpm/30min). The supernatant was used for phytate estimation. About 1 ml of Wade reagent was added to 3ml of the sample solution and centrifuged. The absorbance at 500 nm was read using UV-VIS spectrophotometer (Beckman DU-64-spectrometer, USA).

Tannins: Tannins were determined by the modified vanillin assay (Butter *et al*., 1982) using catechin standard. Using spectrophotometer, the absorbance of sample solution and the standard solution were measured at 500 nm.

Experimental Design and Statistical Data Analysis: Data generated from the CRD were analyzed by one-way analysis of variance (ANOVA) at 5% level of significance using JMP software for statistically analyses.

Results and Discussion

Effects of Processing Methods on Phytonutrient and Nutritional Composition

Effect of germination on nutrient and phytonutrient composition of finger millet varieties

There was a slight but significant ($p<0.05$) increased in protein content at each sampling time as shown in Table 1. Protein increased ranged from 10 to 35% in Padet and Dibates and local varieties during germination. These increases have been attributed to dry matter loss, particularly carbohydrates, through respiration, causing an apparent increase in other nutrients such as protein. Malleshi and Desikacher (1986) reported that germination of finger millet for 48 hrs enhanced the essential amino acid including lysine and tryptophan; however, the sulfur containing amino acid content was not altered appreciably.

Table 1: Effect of Germination on Phytonutrient and Nutritional Composition of Finger Millet Varieties

Varieties	Time of fermentation	Nutrients Composition (%)					Phytonutrient	
		AAsh (%)	Protein	Fiber	Fat	Carbo-hydrates	Tannin (mg/100g)	Phytate (mg/100g)
Padet	0hr	2.5±0.02^{b}	8.9±0.02^{d}	5.83±0.03^{f}	1.8±0.01^{b}	79^{c}	552±0.4^{b}	583±0.08^{d}
	48hrs	2.15±0.01^{c}	7.8±0.02^{e}	6.03±0.01^{e}	1.3±0.01^{e}	80.5^{a}	182±0.01^{f}	179.3±0.4^{f}
	72hrs	0.99±0.02^{f}	10±0.2^{b}	5.15±0.05^{g}	1.4±0.02^{d}	79^{c}	190±0.4^{e}	179.4±0.1^{f}
Dibatse	0hr	1.81±0.01^{d}	9.1±0.0^{cd}	7.0±0.18^{d}	1.84±0.02^{b}	79.6^{b}	1255.3±0.4^{a}	1353.5±0.4^{a}
	48hrs	1.28±0.03^{e}	9.3±0.02^{c}	4.5±0.08^{h}	1.38±0.03^{d}	79.5^{b}	410.4±0.8^{c}	778.6±0.3^{b}
	72hrs	1.23±0.03^{e}	12.0±0.28^{a}	5.1±0.08^{g}	0.87±0.04^{f}	77.3^{e}	407.7±0.4^{c}	759.88±0.2^{c}
Local variety	0hr	2.7±0.08^{a}	8.1±0.01^{f}	8.1±0.21^{c}	2.3±0.06^{a}	79.2^{c}	253.3±0.2^{d}	481±0.21^{e}
	48hrs	2.4±0.11^{b}	8.5±0.02^{e}	9.8±0.18^{b}	1.3±0.0^{e}	80.2^{a}	50.5±0.01^{h}	115±0.16^{g}
	72hrs	2.7±0.04^{a}	9.3±0.08^{c}	10.8±0.04^{a}	1.5±0.05^{c}	78.5^{d}	66±0.02^{g}	87±0.08^{h}

Key: $^{a-h}$ All values are means ± SD. The same superscript letters within a column are not significant different ($p>0.05$).

Germinated finger millet cultivars significantly ($p< 0.05$) decreased crude fat and ash content. The observed decrease in fat content of finger millet during germination might be attributed to the increased activities of lipolytic enzymes during germination, which hydrolyze fats to fatty acids and glycerol or use of fat as an energy source in sprouting process (Ahmadzadeh and Prakash, 2007). The fat contents of finger millet flour decreased during germination help to extend the shelf-life since food products with low values of fat have better shelf-life than similar products with high fat content. In contrast, food products containing high fat are susceptible to both hydrolytic and oxidative or enzymatic rancidity responsible for both the general acceptability and storage stability of

the product (Tizazu *et al*., 2009). The observed decrease in ash content of finger millet flour samples during germination might be due to leaching of minerals during steeping and washing (Ahmadzadeh and Prakash, 2006). The crude fiber content of germinated samples was slightly higher than the control samples. This could be due to the dissipation of some of the starchy endosperm during germination which causes apparent increase in seed coat proportion.

Germination for 48hrs significantly ($p<0.05$) reduced total phytate from 1353.5 to 778.6, 583 to 179.3, and 481 to 115 mg/100g for Dibatse, Padet, and local varieties, respectively. The reduction rate continued and reached its maximum value of 759.8 mg/100g, 179.4mg/100g and 87mg/100g for the varieties, respectively when the flour germinated for 72h. Germination and malting processes are known to activate phytases, which in turn hydrolyze phytate, rendering iron and zinc more available. During germination, endogenous phytase activity in cereals and legumes increases as a result of *de novo* synthesis and/or activation, resulting in reductions in inositol penta- and hexa-phosphates depending on the species and variety (Hemalatha, *et al*., 2007). Tizazu *et al*. *(*2010), also stated that decrease in phytic acid content during germination of cereals including sorghum it could be due to increase in phytase activity. The rate of phytate hydrolysis varies with the species and variety as well as the stage of germination, pH, moisture content, temperature (optimal range 45-57^{o}C), solubility of phytate, and the presence of certain inhibitors (Hotz and Gibson, 2007). Egli *et al*. (2002) observed that during germination, rice, millet, and mung bean had the largest reduction in phytate content. However, Hemalatha, *et al*. (2007), reported that phytate content of finger millet, green gram and chickpea are not affected at 24 and 48 h germination time, while tannin contents and the bioavailability of iron were improved. Phytate_and tannin are reported to be potent inhibitors of iron bioavailability. In the absence of any decrease in phytate content of the grains, the reduction in tannin content during germination of the test could be a factor that contributed to the increase in the bio-accessibility of iron (Hemalatha, *et al*., 2007).

Chopra and Sankhala (2004), has been examined the influence of soaking and germination in horse gram and moth bean, which are rich in phytate and tannin. The amount of tannins and phytates were affected after soaking for 8 and 16 h. Reduction of this phytonutrients were more significant after 24 hrs germination. The bioavailability of iron also improved after soaking and germination.

The tannin content of millet was also found to reduce during this study. Tannin content in control sample was 1255.3, 552 and 253.3mg/100. Hemalatha, *et al*., (2007), have reported germination was reduced tannin contents significantly. The reduction was 44 and 50% in the case

of finger millet, 43 and 74% in the case of green gram, and 47 and 52% in the case of chickpea, respectively after 24 and 48 hrs germination. This decreased steadily and by 72hrs it was undetectably low. Tannins have been found to inhibit digestive enzymes and thereby lower digestibility of most nutrients, especially protein (Ali *et al*., 2009). The observed reduction in tannin content in germinated seeds has been attributed to the formation of hydrophobic associations of tannins with seed proteins and enzymes and not due to actual loss or degradation of tannins.

According to Shimelis and Rakshit (2008), decreased in tannin content during germination may be due to the leaching of tannins in the sprouting medium and decreased activity of polyphenol oxidase and other catabolic enzymes. Hotz and Gibson (2007) also stated that certain tannins and other polyphenols in legumes and sorghum may also be reduced during germination as a result of formation of polyphenols complexes with proteins and the gradual degradation of oligosaccharides. Such reductions in polyphenols may facilitate iron absorption. Mbithi-Mwikya *et al.* (2000), also has been report the inverse relationship between tannin content and in vitro protein digestibility of the germinated finger millet product.

Effect of natural fermentation on nutrient and phytonutrient composition of finger millet

The protein content of the three finger millet varieties (Table 2) increased initially as a result of fermentation. When the flour fermented for 24hrs, the total protein content increased significantly ($p< 0.05$) from 9.1% to 13.0 % for Dibatse and 8.9% to 10.8% for Padet varieties, However, not significant ($p<0.05$) in the case of local variety.

The research findings by Mugocha (2001) revealed that fermentation of finger millet increased total protein content. This is due to the decrease in starch and sugar as a result of hydrolysis by bacteria enzymes with the formation of volatile products such as lactic acid, acetic acid, carbon dioxide, and ethanol. This leads to changes in proportions of nutrient components. It is believed that the increase in protein content at the expense of starch is beneficial to consumers who need a higher protein intake. Improvement in protein quality have also been documented after fermenting blended mixtures of plant-based complementary foods based on maize and legumes, groundnut and millet and cereal and soya bean blends (Hotz and Gibson, 2007). According to the authors such improvements may be associated with the destruction by microbial enzymes of protein inhibitors that interfere with nitrogen digestibility, or from the ability of

starter cultures to synthesize certain amino acid. Fat, fiber and ash contents had significantly ($p<0.05$) decreased during fermentation. Decreased in fiber content during fermentation could be attributed to the partial solubilisation of cellulose and hemicellulosic types of material by microbial enzymes (Mugocha, 2001).

Total carbohydrates content of the unfermented samples is 79.55%, 79%, and 79.2% for Dibatse, Padet and Local varieties, respectively. Fermentation for 48 hrs caused a significant ($p<0.05$) reduction of total carbohydrate in Dibatse and Local varieties, while non-significant ($p>0.05$) variation was observed for Padet variety. The result of this findings concerning the effect of natural fermentation on ash and fiber contents are inconsistent with the research report of Amankwah *et al*. (2009) which states that ash and crude fiber contents increased during fermentation of corn meal.

Fermentation of the varieties for 24hrs significantly ($p<0.05$) reduced total phytate from 1353.5 to 828.3, 583 to 266, and 481 to 394 mg/100g for Dibatse, Padet, and Local finger millet samples, respectively. The reduction rate continued and reached its maximum value of 689.3 mg/100g, 199mg/100g and 99.4mg/100g for the varieties, respectively when the flour fermented for 48h. It has been suggested that by different investigators the loss of phytate during fermentation could be a result of the activity of native phytase and/or the fermentative microflora (Elyas *et al*., 2001; Shimelis and Rakshit, 2008).

Fermentation can induce phytate hydrolysis via the action microbial phytase enzymes, which hydrolyze phytate to lower inositol phosphates. Such hydrolysis is important because myoinositol phosphates with < 5 phosphate groups (i.e., IP-1to IP-4) do not have a negative effect on zinc absorption, and those with < 3 phosphate groups do not inhibit nonheme iron absorption (Hotz and Gibson, 2007). Most of the reduction of phytate occurred during the 48h of fermentation. This may be due to the prevailing pH which is considered to be an optimum pH for microbial phytase activity, since all enzymes have a specific pH in which they function most proficiently. The low pH of the fermented product and the temperature of fermentation may provide favorable conditions for phytase activity has been shown in an earlier study by Dhankher and Chauhan (1987).

Investigators indicated that there are differences in optimal conditions for phytate degradation between plant species. Shimelis and Rakshit (2008) reported that 4-6 as pH optima of phytase activity. The percentage decrease in phytate content was 49, 66, and 79 for Dibatse, Padet, and Local varieties, respectively. Dhankher and Chauhan (1987) reported that endogenous phytase pearl miller contributed significantly to the

reduction of the phytate content of fermented flour which was dependent on pH and temperature of fermentation.

The extent of the reduction in higher inositol phosphate levels during fermentation varies; sometimes 90% or more of phytate can be removed by fermentation of maize, soybeans, sorghum, cassava, cocoyam, cowpeas, and lima beans (Hotz and Gibson, 2007). However, the percentage reductions in phytate achieved within 48h by the three varieties are significantly different ($p<0.05$). In 48h fermentation more phytate reduction was achieved in Padet and Local than Dibatse. This may be described that with high tannin content in Dibatse; phytase activity is inhibited. And thus making fermentation a less-effective phytate-reducing method for these finger millet varieties (Hotz and Gibson, 2007). The presence of tannins in finger millet not only reduces the availability of nutrients, but also inactivates the phytase enzymes. The use of lactic acid fermentation for high- tannin grains therefore could be less effective to reduce the phytate content.

Fermentation at 24hrs for the three varieties are significantly ($p< 0.05$) reduced total tannin, expressed as catechin equivalents (CE). The reduction continued and reached its maximum value when the flour was fermented for 48h. The reduction in tannin content of fermented samples has significant ($p<0.05$) difference compared to unfermented sample. The effect of natural fermentation on the reduction of tannins are not the same with the report of Elyas *et al*. (2002), stated that fermentation for 36 h at room temperature was found to cause no changes in tannin content of pearl millet due to the use of natural fermentation method. Natural fermentation method frequently caused by natural microbes that are a function of the environment and raw materials used.

Table 2: Impact of Fermentation on Nutrient and Phytonutrient Composition of Finger Millets

Varieties	Time	Nutrients Composition (%)					Phytonutrients	
		Ash	Protein	Fiber	Fat	Carbo-hydrates	Tannin (mg/100g)	Phytate (mg/100g)
Padet	0hr	2.5±0.03^{b}	8.9±0.02^{e}	5.83±0.04^{c}	1.8±0.01^{c}	79.6^{b}	552±0.4^{c}	583±0.08^{d}
	48hrs	1.9±0.06^{cd}	10.8±0.03^{b}	5.6±0.06^{d}	1.7±0.01^{d}	76.6^{e}	362±0.3^{d}	226±0.4^{g}
	72hrs	1.3±0.04^{f}	8.6±0.06^{e}	4.1±0.06^{f}	1.3±0.02^{g}	80.0^{a}	214±0.04^{f}	199±0.3^{h}
Dibatse	0hr	1.81±0.01^{d}	9.1±0.0^{d}	7.0±0.18^{b}	1.84±0.02^{c}	79.6^{b}	1255.3±0.4^{a}	1353.5±0.4^{a}
	48hrs	1.76±0.01^{e}	13.0±0.02^{a}	6.5±0.03^{b}	1.59±0.02^{f}	75.1^{f}	663.5±0.18^{b}	828.3±0.4^{b}
	72hrs	1.11±0.01^{g}	10.4±0.09^{c}	4.5±0.01^{e}	1.24±0.01^{h}	78.3^{d}	363.4±0.1^{d}	689.3±0.5^{c}
Local	0hr	2.7±0.1^{a}	8.1±0.01^{g}	8.1±0.16^{a}	2.3±0.04^{a}	79.2^{c}	253.3±0.2^{e}	481±0.21^{e}
	48hrs	1.8±0.1^{d}	8.2±0.01^{g}	7.7±0.11^{a}	2.1±0.01^{b}	79.2^{c}	143±0.3^{g}	394±0.4^{f}
	72hrs	2.0±0.1^{c}	8.3±0.04^{f}	6.4±0.25^{b}	1.3±0.04^{g}	73.0^{g}	92±0.4^{h}	99.4±0.2^{i}

$^{a-i}$ All values are means ± SD. The same superscript letters within a column are not significant different (p>0.05)

Influence of extrusion cooking on phytonutrient and nutritional composition

Feed moisture, barrel temperature and screw speeds are chosen from pre-test experiments of the extrusion process. The effect of extrusion cooking on proximate composition of finger millet extrudates with a barrel temperature of 110^{o}C and 130^{o}C, a screw speed of 250 rpm, and 21% of feed moisture was presented on Table 3. The protein, crude fiber, ash and fat amount of extruded product were significantly ($p< 0.05$) decreased in both barrel temperatures. High temperature and low water content aids the Maillard reaction and reduces the nutritional value of the protein. However, heat may increase digestibility of protein, carbohydrates, and other nutrients, thereby enhancing the nutritive value of the food (Thilagavathi *et al*, 2015). Agroturia (1997), have reviewed that soybeans and oilseeds or legumes provide a good example of improved protein digestibility and bioavailability of sulphur amino acids through thermal unfolding of the major globulins, and thermal inactivation of trypsin inhibitors and other growth-retarding factors such as lectins. And lysine loss can take under sever conditions of temperature or shear force (>100rpm) at low moisture (<15%) especially in the presence of reducing sugar.

The observed decrease in fat content of finger millet during extrusion on in this study might be as a result of oxidation, hydrogenation, isomerize-tion or polymerization of fat. How-ever, the amount of hydrogenation and cis-trans isomerization of fatty acids that takes place during extrusion is too small to be nutritionally significant. Extrusion-inactivation of lipase and lipoxidase helps protect against oxidation during storage. Higher temperatures reduce the lipase activity and moisture level, thereby decreasing favoring free fatty acids development (Agroturia 1997),

The reduction of phytic acid in extrusion process was less significant compared with germination and

fermentation processing methods. These could be during food processing, such as soaking; germinating, and fermenting, phytate is hydrolyzed because of the activation of intrinsic plant phytases, extrinsic microbial phytases, or both. However, thermal processing can lead to a partial nonenzymatic hydrolysis of phytate. Because phytate is heat-stable, significant heat destruction of phytate is not expected to occur. Prolonged times at elevated temperatures were lead to a progressive inactivation of the endogenous enzymes.

In the present study, the effect of extrusion showed a 62 % and 78% reduction of tannins at the 110^{o}C and 130^{o}C treatment temperature, respectively. This high extrusion temperature can affect the molecular structure of tannins and polyphenols, and thus improve digestibly, bio-availability of nutrients and diminishing fatty acid development. Furthermore, the chemical modification may alter solubility of tannins or chemical reactivity. Alonso and Marzo (1998) stated that thermal processing methods were the most effective in the reduction of condensed tannins. Accordingly, using optimum feed moisture level and ideal barrel temperature can enhance nutritional value of end products processed by extrusion cooking.

Table 3: Influence of Extrusion Cooking on Phytonutrient and Nutritional Composition

Temperature	Protein (%)	Fat (%)	Fiber (%)	Ash (%)	Carbohydrates (%)	Phytate (mg/100g)	Tannin (mg/100g)
Untreated	9.1±0.01^{a}	1.8±0.02^{a}	7.0±0.18^{a}	1.81±0.01^{a}	79.6^{a}	1353.5±0.4^{a}	1255.3±0.4^{a}
110^{0}c	7.6±0.01^{c}	1.0±0.01^{b}	6.6±0.01^{b}	1.69±0.01^{b}	78.7^{a}	951.3±0.14^{b}	478.4±0.84^{b}
130^{0}c	7.8±0.01^{b}	1.0±0.01^{b}	6.0±0.01^{c}	1.67±0.04^{b}	77.0^{b}	950.5±0.4^{b}	273.7±0.1^{c}

$^{a-c}$ All values are means ± SD. The same superscript letters within a column are not significant different (p>0.05)

Influence of Hydration Process on Phytonutrient Reduction

The level of tannins and phytic acid in the samples have been affected by hydration (soaking) process in distilled water was presented in Table 4. Hydration process (8h) significantly ($p< 0.05$) reduced the phytic acid contents of all the three finger millet varieties. Soaking of these grains generally had very little influence on the phytic acid concentration. The most pronounced effect was found for Local variety, in which the phytic acid content was decreased by 16.4% of the initial values.

According to Egli *et al.* (2002) reported during soaking, phytase activity of all cereals decreased. The decreased ranged from 10% of the initial value for millet and about 60% of the initial value for barley. However, an increased in the phytase activity with a decrease in the level of phytate as a result of hydration in

haricot bean had been indicated in the research investigated by Shimelis and Rakshit (2008). Some of this loss could be explained by leaching of phytate ions into the soaking water under the influence of concentration gradient (difference in chemical potential) which governs the rate of diffusion. And temperature and pH value have been also shown to have a significant effect on enzymatic phytate hydrolysis during soaking (Greiner and Konietzny, 2006). The percentage loss of phytic acid and tannins during hydration revealed significant ($p<0.05$) differences for each variety.

Effect of Germination and Natural Fermentation Processes on Mineral Composition

The effects of germination and fermentation on mineral content of Dibatse variety was presented in Table 5. The effect of extrusion cooking on mineral content not included because of extrusion has a slightly significant effect on the reduction of phytate. Thus not predominantly improve the bioavailability of mineral.

Table 4: Influence of Hydration Process on Phytonutrient Reduction

Hydration (8hrs)				
Varieties	Unprocessed (Control)		Processed	
	Phytate(mg/100g)	Tannin(mg/100g)	Phytate(mg/100g)	Tannin(mg/100g)
Padet	583.0±0.08^{b}	552.0±0.4^{b}	515±0.01^{b}	449.0±0.14^{b}
Dibatse	1353.5±0.4^{a}	1255.3±0.4^{a}	1238.3±0.4^{a}	970.0±0.03^{a}
Local	481.0±0.21^{c}	253.2±0.2^{c}	402.0±0.24^{c}	211.0±0.02^{c}

$^{a-c}$ All values are means ± SD. The same superscript letters within a column are not significantly different (p>0.05

Table 5: Effect of Germination and Natural Fermentation Processes on Mineral Composition of Dibatse Finger Millet Variety

Processing Methods	Mineral (mg/100g)			
	Ca	Fe	Zn	P
Unprocessed (Control)	631.1 ±0.01a	3.8 ±0.04a	1.94 ± 0.03a	455.1 ± 0.07a
Germinated (48 hrs)	610.8 ±0.35c	3.6 ±0.04ab	1.76 ±0.01bc	432.2 ±0.5d
Germinated (72 hrs)	592.5 ±0.14e	3.5 ±0.03b	1.70 ±0.02 d	420.6 ±0.3e
Fermented (24 hrs)	619.0 ±0.28b	3.5 ±0.014b	1.80 ±0.01b	448.4 ± 0.01b
Fermented (48 hrs)	606.1 ±0.42d	3.4 ±0.11b	1.71 ±0.01bc	432.9 ±0.14c

Key: a-e All values are means ± SD. The same superscript letters within a column are not significant different (p>0.05)

Effect of Extrusion Operating Variables on Physical Properties of Extrudates

The effects of barrel temperature, screw speed and moisture content on the physical properties of extrudates are shown in Table 6. The expansion ratio of the products ranged from 1.38-1.90 with the highest expansion rate (ER) obtained with process conditions of barrel temperature, moisture content and screw speed at 130^{o}C, 17% m.c and 250rpm, respectively. Whereas, the lowest expansion rate was found with process conditions of barrel temperature, moisture content and screw speed at 110^{o}C, 21%m.c and 200 rpm, respectively. Majumdar *et al.*

(2011), reported on the effect of barrel temperature (100 and 120^{o}c), screw speed (350, 425 and 500rpm) and die diameter (3 and 3.5 mm) on the expansion index of extrudates in soybean-fish based ready to eat snacks. And findings described that all three parameters were affect the product expansion index. Agroturia (1997) stated that a complete starch gelatinization is generally achieved at temperature of $\geq$120^{o}C, moisture of 10-30 %, provided higher shear and temperature are reached during extrusion.

The bulk density of the product ranged from 0.36-0.68 g cm^{-3}. The lowest bulk density obtained with process conditions of barrel temperature, screw speed and moisture content at 130^{o}C, 250 rpm and 17%m.c, respectively. Whereas, the highest bulk density was found with process conditions of barrel temperature, screw speed and die diameter at 110^{o}C, 200 rpm and 21% m.c, respectively. In this experimental study, the highest expansion ratio and lowest bulk density was obtained at temperature of 130^{o}C and screw speed of 250 rpm and 17% moisture content. Majumdar *et al*. (2011) reported that the combination of high temperature and high screw speed yielded a product with low density. Generally, high temperature provides more thermal input, leading to complete gelatinization even at high screw speeds that decrease residence time. In high shear environment, the structural breakdown of protein and starch also leads to low density of products. Bulk density also describes the degree of expansion undergone by the melt as it exits the extruder. The desired products characteristics of high expansion ratio and low bulk density and hardness were obtained at low feed moisture, high screw speed and medium to high barrel temperature. This implies that all the independent factors of extrusion process affects extrudates (Majumdar, *et al*., 2011).

Specific length (cm/g) of extruded product related to weight and measures the axial expansion of the extrudates. The specific length of the product ranged 10.9-18cm/g. Extruding at barrel temperature of 130^{o}C and screw speed of 250 rpm at moisture content of 21% resulted in high specific length, whereas extruded at 110^{o}C temperature, 200rpm screw speed and 21% moisture content gave low specific length. Extrudates specific length is related to the expansion volume. The more the extrudates in either the axial and radial direction, the less dense they become indicating the higher proportion of starch gelatinization. The mean extrudates moisture content was less than the feed moisture content under all processing conditions. The research findings agrees with the outcome of Cammire *et al*. (1991) who reported the influence of moisture content of the material before extrusion on the moisture content of the extruded samples from mixtures of corn meal and glandless cotton seed.

Table 6: Effect of extrusion operating variables on physical properties of extrudates

Treatment	Processing methods			Physical properties of extruded products			
	BT (°C)	MC (%)	SS (rpm)	RE (cm/cm)	SL (cm/g)	BD (g/cm^3)	FMC
1	130	21	250	1.67±0.01^{c}	18.5±0.14^{a}	0.40±0.01^{e}	10.38±.0176^{f}
2	130	21	250	1.67±0.01^{c}	18.5±0.14^{a}	0.40±0.01^{e}	10.38±.0176^{f}
3	130	17	250	1.85±0.01^{a}	13.5±0.07^{d}	0.36±0.01^{f}	13.5±.0104^{d}
4	130	17	200	1.75±0.01^{b}	13.0±0.14^{e}	0.39±0.00^{ef}	14.72±.0805^{b}
5	110	21	250	1.38±0.01^{f}	13.3±0.14^{d}	0.65±0.01^{ab}	5.111±.0802^{h}
6	110	21	200	1.32±0.01^{g}	10.9±0.14^{g}	0.68±0.03^{a}	11.287±.068^{e}
7	110	17	250	1.45±0.01^{e}	15.5±0.14^{c}	0.53±0.01^{c}	14.417±.012^{c}
8	110	17	200	1.41±0.01^{f}	11.2±0.14^{f}	0.62±0.02^{b}	15.51±.0546^{a}

Key: $^{a-h}$ All values are means ± SD. The same superscript letters within a column are not significantly different ($p>0.05$), BT = Barrel temperature, MC =Feed moisture content, RE= Radial expansion, BD= Bulk density, SL = Specific length, FMC = Fresh extrudates moisture content (% wb)

Conclusions

Germination and fermentation processing methods showed that significant reduction of phytic acid when compared to extrusion cooking and less impact on reduction of tannin in finger millet flour were observed. Furthermore, germination and natural fermentation processing methods are inexpensive, energy efficient and environmentally friendly. Germination was effective in starch and protein hydrolysis, while fermentation was more effective in reducing of phytate consequently increases the mineral bioavailability. This indicated that a combination of germination followed by fermentation is a potential process for food products design and development in order to improve nutritive value and bio-digestibility of finger millet.

The physical properties of extrudates are depending on the barrel temperature, moisture content and screw speed. Extrusion cooking shows more significant reduction of tannins than phytate. The physical properties and level of reduction of phytonutrients results from this research indicate the opportunity of product diversification of finger millet in the form of different commercial value added products. The rate of reduction of phytate and tannins contents with a simultaneous increment of minerals availability depends on the duration of processing methods.

The research finding ascertained the prospective use of finger millet for manufacture of processed commercial value added products thereby support the community who are using the crop as food. Processing of finger millet at small scale and or commercial level might maximize resource utilization, contribute to food security, enhancing of acceptability of the finger millet based products, improving digestibility of macronutrients and search for high quality source of protein and energy. And also might encourage export earnings from finger millet based products in the upcoming years instead of whole finger millet grains export to

earn foreign currency. Africa can fetch revenue by processing market-oriented value added products and thereby share the World huge gluten free value added products market in the upcoming periods.

Abandoning this nutritious grain millet is not optional, and due attention need to provide on crop improvement, large scale production, processing, value addition, marketing and utilization by institutions in synergy mode. Among the excellent prospects for finger millet includes particular research emphases, recognition, and sympathetic policies which in turn plays to expand production dramatically. In final, African researchers and policy makers must give due attention for one of the future crops (finger millet) which has a potential for significant contribution to feed millions of people in Ethiopia and manufacture desirable qualities of gluten free value added products to the World market.

References

Anubha, S., Adarsh, L., Vinay, S., Sharad, V. and Afroz, A. 2015. Pearl and Finger Millets: The Hope of Food Security. Applied Research Journal, Volume11, Issue (2):59-66.

Agroturia, X.S.A. 1997. The extrusion-cooking process in animal feeding nutritional implications. Vall company groups.

Ahmadzadeh, R.G., and Prakash, J. 2007. The impact of germination and dehulling on nutrients, antinutrients, *in-vitro* iron and calcium bioavailability and *in-vitro* starch and protein digestibility of some legume seeds. LWT, 40: 1292-1299.

Ali, N.M., El Tiny, A.H., Elkhalifa, A.E., Salih,O.A and Yousif, N.E. 2009. Effect of alkaline pretreatment and cooking on protein fractions of a high-tannin sorghum cultivar. Food Chemistry, 114: 649-651.

Alonso, R., E.Orue and F. Marzo. 1998. Effects of extrusion and conventional processing methods on protein and antinutritional factor contents in pea seeds. Food chemistry, 63:505-512.

Amankwah, E.A., J. Barimah, R. Acheampong, L.O. Addai and C.O. Nnaji. 2009. Effect of fermentation and malting on the viscosity of maize-soyabean weaning blends. Pakistan journal of nutrition, 8: 1671-1675.

AOAC. Association of Official and Analytical Chemists. 1984. Official method of analysis of the Association of Official Analytical Chemists. Washington DC.

Barbeau, W.E and Hilu, K.W. 1993. Protein, calcium, iron, and amino acid content of selected wild and domesticated cultivars of finger millet. Plant foods for human nutrition, 43: 97-104.

Butter, L.D., Price, M.L., Brotheton, J.E. 1982. Vanillin assay for proanthocaynidins (Condensed Tannins): Modification of the solvent for estimation of the degree of polymerization. Journal of agricultural food chemistry, 30:1087-1089.

Cammire, M., Clykink, C. and Bittner, R. 1991. Characteristics of extruded mixture of corn meal and glandless cottonseed flour. Cereal chemistry, 68: 419 - 424.

Chopra, S. and Sankhala, A. 2004. Effect of soaking and sprouting on tannin, phytate and in vitro iron in under –utilized legumes- horse gram (Dolichosbiflours) and moth bean (Phaseolus aconitifolus). Journal of Food Science Technollogy, 41:547-550.

Desai, A.D., kulkarni, S.S., Sahoo, A.K., Ranveer, R.C. and Dandge, P.B. 2010. Effect of supplementation of malted ragi flour on the nutritional and sensorial quality characteristics of cake. Advance journal of food science and technology, 2: 67-71.

Dhankher, N and Chauhan, B.M. 1987. Effect of temperature and fermentation time on phytic acid and polyphenol content of Rabadi-a fermented pearl millet food. Journal of food science, 52: 828-829.

Egli,I., Davidsson, L., Juilleart, M.A., Barclay, D. and Hurrell, R.F. 2002. The influence of soaking and germination on the phytase activity and phytic acid content of grains and seeds potentially useful for complementary feeding. Journal of food science, 67:3484-3488.

Elyas, S.H.A., El Tinay, A.H., Yousif, E. N., Elsheikh, A.E. 2002. Effect of natural fermentation on nutritive value and invitro protein digestibility of pearl millet. Food chemistry, 78: 75-79.

Erenso Degu, Asfaw Adugna, Taye Tadesse and Tesfaye Tesso. 2007. Genetic resources, breeding and production of millets in Ethiopia. In: *New approaches to plant breeding of orphan crop in Africa*.pp.43-59, Ed: Zerihun Tadele. Proceedings of International Conference, Bern, Switzerland.

Greiner, R. and Konietzny, U. 2006. Phytase for food application. Food technology and biotechnology, 44:125-140.

Hemalatha, S., Platel, K. Srinivasan, K. 2007. Influence of germination and fermentation on bioaccessibility of zinc and iron from food grains. European Journal of Clinical Nutrition ,61: 342–348.

Hotz, C., and Gibson, R.S. 2007. Traditional food processing and preparation practices to enhance the bioavailability of micronutrients in plant- based diets. Journal of nutrition, 137: 1087-1100.

Ibanoglu, S., Ainworth, P.,Ozer, E.A. and Plunkett, A. 2005. Physical and sensory evaluation of nutritionally balanced gluten free extruded snack. Journal of Food Engineering, 75:469-472.

ICRISAT/FAO.1996. The World sorghum and millet economics: facts, trends and outlook. Retrieved on January, 2017.

Itagi, S., Naik, K., Bharathi, P. and Sharma, P. 2012. Readymade foxtail millet mix for diabetics. International Journal of Science and Nature, 3: 47-50.

Majumdar, R.K., Venkateshwarlu, G and Roy, A.K. 2011. Effect of extrusion variables on the physico-chemical properties of soybean-fish based ready-to-eat snacks. Agricultural journal, 6:23-27.

Malleshi, N.G and Desikachar, H.S.R. 1986. Nutritive value of malted millet flours. Plant foods and human nutrition, 36:191-196.

Malleshi N.G. 1986. Processing of small millets for food and industrial uses. Small millets in Global Agriculture, Oxford and IBH Publishing Company, New Delhi.

Mbithi-Mwikya, S., Camp, J.V., Yiru, Y., huyghebaert. A. 2000. Nutrient and antinutrient changes in finger millet (*Eleusine coracan*) during sprouting. Lebensm. Wiss. U. Technology (LWT), 33:9-14.

Mugocha, P.T. 2001. Fermentation of a finger millet-dairy composite gruel. PhD thesis, University of Pretoria, Pretoria. pp.184.

National Research Council. 1996. Lost Crops of Africa: Volume I: Grains, Finger Millet. Washington, DC: The National Academies Press. doi: 10.17226/2305, ISBN:0-309-58615-1, pp.408.

Shashi, B.K., Sharan,S., Hittalaman, S., Gshankarandt,A., Nagarathna, K. 2007. Micronutrient composition, antinutritional factors and bio-accessibility of iron in different finger millet (*Eleusine corcana*) genotypes. Karnataka journal of agriculture science, 20: 583-585.

Shimelis, E.A.and S.K.Rakshit. 2008. Influence of natural and controlled fermentations on α-galactosides, antinutrients and protein digestibility of beans. International journal of food science and technology, 43: 658-666.

Siwela,M., Taylor, J.R.N., Milliano, W.A.J.de. and Duodu, K.G. 2007. Occurrence and location of tannins in finger millet grain and antioxidant activity of different grain types. Cereal chemistry, 84: 169-174.

Sridevi, Y. Nirmala and Basarkar D.W. 2008. Antioxidant contents of whole grain cereals of North Karanataka. Karnataka Journal of Agricultural Science, 21 : 602-603.

Thilagavathi, T., Banumathi,P., Kanchana, S., and Ilamaran, M. 2015. Effect of heat moisture treatment on functional and phytochemical properties of native and modified millet flours. Plant Archives, 15:15-21.

Tizazu, S., K.Urga, C.Abuye and N.Retta. 2009. Improvement of energy and nutrients density of sorghum based weaning food using germination. M.Sc Thesis. Addis Ababa University.

Tizazu, S., K.Urga, C.Abuye and N.Retta. 2010. Improvement of energy and nutrient density of sorghum based complementary foods using germination. African journal of food, agriculture, nutrition and development, 10: 2928-2942.

Upadhyaya, HD., Gowda, C.L.L and Reddy, G.V. 2007. Morphological diversity in finger millet germ plasm introduce from Southern and Eastern Africa. An open access journal published by ICRISAT.

Vaintraub, IA. and Lapteva, N.A. 1988. Colorimetric determination of phytate in unpurified extracts of seeds and products of their processing. Annual biochemistry, 175:227-230.