Effects of Extrusion on the Nutritional Properties of Millet Based Extruded Products - A Review

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ABSTRACT

Millets are small-grained, annual, warm-weather cereals belong to grass family. They are highly tolerant of drought and other extreme weather conditions and have a rich nutrient compared to other major cereals. Food extrusion is one of the latest multidimensional food processing techniques which enables the consumers to have variety of convenient products. Great possibilities are offered in food processing field by the use of extrusion technology to modify physiochemical properties of food components. This review of literature features the past research on manufacture of millet based extruded foods, along with integration of various food components. The effects of extrusion conditions on the nutritional properties of extruded products are thoroughly discussed in this paper. The present article describes in detail about food extrusion technology, application of food extrusion to develop millet based extruded products, quality of millet based extruded products and future aspects of the technology.

Keywords : Food extrusion, Millets, Nutrition, Processing parameters, Nutritional properties

MILLETS are drought-resistant crops and the 6th cereal crop in terms of world agriculture production. Also, millets have better resistance to pests and diseases, with short growing season and highly productivity under drought conditions, compared to major cereals. Millets are small-seeded with different varieties such as pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), kodo millet (*Paspalum scrobiculatum*), proso millet (*Penicum miliaceum*), foxtail millet (*Setaria italica*), little millet (*Panicum sumatrense*), barnyard millet (*Echinochloa utilis*) and sorghum (*Sorghum bicolor*) (Ahmed *et al*., 2013).

With gradually increasing human population, millets are acquiring a status in the diet of health conscious consumers. This is the vital food crop for millions of people in part of Africa and Asia. They are underutilized food resource in most developed countries and it has a considerable potential to be used as human food and beverage source. In India, millets are staple to large section of people in semi-arid region (Talukder and Sharma, 2014).

India is the largest producer of millets and these grains have been staple food for sustaining the lives of millions in rural area. It will continue to do so in foreseeable future due to its richness in nutrients such as carbohydrate, protein, fibre and well balanced amino acid profile. Besides these, millets as considered as good source of several non nutrient compounds like phenols, flavonoids, phytates, tannins, glucosides etc. and playing important role in human health (Gupta *et al*., 2012).

Extrusion cooking is one of the contemporary food processing technologies applied to foods (Harper and Jansen, 1985) and can be applied to mitigate the problems associated with processing of traditional cereal based products in terms of improvement in functionality, physical state and shelf stability. It offers many advantages over other process technologies in terms of preparation of ready-to-eat foods of desired shape, size, texture and sensory characteristics at relatively low processing cost (Sumathi *et al*., 2007). Extrusion is a powerful food processing operation which utilizes high temperature, short time, high shear force, versatile and modern food operation to produce a product with unique physical and chemical characteristics (Pansawat *et al*., 2008) (Filli *et al*., 2012). The most important difference between extrusion and conventional cooking process is that additional intensive shear forces occur in the extruder (Ilo and Berghofer, 1999). Due to the processing flexibility offered by extrusion technology, it has become a cornerstone of the food industry, primarily in the cereal, dairy, bakery, confectionary and pet food industries (Berrios *et al*., 2010). Most recently, extrusion technology was used in the development of expanded, novel value added millet based extruded foods (Chakraborty *et al*., 2009; Seth & Rajamanickam, 2012; Geeta *et al*., 2012; Sawant *et al*., 2013 and Asefa and Melaku, 2017).

Principle of Food Extrusion Technology

Food extrusion is a process of forcing pumpable material through a restricted opening. It involves compressing and working a material to form a semisolid mass under a variety of controlled conditions and then forcing it at predetermined rate to pass through a die (Ainsworth *et al*., 2007).

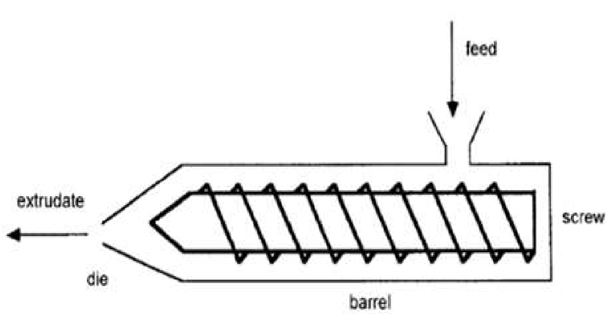

Fig. 1 : Schematic diagram of an extruder

TABLE 1

Nutrient composition of millets (per 100 g edible portion with 12% moisture)

Millet	Protein[a] (g)	Fat (g)	Ash (g)	Crude fiber (g)	Carbo-hydrate	Energy (kcal)	Ca (mg)	Fe (mg)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg)
Sorghum	10.4	3.1	1.6	2.0	70.7	329	25	5.4	0.38	0.15	4.3
Pearl millet	11.8	4.8	2.2	2.3	67.0	363	42	11.0	0.38	0.21	2.8
Finger millet	7.7	1.5	2.6	3.6	72.6	336	350	3.9	0.42	0.19	1.1
Foxtail millet	11.2	4.0	3.3	6.7	63.2	351	31	2.8	0.59	0.11	3.2
Little millet	9.7	5.2	5.4	7.6	60.9	329	17	9.3	0.30	0.09	3.2
Barnyard millet	11.0	3.9	4.5	13.6	55.0	300	22	18.6	0.33	0.10	4.2
Kodo millet	9.8	3.6	3.3	5.2	66.6	353	35	1.7	0.15	0.09	2.0

[a]All values except protein are expressed on a dry weight basis; Sources: Ahmed *et al.* (2013)

Extrusion cooking is defined by Berk (2009) as a thermo-mechanical process in which heat transfer, mass transfer, pressure changes and shear are combined to produce the effects such as conveying, mixing, kneading, melting, cooking, sterilization, drying, texturizing, puffing, cooling, freezing, forming, conching (chocolate) etc. The food extruder is a pump, a heat exchanger and a continuous high temperature-high pressure reactor, all combined in one piece of equipment.

As per Fellows (2000), the two main factors that influence the characteristics of extruded products are : raw material characteristics and operational conditions of extruder. As main characteristics of the raw material, the following can be highlighted: type of material, moisture content, physical state, chemical composition (quantity and type of starch, proteins, fats and sugars) and pH of the material. The operational parameters that can be pointed out as important are: temperature, pressure, die diameter and shear force with the latter being influenced by the internal design of extruder and by its length; as well as screw geometry and rotation speed.

Therefore this review represents literature on application of food extrusion technology to develop millet based products, on nutritional changes and other modification occurring during extrusion.

Effects of Extrusion on the Nutritional Properties of Millet Based Extruded Products

Protein : Proteins are polymers of some 21 different amino acids joined together by peptide bonds (deMan, 2009). The nutritional energy value of proteins (17 kJ/g or 4 kcal/g) is as high as that of carbohydrates (Belitz *et al*., 2009). The conditions of extrusion carry a profound effect on the intrinsic properties of plant protein which leads to breakage of existing bonds, cross-linkage with nutrient and formation of new compounds. Depending on the process parameters, extrusion can both improve and impair protein digestibility (Leonard *et al*., 2019). The Omwamba and Mahungu (2014) developed a protein-rich extruded snack from a composite blend of rice, sorghum and soybean flour. They reported that lysine loss in extrusion is largely influenced by process temperature, feed moisture and the presence of other sugars. Low-moisture conditions and high temperature promote maillard reaction which according to Singh *et al*. (2007) causes significant loss in lysine (5-40%) and other sulphur containing amino acids in conventional steam-based extrusion depending on processing conditions and ingredient composition. Pelembe *et al*. (2002) studied that nitrogen solubility index increased at both extrusion temperatures as the amount of cowpea increased. This increase is related to the higher protein content of the extrudates of higher cowpea content due to the fact that cowpea proteins are more water soluble (Chavan *et al*., 1989) than those of sorghum (Serna-Saldivar and Rooney, 1995). During high temperature short time (HTST) extrusion cooking process, the quaternary structure of proteins opens in the hot moist conditions, to produce a viscous plasticised mass (Fellow, 1990). The proteins are then polymerised, cross-linked and reoriented to form a new fibrous structure. HTST extrusion cooking reduces protein solubility as function of temperature, probably as a result of thermally induced cross-links among subunits of protein by heat (Stanley, 1989). Most of the porridges extruded at 130°C had far higher NSI (nitrogen solubility index) content than the ProNutro (a commercial maize - soybean composite instant porridge widely consumed in Southern Africa manufactured by Bokomo Foods (Wadeville, South Africa) was higher than that of sorghum - cowpeas porridges extruded at 165°C. Fapujuwo *et al*. (1987) studied the effect of extrusion cooking on *in vitro* protein digestibility of sorghum. The results of the initial study on the digestibility values of U.S. market class sorghum as influenced by extrusion temperature, screw speed and grain moisture. There was no significant difference in digestibility values observed for grain containing 15 and 25 per cent moisture. However, increased screw speed and barrel temperature significantly improved sorghum digestibility. Digestibility values increased with increasing barrel temperature in all cases thus showing that extrusion temperature was a key factor to improve digestibility. The protein digestibility of raw sorghum variety CS3541 was 44.8 per cent in the pepsin assay. Which was increased to 74.6 per cent by extrusion at 200°C. Likewise, the U.S. market class sorghum had a digestibility value of 43.3 per cent which increased to 68.2 per cent by extruding at 200°C. These results verify the conclusions of MacLean *et al*. (1983) and Mertz *et al*. (1984) on improved digestibility of sorghum.

Llopart *et al*. (2014) studied the nutritional properties of extruded whole grain red sorghum (*sorghum* spp), and reported that a reduction of 25.3 per cent available lysine was observed for the extruded product. This value was within the range reported for other extruded materials. Bjork *et al*. (1984) studied the effect of extrusion cooking on the nutritional value of wheat flour and whole wheat flour proteins. Values between 63 and 100 per cent for lysine retention were observed, while the losses of other amino acids were small. Konstance *et al*. (1998) studied available lysine of extruded corn and soybean blends. The lysine losses ranged from 3 to 20.5 per cent for less critical to more severe conditions. An excessive maillard reaction can result in lysine losses up to about 50 per cent, as was observed by De La Gueriviere *et al*. (1985) in the extrusion of wheat. In case of rice flour, extrusion performed at 15 per cent moisture and 120-150°C reduced the total lysine content of 11-13 per cent (Eggum *et al*., 1986). Moreover, Perez-Navarrete *et al*. (2006) evaluated the effect of extrusion on nutritional quality of corn with beans blend and found that lysine availability decreased between 15 and 25 per cent.

Thus, lysine availability can be used as a measure of processing damage (Walker, 1983), since at conditions normally used for extrusion, maillard reactions are promoted and a negative effect on the availability and digestibility of amino acids could be observed (Asp and Bjorck, 1989). Extrusion increased protein digestibility. The extrusion process increased the protein digestibility by 31 per cent. This confirms that the increase in protein digestibility is one of the advantages attributed to the extrusion cooking process (Drago *et al*., 2007). Increasing protein digestibility can also result from the reduction of polyphenols, since the low-protein digestibility is due to protein-protein, protein-carbohydrate, protein-(poly) phenol and carbohydrate-(poly) phenol interactions (Taylor and Taylor, 2002).

Starch : The major carbohydrate polysaccharide in plant tubers and seed endosperm is starch. Starch is a homopolymer of D-glucose and storage carbohydrate in plants. It occurs as small granules with the size range and appearance characteristics to each botanical plant species (Eggleston *et al*., 2018). During extrusion, starches are subjected to relatively high pressure, heat and mechanical shear forces. Additionally, the food extruder can be regarded as a high-temperature short-time (HTST) bioreactor that can cause starch gelatinization, melting and fragmentation reactions. The main parameters that influence these reactions, such as shear forces, residence time and shear rate defined by the geometry of the extruder as well as processing variables, such as temperature, screw speed, feed composition and moisture content (Lai and Kokini, 1991) while Pelembe *et al*. (2002) studied the effect of extrusion on starch for development of composite sorghum-cowpea instant porridge. They reported that, prior to extrusion, sorghum had 84.7 while cowpeas had 41.4 g starch/100 g material on dry weight basis (d.b.). As the percentage of cowpeas increased, total starch decreased in the extrudates. The material extruded at lower temperature (130°C) had a higher total starch content than that extruded at the higher temperature (165°C). Higher temperatures are known to favour the reaction between starch and protein in an irreversible reaction (Bjorck *et al*., 1984). The porridge of 50 per cent sorghum and 50 per cent cowpea extruded at 130°C had similar total starch content to Pro Nutro (commercial ready-to-eat maize soya composite porridge).

For extrusion temperatures, the percentage of starch that was enzyme-susceptible (gelatinised) decreased with the proportion of cowpeas in the composite. One factor which may have affect the enzyme susceptible

TABLE 2

Selected studies in manufacturing of millet based extruded products

Millet and other ingredient used	Product Developed	MC of Feed (%)	SS (rpm)	Temp. (^{0}C)	Reference
Barnyard millet (72-88%) and pigeon pea (28-12%)	Extruded snack	12-24	100-140	100-140 (BT), 160-200 (DHT)	Chakraborty *et al*. (2009)
Finger millet (80, 85 and 90%), soybean (20, 15 and 10 %)	Complimentary food for children	18	300, 350	170 and 400	Asefa and Melaku (2017)
Finger millet (10 to 40%), maize (50 %), rice (10 or 20 %), soybean (10 %), bengal gram (10 or 20 %) and skimmed milk powder (10 or 20 %).	Ready-to-eat extrudates	16-17	130	140	Sawant *et al*. (2013)
Finger millet (40-50%), sorghum (10-20%), soy (5-15%) and rice (30%)	Extruded snack	18	285	184 (BT)	Seth and Rajamanickam (2012)
Finger millet: mung bean: non fate dry milk (60: 30: 10)	Ready-to-eat weaning food	18	160	140	Malleshi *et al*. (1996)
Foxtail millet, amaranth, rice, Bengal gram and cowpea (at ratio 60:5:5:20:10)	Ready-to-eat extruded sanck	0	400	115	Deshpande and Poshadri (2011)
Kodo millet (60, 70, 80 and 100%) and chickpea	Extruded sanck	20	250 to 300	80 to 150	Geeta *et al.* (2012)
Pearl millet and Cowpea (at ratio 63.2:36.8 to 96.8:3.2)	Extruded Fura (Fura-a semi solid dumpling cereal based meal, (Jideani, *et al.,* 2002)	16.6-33.4	116-284	120	Filli *et al.* (2012)
Pearl millet, finger millet and decorticated soy bean (81.68: 7.02: 11.29)	Extruded snack	14	200- 350	120 (BT)	Balasubramanian et al. (2012)
Pearl millet: defatted soy flour (85:15) and Pearl millet: Bengal gram: green gram (70: 20: 10)	Extruded supplementary food	18 ±1	200±10	150 ±5	Sumathi *et al.* (2007)
Pearl millet and grape pomace (at ratio 100: to 87.27:12.3)	Extruded snack	21.66 ± 0.49	-	133.18-166.82	Altan *et al*. (2008)
Pearl millet and grain legumes (cowpea, groundnut and soybean) -pearl millet (100%), -millet:cowpea (80:20 & 70:30) -millet:groundnut (80:20 & 70:30) -millet:soybean (80:20 & 70:30)	Extruded fura	30	180	150, 170 150 (barrel zone temp) 150, (DHT)	Nkama and Filli (2006)

Millet andother ingredient used	Product Developed	MC of Feed (%)	SS (rpm)	Temp. (^{0}C)	Reference
Pearl millet: mung bean: non fat dry milk (60 : 30 : 10)	Ready-to-eat weaning food	18	160	140	Malleshi *et al.* (1996)
Sorghum, rice and defatted soy flour (20:65:15)	Extruded snack	10-14	350-450	110-150	Omwamba and Mahungu (2014)
Sorghum	Extruded Food	14, 16.5 and 19	150	164, 182 and 200	Llopart *et al.* (2014)
Sorghum (50, 60, 71.4, and 85.7 %), corn flour, whey protein isolate, soy flour amd lentil flour	Extruded snack	17	400	140	Devi *et al.* (2013)
Sorghum-black gram, sorghum-green gram, sorghum-lentil and sorghum-pea (at ratio 100:0, 95:5, 90:10 and 85:15)	Extruded	14	500	-	Balasubramanian *et al.* (2012)
Sorghum and soybean (3.2, 10, 20, 30 and 36.8%)	Extruded Fura	16.6-33.4	116-284	-	Filli *et al.* (2010)
Sorghum (0, 30, 50, 70 and 100 %) and cowpea	Instant porridge	20	200	130 and 165 (BT)	Pelembe *et al.* (2002)
Sorghum: mung bean: non fate dry milk (60: 30: 10)	Ready-to-eat weaning food	18	160	140	Malleshi *et al.* (1996)
Surghum : cowpea (at ratio 100:0, 67:33, 33:67 and 0:100)	Extruded snack	13-25	180	160-205	Falcone and Phillips (1988)

MC-moisture content, Temp.-Temperature, SS-screw speed, BT-barrel temperature and DHT-die head temperature

starch (ESS) is amylase/amylopectin ratio. Sorghum starch has more amylopectin than amylase (Serna-Saldivar and Rooney, 1995), while legume starch has more amylose than amylopectin (Guilbot and Mercier, 1985). Grains with a high proportion of amylopectin content are more enzyme-susceptible (Harper, 1991). The fact that cowpeas had far higher protein content than sorghum could also have been responsible for lower starch enzyme susceptibility of the extrudates of higher cowpea content. Protein structures encapsulating starch or covering starch granules surfaces would be expected to decrease the availability of starch to amylase in vitro (Asp and Bjorck, 1989). The proportion of ESS was higher at the higher extrusion temperature. This is because high temperature and high shear rate cause disruption of starch granule structure which leads to mechanical damage of starch molecules and or gelatinisation in the starch fraction (Asp and Bjorck, 1989).

In another study, Gomez *et al*. (1988) studied the effect of extrusion on amylose content of sorghum. They reported that raw grain contained native starch granules that resisted enzyme hydrolysis, solubilisation and water absorption. Starch damage increased during extrusion, especially at lower moisture content. Maximum enzyme susceptible starch ratio occurred when extrusion moisture level was under 30 per cent. Increased moisture content resulted in decreased water solubility. Maximum water absorption capacity of extrudates was obtained at 32 per cent extrusion moisture. This maximum value corresponded to the hydration of the extruded flour until a gel-like state was obtained. This was probably due to gelatinization of the starch without depolymeriation. Maximum water absorption values were previously reported by Williams *et al.* (1977) and Gomez and Aguilera (1983) who suggested that maximum 'gelatinization' during extrusion-cooking of corn grits and corn starch occurred at 27-29 per cent moisture.

Fibre : Lue *et al.* (1991) stated that dietary fibre has received more attention in the last few years as epidemiological studies indicated our inadequate intake of dietary fibre to the incidence of a wide spectrum of diseases. The dietary fibre as the remnants of the edible part of plants and analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the human large intestine. It includes polysaccharides, oligosaccharides, lignin and associated plant substances (Gordon, 1999).

Dietary fibre can be classified as insoluble dietary fibre (IDF) and soluble dietary fibre (SDF). IDF, which includes cellulose, lignin and some hemicelluloses has been linked to the shortening of transit times in small intestine and to the softening and bulking of stool. It alleviates the risk of constipation, appendicitis, irritable bowel syndrome and possibly colon cancer. However, SDF, which include pectin and vegetable gums is believed to increase intestinal transit times, absorb serum cholesterol and enhance glucose tolerance (Best, 1987).

Extrusion cooking is a suitable process for the production of fibre-enriched products. The potential change of dietary fibre content during extrusion cooking is of concern to nutritionists, food processors and health-conscious consumers. Extrusion cooking may change the content, composition and physiological effects of dietary fibre in various ways. First, starch could undergo modification and form enzyme-resistant fraction which have acted *in vivo* as dietary fibre (Bjorck *et al.*, 1986). Second, degradation of dietary fibre to low molecular weight fragments would diminish its content and hence reduce its benefits. Third, macromolecular degradation of fibre may increase the solubility and change the physiological effects of the fibre.

Talukder and Sharma (2014) stated that millet is one of the excellent source of the dietary fibres and its bran contributes the maximum. The dietary fibre content of millet bran is about 73.18 g/100 g among total dietary fibre, 65.55 g/100 g, insoluble and 7.63 g/100 g soluble dietary fibre, respectively. The dietary fibre exhibits an excellent binding ability to the cholesterol at pH 7. Therefore, the use of millet grain can fulfil the requirement of dietary fibre in human body (Liu *et al*., 2011). Malleshi *et al*. (1996) prepared extruded weaning foods containing sorghum, pearl millet and finger millet blended with mung bean (green gram) and nonfat dried milk. They reported that the total dietary fibre (TDF) content increased about 20 per cent after extrusion. Soluble dietary fibre increased about 19 per cent in the sorghum food and 6.5 per cent in the pearl millet food. Increased TDF could have resulted from the formation of enzyme resistant macromolecules containing starch, protein, lipid and or nonstarch polysaccharides. The increase in soluble dietary fibre could have been the result of depolymerisation and or solubilisation of nonstarch polysaccharides during extrusion (Huber, 1991).

Lipid : Lipids are a concentrated form of energy providing 9 kcal/ g. It is challenging to extrude foods containing more than 10 per cent lipids reduce shear within the extruder barrel (Camire, 2011). Guy (2001) states that oils and fats have a powerful influence on extrusion cooking processes by acting as lubricants between the particulate matter and the screws of the extruder. Both materials can be described as lipids but fats are those materials which contain crystalline material at ambient temperatures and appear to be solids. In the extruder they all become liquid at temperatures more than 40^{o}C and so function as liquid oils during critical stages of the process. Lipids do not affect water activity but they drastically reduce viscosity in the extruder and weaken gel strength (and therefore elasticity), even at levels below 2 per

TABLE 3
Nutritional composition of some millet based extruded products

Millet and other ingredient used	Product developed	Protein (%)	Fat (%)	Carbohydrate (%)	Moisture (%)	Ash (%)	Fiber (%)	Reference
Finger millet (80, 85 and 90 %), soybean and carrot	Complimentary food for children	11.3 ± 1.26	-	71.55 ± 1.93	8.694 ± 0.55	3.572 ± 0.19	1.066 ± 0.48	Asefa and Melaku (2017)
Pearl millet: defatted soy flour (85:15)	Extruded supplementary food	16.0	4.4	61.3	-	2.8	1.7	Sumathi *et al.* (2007
Pearl millet: Bengal gram: green gram (70: 20: 10)		14.7	4.7	65.2	-	2.5	1.2	
Pearl millet : cowpea 80:20 70:30	Extruded fura	13.0 13.8	3.5 3.2	69.2 67.8	11.3 11.5	1.7 1.7	1.9 1.9	Nkama and Filli (2006)
Pearl millet : soybean 80:20 70:30		16.4 19.1	7.4 9.2	61.3 56.6	11.3 11.3	1.8 1.8	0.9 2.0	
Pearl millet : groundnut80:20 70:30		13.7 14.9	11.5 15.3	61.4 56.6	10.8 10.0	1.5 1.5	1.6 1.8	
Sorghum, rice and defatted soy flour (20:65:15)	Extruded snack	15.31 ± 0.12	1.89 ± 0.09	73.07 ± 0.08	6.72 ± 0.15	3.01 ± 0.11	5.20 ± 0.011	Omwamba and Mahungu (2014)
Sorghum	Extruded food	10.67 ± 0.04	2.72 ± 0.02	-	14%	1.53 ± 0.03	9.92 ± 1.15	Llopart *et al.* (2014)
Sorghum (50, 60, 71.4 and 85.7 %), corn flour, whey protein isolate, soy flour amd lentil flour	Extruded snack	7.69 - 29.9	1.311	-	6.89 - 8.33	1.136 - 2.607	7.01 - 14.13	Devi *et al.* (2013)
Surghum : cowpea(at ratio 100:0, 67:33, 33:67 and 0:100)	Extruded snack	7.69 - 29.9	1.311-2.362	-	6.89 - 8.33	1.136 - 2.607	7.01 - 14.13	Falcone and phillips (1998)

cent (Miller and Mulvaney, 2000). The recent study by Anderson (2014) elaborated the role of millet lipids on extrudates sensory properties. He reported that millet has free and bound lipids ranging from 3.0 to 6.7 per cent that could contribute to off flavors during extrusion (Ghodsized & Safekordi, 2012 and Rao & Artz, 1989). Lipids are cited for their ability to form amylose-lipid complexes that can affect expansion and texture of extrudates (Bhatnagar & Hanna, 1994; Desrumaux *et al*., 1999 and Putseys *et al*., 2010). The role of lipids in extrusion can also be characterized by oxidation which may or may not affect final extrudate flavour. Due to the extreme processing conditions, encountered by extrusion, lipid stability can be reduced significantly. Bjorck & Asp (1983), found that stored extrudates showed an increase in peroxide value as extrusion parameters were increased; temperature from 121°C to 149°C, moisture levels from 15.0 to 30.0 per cent and extruder residence time from 0.5 min to 2.0 min. Lipid oxidation favors the production of specific off flavor aldehydes such as hexanal and 2, 4-decadienal (Bruechert *et al*., 1988). Zadernowski *et al*. (1997) studied the changes in oat lipids affected by extrusion. They reported that due to extrusion, the percentage of non-polar lipids in the total bound lipids increases. The addition of starch to the oat flour mixture for extrusion increases the susceptibility of extrudate lipids to oxidation. The fatty acids of free fat and bound lipids are oxidized in a higher degree in oat flour extrudates than in oat flour. Lipids in oat grains could be stabilized by extrusion even at a temperature of 70^{o}C (Lampi *et al*., 2015).

Antinutritional factors : Mbithi-Mwikya *et al.* (2000) states that cereals and legumes contain significant amounts of inositol hexaphosphates (IP6) generally referred to as phytic acid or phytates. Phytate has long been recognized as an antinutritional factor, 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+} (Honke *et al.*, 1998). Besides its well known negative properties, phytate has been found to form chelates *in vitro*, inhibiting the formation of iron-catalysed hydroxyl radicals (Fenton reaction) and lipid peroxidation. Consequently, phytic acid has gained in significance as a naturally occurring antioxidant (Honke *et al*., 1998). Nikmaram (2017) states that extrusion is also a very effective method to inactivate α-amylase inhibitors, trypsin and chymotrypsin and heamagglutinin activity without modifying the protein level in food products (Soetan and Oyewole, 2009). In general, moisture content and composition of raw material, barrel temperature and the feed rate of extruder are the most significant factors affecting the extrusion process, in terms of reducing the amount of anti nutritional factors (Levic, 2010).

Onyango *et al*. (2005) studied the antinutrient properties of extruded maize-finger millet in the production of *uji*. Uji is a thin lactic fermented porridge prepared from cassava flour or whole milled cereals of maize, sorghum and finger millet and is widely consumed in eastern Africa as a refreshing drink. The most important antinutrients in uji prepared from maize-finger millet blend are polyphenols and phytates. These antinutrients form complexes with micronutrients such as iron, calcium and zinc which reduce their solubility and bioavailability. Tannins also complex enzymes of the digestive tract adversely affecting utilization of proteins and carbohydrates thus resulting in reduced growth, feeding efficiency, metabolizable energy and bioavailability of amino acids. The study of Le Francois (1988) reported a decrease in phytic acid content in extruded products. El-hady and Habiba (2003) have reported a significant reduction in tannin content after extruding legume seeds at different moisture levels. The high tannin content (1677mg/100g) of the raw material is due to the finger millet variety used since maize does not have detectable amounts of tannins (Lorri & Svanberg, 1993). Tannin content decreased to 697mg/100g after extrusion of the unfermented blend and further to 551mg/100g after fermentation and extrusion. Extrusion of the blends with lactic or citric acids counteracted thermal degradation of tannins and the values ranged from 861-1093 mg/100 g and 777-817 mg/100 g for blends extruded with lactic and citric acids, respectively. Fermentation or treatment of the blends with lactic or citric acids before extrusion had no effect on phytic acid content, which ranged from 247 to 286mg/100g. The amount of phytic acid in the unfermented-extruded blend also remained unchanged. The inability of extrusion cooking to degrade phytic acid has also been reported in wheat, rice and oat bran (Gualberto *et al*., 1997), legumes (Ummadi *et al*., 1995) and a high-fibre cereal (Sandberg *et al*., 1986).

Thus the present review study highlights the effect of extrusion conditions on the nutritional properties of millet based extrude products, for purpose of processing and nutritional quality improvement. Food extrusion processing generated a great versatility for the development of new low cost, nutritional and convenient food products. The major conditions during extrusion processing which effect the physicochemical properties of final products are feed moisture, barrel temperature, raw ingredients (protein and starch) and the screw speed. Extrusion conditions and changes in ingredients will affect the system variables as well as product quality. Based on the literature of studies carried out, it is process that millets contain many health promoting components such as dietary fiber, mineral and vitamins. Food extrusion technology is a novel processing method to enhance the bioavailability of micronutrients and to improve the quality of millets. Making millet based extruded products to deliver nutritious, convenience, taste, texture, colour and shelf stability at economical cost for poor people is needed. For promoting utilization of millets in urban areas to open new avenues to enhance their income and can be developed as nutraceutical and industrial products to serve purpose of nutrition and dietary diversity.

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