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Review

Starch and modified starch in bread making: A review

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Starch is an important source of energy in human nutrition. It is also widely used as a processing aid in several food and non-food industries. Starch in wheat flour contributes to the development of optimal bread crumb and crust texture. It is also responsible for physical deterioration of bread quality through staling. Starch is mainly extracted from starch-rich plants such as cereals, root and tuber crops and legume seeds. It can be modified using chemical, physical or enzymatic techniques to obtain modified starch. Traditional plant breeding or genetic modification can also be used to produce starches with modified functionalities. Modified starches are essential food processing aids because of their enhanced functional properties. The aim of this paper is to review the role of starch in bread making and subsequently elucidate the influence of modified starch on the quality of wheat bread.

Key words: Bread, modified starch, starch, wheat.

INTRODUCTION

Bread is an important source of energy in the human diet because of its high content of readily digestible starch (40 g/100 g) (Mckevith, 2004). Bread is an unstable, elastic, solid foam, the solid part of which contains a continuous phase composed in part of an elastic network of cross-linked gluten molecules and in part of leached starch polymer molecules; and a discontinuous phase of entrapped, gelatinized, swollen, deformed starch granules (Gray and Bemiller, 2003). It is made from four principle ingredients: wheat flour, water, salt and yeast. In modern production processes, other ingredients and additives such as fat, sugar, emulsifiers and enzymes must be added to ensure uniformity in quality and increase product diversity. These essential and non-essential ingredients used in bread making are first mixed into viscoelastic dough which is then fermented in two or several stages before being baked. Starch is the most abundant fraction of milled wheat flour. The amount of starch (and sugars) in wheat flour increases from about 64% (dry-basis) in flour of 100% extraction rate to 71% (dry-basis) in flour of 70% extraction rate (Delcour and Hoseney, 2009). The contribution of starch to bread making is related to its water absorption property during dough development; gelatinization and pasting behavior during baking; and crystallization and retro gradation behavior on cooling and storage. The impact of starch on bread making is also influenced by other flour components, especially protein, which, although present in a relatively smaller

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quantity (12-14%, dry-basis), plays an important functional role in the development of the characteristic bread texture (Lagrain et al., 2013; Goesaert et al., 2005). The other important dry-matter constituents of wheat flour are the non-starch polysaccharides, lipids and ash (Goesaert et al., 2005; Delcour and Hoseney, 2009).

Starch structure and composition

Starch is the major source of stored energy in plants. Cereal grains, legume seeds and root and tuber crops are the principle sources of starch for human nutrition. Starch is a macronutrient in several foods and supplies 50 to 80% of the calories consumed by most of the world's population (Bertolini, 2010; Copeland et al., 2009). Starch is metabolized in the human body to sugars, which are an important source of energy, and which enables the body to perform several functions. Starch also serves as an important ingredient in several food products and as a processing aid in several non-food industries (Bertolini, 2010; Bemiller and Whistler, 2009). Starch is synthesized in the plastid of plant cells through a series of complex biosynthetic pathways controlled by several enzymes (Jobling, 2004). It is deposited as water insoluble semi-crystalline granules in the storage tissues of plants such as grains, roots and tubers (Copeland et al., 2009). Each starch granule is composed of two homo-polysaccharide fractions (amylose and amylopectin), which make up 98-99% of the dry-weight of the granule (Tester et al., 2004; Copeland et al., 2009). The amylose fraction makes up 20 to 30% of the starch granule while the amylopectin fraction makes up 70 to 80% (Belitz et al., 2009; Liu, 2005; Jobling, 2004). Starch granules also contain small amounts (0.5 to 2% w/w) of non-starch polysaccharides, lipids, proteins and ash (Liu, 2005; Copeland et al., 2009).

The amylose fraction of starch is an essentially linear polymer that is made up of about 99% α-(1→4) linked D-glucopyranose molecules and less than 0.5% α-(1→6) branches (Copeland et al., 2009). The degree of polymerization of amylose ranges from 1,000-10,000 glucose units, which corresponds to a molecular weight of 10^5-10^6 (Copeland et al., 2009). By contrast, the amylopectin fraction is a highly branched polymer consisting of about 95% α-(1→4) linked D-glucopyranose molecules and 5% α-(1→6) branches (Copeland et al., 2009). The degree of polymerization of amylopectin exceeds 10^6 glucose units, which corresponds to a molecular weight of about 10^8 (Copeland et al., 2009). In addition to amylose and amylopectin, some starch granules also contain molecules with characteristics (such as chain length of linear molecules, branch chain length and density of branching points) that lie between those of amylose and amylopectin (Liu, 2005). Starch granules differ in shape, size, size distribution and crystallinity depending on the botanical source. Starch granules may be lenticular, polyhedral, spherical, oval, elliptical or kidney-shaped, and range in size from 2 to 150 µm (Belitz et al., 2009; Liu, 2005; Tester et al., 2004). Starch granules are simple or compound in nature with concentric or eccentric layers of varying density (Belitz et al., 2009). Some granules have bimodal size distribution whereas others have unimodal size distribution (Delcour and Hoseney, 2009; Tester et al., 2004; Copeland et al., 2009). Starch granules exist individually or clustered as compound granules (Copeland et al., 2009; Delcour and Hoseney, 2009). About 70% of the mass of a starch granule is amorphous and 30% crystalline (Belitz et al., 2009). The semi-crystalline character of starch granules indicates a high degree of orientation of glucan molecules, which is attributed to double helical structures formed by the outer branches of amylopectin polymers. Amylose, amylopectin branching points and the amylopectin molecules in a disordered conformation make up the amorphous portion of starch granules (Eliasson et al., 2013; Copeland et al., 2009).The major sources of industrial starch are maize (corn), cassava (tapioca), wheat and potato. These crops account for more than 99% of world starch production (Bertolini, 2010). United States of America is the major producer of maize starch; Europe is the major producer of wheat and potato starch; whereas cassava starch is mainly produced in Asia (Jobling, 2004).

Native starch has limited industrial applications because of its high hot-paste viscosity; poor thermal, shear and acid stability; and high susceptibility to retrogradation and syneresis (Huber and Bemiller, 2010; Bertolini, 2010; Singh et al., 2007). However, when starch is modified, it serves as a useful polymer material in several food and non-food industries. Starch modification changes several physicochemical features of the amylose and amylopectin polymers: the positive characteristics are enhanced whereas the undesirable qualities are suppressed (Ashogbon and Akintayo, 2014; Kaur et al., 2012; Huber and Bemiller, 2010). Starch can be modified using physical, chemical, enzymatic or genetic methods (Kaur et al., 2012; Huber and Bemiller, 2010; Tharanathan, 2005) in order to enhance its positive functional attributes that can be used in food and non-food processing industries. Modified starch is used in the food industry to texturize and thicken foods, maintain gel strength and clarity, make edible food coatings, retard retro gradation, stabilize emulsions, improve freeze-thaw stability, substitute fat, encapsulate aroma compounds and increase the resistant starch content (Belitz et al., 2009; Bertolini, 2010). Modified starch is also an important raw material in several non-food industries, such as paper, adhesive, agricultural, cosmetic, medical, pharmaceutical, oil, plastics and textile industries (Bertolini, 2010; Bemiller and Whistler, 2009). Starch

hydrolysis products (i.e. glucose syrups, high fructose syrups, syrup solids, maltodextrins and fructose) are used in confectionery and beverage industry and can be subjected to microbial fermentation to yield organic acids, alcohols, ketones, polyols, amino acids, nucleotides, biopolymers, lipids, proteins, vitamins, antibiotics and hormones (Bertolini, 2010; Bemiller and Whistler, 2009).

Starch in bread making

The unique dough-forming and bread making property of wheat flour is attributed to the storage protein fraction known as gluten, which is formed when wheat flour is hydrated and subjected to mechanical shear (Goesaert et al., 2005). The three dimensional gluten network is responsible for retention of carbon dioxide formed during fermentation, temporary binding of water required to gelatinize starch and formation of the typical foam structure of bread (Lagrain et al., 2013; Goesaert et al., 2005). Gluten functionality in bread making is enhanced by interaction with other wheat flour components, especially starch. Starch constitutes 70 to 85% of wheat flour (Goesaert et al., 2005; Slavin et al., 2001) and is, after gluten, the second most important fraction in wheat flour for bread making. When starch granules in wheat flour are hydrated, they absorb up to 50% of their dry weight of water and swell slightly and reversibly (Goesaert et al., 2005). The interaction of starch and gluten in dough creates a stable network that can retain fermentation gas in the dough structure and prevent collapse of bread during baking and cooling (Delcour and Hoseney, 2009; Ahlborn et al., 2005; Hoseney and Rogers, 1990). Wheat flour destined for bread making usually has a small amount of damaged starch (about 8%) (Goesaert et al., 2005), which is vital to the development of bread with good quality characteristics. Damaged starch in wheat flour increases the water absorption capacity of the flour and is hydrolyzed by α-amylase into maltose, which is used as a fermentable sugar by yeast (Delcour and Hoseney, 2009). However, too much damaged starch (> 10%) is not desirable in wheat flour because it causes formation of sticky dough, which is difficult to handle and gives bread with an adhesive crumb (Sluimer, 2005).

When dough is heated, starch granules absorb water, swell, gelatinize and lose their semi -crystalline nature. The linear amylose polymers leach out of the granules leaving amylopectin-enriched granules. Starch gelatinization in the crumb causes formation of a porous crumb structure whereas the higher temperature at the dough surface results in crust formation (Eliasson et al., 2013; Primo-Martin et al., 2007). Starch swelling and loss of granular structure is restricted by the limited amount of water in dough and competition between starch and non-starch polysaccharides for the available water in the dough (Gray and Bemiller, 2003). The net effect is that only a small amount of amylose is leached in the intergranular phase where it forms inclusion complexes with polar lipids, which are endogenously present in wheat starch or which may have been added as a baking ingredient (Goesaert et al., 2005). Moisture gradient in the bread, the temperature profile and added ingredients, such as sugar, are the most important factors that affect starch gelatinization and swelling in dough (Hoseney and Rogers, 1990; Varriano-Marston et al., 1980). Starch granules in the exterior portions of the bread are less swollen, and thus less gelatinized, than those in the centermost portions because the higher temperatures on the crust surface accelerate loss of moisture by evaporation and thus limit the extent of gelatinization (Varriano-Marston et al., 1980). The different molecular organizations of starch in the crumb and crust can be evaluated using X-ray diffraction patterns. Starch crystallinity is higher in the crust than in the crumb. The X-ray pattern of starch granules in the crust is predominantly an A pattern superimposed with a V pattern (fat-amylose complex) whereas crystallinity in the crumb is mainly characterized by the fat-amylose complex (Varriano-Marston et al., 1980). Freshly baked bread has a soft and resilient crumb that is attributed to crystallization of amylose (Goesaert et al., 2005; Hug-Iten et al., 2003). Long term storage of bread leads to loss of flavour, deterioration of crumb quality and development of a tough leathery crust (Delcour and Hoseney, 2009; Gray and Bemiller, 2003), which are collectively referred to as staling. Amylopectin recrystallization (i.e. retrogradation) plays a major role in bread firming after the initial cooling process (Eliasson et al., 2013; Bosmans et al., 2013; Goesaert et al., 2009a; Goesaert et al., 2008; Ribotta and Le Bail, 2007; Hug-Iten et al., 2003). However, it is important to note that the mechanism of staling is a complex phenomenon that is also influenced by several other physico-chemical reactions, such moisture migration from the crumb to the crust (Bosmans et al., 2013; Purhagen et al., 2011; Ribotta and Le Bail, 2007) and gluten-starch interactions (Goesaert et al., 2008). Microbial amylases or malt enzymes are regularly added to wheat flour to optimize the amylase activity of the flour (i.e. standardize the flour) and retard bread staling (Goesaert et al., 2005). Amylase degrades damaged starch particles in the dough and thus increases the maltose content, which promotes yeast activity during fermentation. The increased levels of maltose also promotes the formation of Maillard reaction products, which intensify bread flavor and give the crust its characteristic smell and dark brown colour. Furthermore, amylase decreases the molecular weight of starch polymers and causes the formation of maltodextrins, which contribute to increased crumb softness, improved crumb resilience and decreased staling rate (Goesaert et al., 2009a; Hug-Iten et al., 2003; Rojas et al., 2001). The

reduction in molecular weight of starch polymers contribute to the antifirming effect by weakening the amylopectin networks and increasing amylose mobility, crystallization and network formation (Goesaert et al., 2009b; Hug-Iten et al., 2003). Maltodextrins act as antifirming agents by hindering the association of crystallizable helices and / or by their plasticizing action, which reduce amylopectin chain mobility (Goesaert et al., 2009b).

Chemically modified starch in bread making

Chemically modified starch is obtained when starch is treated with chemical reagents to introduce new chemical substituent groups, effect molecular scission, or promote molecular oxidation or molecular re arrangement (Huber and Bemiller, 2010). Starch is a suitable material for chemical modification because of the numerous hydroxyl groups in its constituent polymers. The reaction of chemicals with starch takes place at the hydroxyl groups on carbon 2, 3 and 6 of the anhydroglucose units to give converted (depolymerized), dextrinized, cross-linked, stabilized (substituted), oxidized, cationized or graft copolymerized starch (Singh et al., 2007; Huber and Bemiller, 2010; Tharanathan, 2005). Due to concerns on consumer safety and technological reasons, not all types of substituted starches are suitable for application in food processing. The types of chemically modified starches that are useful in food processing are the converted, dextrinized, cross-linked, stabilized and oxidized starches (Huber and Bemiller, 2010).

Bread made from wheat flour that is partially substituted with esterified (acetylated) or etherified (hydroxypropylated) starch shows increased crumb adhesiveness and a more open crumb structure but no improvement in specific volume (Miyazaki et al., 2008; Miyazaki et al., 2005; Goesaert et al., 2008). However, when vital gluten is added to wheat flours containing hydroxypropylated or acetylated tapioca starch, the bread is softer than that containing the same amount of native tapioca starch or wheat flour alone (Miyazaki et al., 2005a, b). Among the various esterified and etherified starches studied by Miyazaki et al. (2005a) and Miyazaki et al (2008), it is only hydroxypropylated starch that was able to decrease the staling rate of bread. Octenyl succinic anhydride starch (OSA starch) is an esterified starch with surface active properties (Eliasson et al., 2013; Sweedman et al., 2013; Dokić et al., 2008). The glucose subunits within the starch molecule are hydrophilic and soluble in aqueous solution, whereas the n-octenyl succinate chains are hydrophobic and lipophilic (Sweedman et al., 2013). These starch granules have high effective surfaces, which induce high density of non-covalent bonds between the system components and thereby increase dough rigidity (Hadnadev et al., 2013). Breads treated with OSA starches show improved specific volumes, crumb whiteness and softness (Hadnadev et al., 2014).

Partial substitution of wheat flour with cross-linked starch increases crumb dryness and firmness but does not improve the specific volume or decrease the staling rate (Goesaert et al., 2008; Miyazaki et al., 2008; Miyazaki et al., 2005a; Hung and Morita, 2005; Hung and Morita, 2004). Hung and Morita (2004) found that cross-linked corn starch (5-10%) was able to increase the specific volume of bread and decrease crumb firmness when vital gluten was added to the formulation. Yeo and Seib (2009) found that partial substitution of wheat flour with cross-linked wheat starch (30%) and supplemented with vital gluten increases the specific volume of bread but decreases crumb firmness. Furthermore, Yeo and Seib (2009) noted changes in the nutritional quality of the bread in the form of increased contents of total dietary fibre, slowly digestible fibre and resistant starch.

Genetically modified starch in bread making

Native starch granules contain 70-80% amylopectin and 20-30% amylose and small amounts (0.5-2% w/w) of non-starch polysaccharides, lipids, proteins and ash (Belitz et al., 2009; Copeland et al., 2009; Liu, 2005). Traditional plant breeding techniques or genetic modification can be used to produce novel starches with modified functionalities (Davis et al., 2003). High amylose starch (starch with up to 70% amylose content), waxy starch (99-100% amylopectin content) or starch with modified amylopectin structure, phosphate content or granule size and number have been produced by genetic modification (Kaur et al., 2012; Jobling, 2004). Starch modification in planta changes the physicochemical properties, thermal characteristics and granule structure of starch and consequently its functionality during processing (Abdel-Aal et al., 2002). High-amylose wheat flour and waxy wheat flours are, on their own, unsuitable for bread making. Waxy wheat flour decreases bread volume and gives a glutinous and weak crumb with large gas cells (Park and Baik, 2007; Morita et al., 2002). Sahlstrom et al. (2006) found that waxy wheat flour has no significant effect on the volume of hearth bread, but it decreases the form ratio, weight and overall appearance of the bread and causes development of a crumb with a more open pore structure. High amylose wheat flour gives bread with low specific volume and crumb with small gas cells (Morita et al., 2002). The only positive attribute of bread made from waxy wheat flour is that it stales at a slower rate than bread made from standard wheat flour or high-amylose wheat flour (Morita et al., 2002). This is because the absence of amylose in waxy starch decreases the tendency of gelatinized material to gel (Jobling, 2004). Bread made from whole waxy wheat

flour has low specific volume, bitter taste and dark brown colour (Hung et al., 2007). The additional deterioration in quality characteristics of bread made from whole waxy wheat flour, in comparison to that made from refined waxy wheat flour, is due to the high fibre and ash contents in the whole waxy wheat flour rather than the high amylopectin content. Similarly to bread made from refined waxy wheat flour, bread made from whole waxy wheat flour stales at a slower rate than bread made from standard wheat flour (Hung et al., 2007). Bread made from standard wheat flour contains small amounts of resistant starch (Sajilata et al., 2006). The amount of resistant starch in baked bread can be increased further by adjusting the processing conditions or using processing aids such as sour dough acids (Liljeberg et al., 1996) or by partial substitution of wheat flour with high amylose starch (Hung et al., 2005; Hoebler et al., 1999; Liljeberg et al., 1996; Eerlingen et al., 1994). On storage, the resistant starch content in bread increases further due to amylopectin retrogradation (Miyazaki et al., 2005b; Eerlingen et al., 1994). Partial replacement of wheat flour with high amylose starch or flour in bread making is of nutritional importance because waxy starch is able to resist digestion in the intestine and hence decreases the glycaemic index of bread (Hoebler et al., 1999). The nature of the substitute high amylose flour and the level of substitution impart different effects on bread quality. Miyazaki et al. (2005b) showed that substitution of wheat flour with 10% or 30% high amylose wheat flour does not affect loaf volume or appearance of the bread crumb but 50% substitution decreases loaf volume and gives bread crumb with inferior appearance. By contrast, Eerlingen et al. (1994) found that substitution of wheat flour with a relatively low amount (20%) of high amylose corn starch decreased bread volume.

Partial substitution of wheat flour with waxy flours or starches from different botanical sources decreases bread volume (Hung et al., 2007; Bhattacharya et al., 2002; Hibi, 2001) and crumb firmness (Bhattacharya et al., 2002; Purna et al., 2011; Purhagen et al., 2011). The results obtained with staling rate are less conclusive. Bhattacharya et al. (2002) and Hayakawa et al. (2004) showed that substitution of wheat flour with waxy durum wheat flour (10-30%) or waxy wheat flour (less than 20%), respectively, decreases the staling rate of bread. By contrast, Purna et al. (2011) found that substitution of wheat flour with hard waxy wheat flour (15-45%) does not decrease the staling rate of bread. High levels of waxy wheat flour (more than 20%) damages the crumb texture and causes post-bake shrinkage (Purna et al., 2011; Hayakawa et al., 2004). The negative effects of waxy flours on bread quality can be mitigated by supplementing wheat flour with vital gluten. Lee et al. (2001) showed that bread made from wheat flour, waxy wheat starch (25 or 50%) and vital gluten had a higher volume and softer and porous crumb structure than bread baked from blends of regular wheat starch (24% amylose) and vital gluten. Although amylopectin recrystallization is a major cause of crumb firming in stored bread (Eliasson et al., 2013; Bosmans et al., 2013; Goesaert et al., 2009a; Goesaert et al., 2008; Ribotta and Le Bail, 2007), partial substitution of wheat flour with waxy flours decreases crumb firmness because the low amylose content in the bread gives it a lower than normal post-bake crumb firmness (Purna et al., 2011). The increased water absorption capacity of waxy flour and modified water distribution also contribute to increased crumb softness of bread containing waxy flour (Eliasson et al., 2013; Purna et al., 2011; Purhagen et al., 2011; Hung et al., 2007).

Physically modified starch in bread making

Physically modified starches are considered to be natural materials with high safety because they are produced without the use of chemicals or biological agents (Ashogbon and Akintayo, 2014; Kaur et al., 2012). Physically modified starch can be obtained by heat treatment or mechanical shearing and include pre-gelatinized starch, granular cold water soluble starch, mechanically sheared starch, annealed starch, heat-moisture treated starch and dry-heated starch (Kaur et al., 2012; Huber and Bemiller, 2010). Novel methods that can be used to synthesize physically modified starch include osmotic pressure treatment, deep freezing, instantaneous controlled pressure drop, pulsed electric field, corona electrical discharges, superheat treatment, iterated syneresis, radiation, sonication, photo-oxidation and exposure to ultra violet or polarized light (Kaur et al., 2012; Tharanathan, 2005).

Partial substitution of wheat flour with extruded wheat flour (Martínez et al., 2013) or pregelatinized wheat starch (Miller et al., 2008) increases the damaged starch content of the flour leading to increased water absorption and gas production during fermentation. To ensure that adequate bread characteristics are maintained, only small amounts (less than 5%) of damaged flour should be used to replace the wheat flour (Martínez et al., 2013; Miller et al., 2008). Partial substitution of wheat flour with heat-moisture treated maize starch (modification conditions are not clearly defined) decreases the specific volume and crumb softness of bread (Miyazaki and Morita, 2005). The heat-moisture treated starch is unable to improve the quality of bread due to the inability of the modified starch to effectively interact with gluten (Miyazaki and Morita, 2005). Bread made from wheat flour that has been partially substituted with high pressure-treated oat, millet or sorghum flours has higher crumb firmness, lower crumb cohesiveness and specific volume than bread made from standard wheat flour (Angioloni and Collar, 2012).

Enzymatically modified starch in bread making

Enzymatic modification of starch during bread making takes place in situ. Native wheat flour is rich in β-amylase, which is largely inactive, and which is susceptible to heat inactivation before starch gelatinizes. By contrast, wheat is low in α-amylase activity although this enzyme is essential for the development of desirable bread properties such as high volume, low staling rate and soft crumb texture (Delcour and Hoseney, 2009). Thus, wheat flour is normally supplemented with malt or fungal α-amylase to improve its bread making properties. α-Amylase improves bread volume by catalyzing the breakdown of damaged starch to maltose, which the yeast utilizes to produce carbon dioxide. The antistaling action of amylases is due to the formation of dextrins of a particular size and / or modification of the starch structure to give it different retrogradation properties (Delcour and Hoseney, 2009). There are several other novel kinds of enzymatically modified starch (Kaur et al., 2012) that could be useful in bread making. For instance, glycogen-branching enzymes or cyclomaltodextrinase can be used to synthesize starches with limited retrogradation ability (Kim et al., 2008; Auh et al., 2006), which could be used to decrease the staling rate of bread.

Dual-modified starch in bread making

A single type of modification is usually insufficient to impart all the desired properties to starch intended for a specific application. Although many commercial starch products are made with more than two types of modification (Huber and Bemiller, 2010), most of the published studies in bread making have investigated the impact of dual-modified starches (i.e. modified starches made with only two types of modification such as physical/chemical, chemical/chemical or chemical/ enzymatic methods). Hibi (2001) showed that substitution of wheat flour with retrograded waxy corn starch (5%) increases specific volume and decreases staling rate, whereas Eerlingen et al. (1994) found that extruded retrograded waxy corn starch (20%) decreases bread volume and crumb firmness and increases resistant starch content in bread. Bread made from wheat flour that has been substituted with 5-15% cross-linked waxy corn starch, with or without vital gluten, has a higher specific volume and stales at a slower rate than the control (Hung and Morita, 2004; 2005). Bread made from wheat flour and cross-linked waxy barley starch stales faster and shows a higher enthalpy change in melting of crystalline region of starch than control bread containing normal wheat starch (Inagaki and Seib, 1992) or bread formulated with waxy barley starch (Toufeili et al., 1999).

As already discussed earlier, non-physically modified OSA starch granules are able to increase dough rigidity because of the high density of non-covalent bonds between the system components. By contrast, pre-gelatinized or hydrolyzed OSA starch granules possess weakened or destroyed crystalline structures which create fewer bonds with the system components and thus decrease dough rigidity (Hadnadev et al., 2013). Nonetheless, the differences in dough quality are not reflected in the bread quality, except for crust color. Breads treated with non-physically modified OSA starches or dual-modified OSA starches show increased specific volumes, crumb whiteness and softness as compared to breads prepared from normal wheat flours (Hadnadev et al,. 2014). Crusts of breads treated with dual-modified OSA starches are darker than for those treated with non-physically modified OSA starch (Hadnadev et al., 2014).

CONCLUSION

Starch is an important source of energy in human nutrition. The major sources of starch for human nutrition are cereals, root and tuber crops, and legumes. Wheat is the most widely used cereal for bread making because of the chemical nature of its storage protein fraction, which form viscoelastic dough when hydrated. After protein, starch is the second most functionally important fraction in wheat flour for bread making. Starch contributes to the formation of optimal dough; is responsible for setting of the crumb during baking; and contributes to the physical deterioration of bread quality through staling. Attempts have been made to improve the baking quality of wheat flour through the addition of chemically, physically, genetically or enzymatically modified starches. Improvement in the quality of bread has been achieved in some instances and appears to be dependent on the nature of the modified starch, botanical origin of the starch, dosage used, and presence or absence of dough improving agents such as vital gluten.

Conflict of interests

The author declares that there is no conflict of interests regarding the publication of this paper.

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Physicochemical and sensory characteristics of pepper oil sauce prepared from perilla oil

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Pepper oil sauce or 'rayu', is one of the most famous traditional condiments in Korea, Japan and China. Generally, it is prepared using edible oil from soybean, corn among others. Since perilla possesses high amount of omega-3 polyunsaturated fatty acids, the objective of the present study was to investigate the quality characteristics of pepper oil sauces prepared using perilla oil. The quality characteristics of perilla sauces (ONP: onion pepper oil, OIP: oil cake pepper oil and SHP: shrimp pepper oil) were compared with those of the commercially available sauce in Korea (KPO). Carbohydrate and sugar contents and calorie and peroxide values of commercial sauce were higher than those of the perilla oil sauces. However, crude protein and fat were higher in the perilla oil sauces. Soluble solid content of perilla oil sauces was significantly high as compared to that of KPO. The sauce prepared from perilla oil was found to be 12 times higher in omega-3 polyunsaturated fatty acid and 25%less in sodium than a commercial pepper oil sauce. Moreover, the sensory characteristics in terms of overall acceptability of OIP and SHP were also higher than that of the KPO. Results of the present study offer a good choice for production of high value perilla sauce.

Key words: Omega-3 fatty acid, pepper oil sauce, perilla oil, perilla sauce, rayu.

INTRODUCTION

Condiments stand as one of the significant traditional foods of Korea. Pepper oil or hot pepper oil, also known as pepper oil sauce or 'rayu', is one of the most famous traditional condiments in Japan, China and Korea. It is a condiment made of vegetable oil that has been infused with chili peppers and used as an ingredient in cooked dishes. It is sometimes used as a dip for meat and also employed in the Korean Chinese noodle soup dish, *jjamppong*. In addition, it serves as enhancer of flavour and colour to the cuisine and a good appetizer. The sauces increase the nutritional value of the dishes as well as help in digestion (Kim, 2004; Kim et al., 2002).

People are becoming more conscious about the health benefit of functional foods (Kapsak et al., 2011). With this change in the food habits of the people, the food industries are likewise giving high priority to production of variety of healthy foods containing functional materials (Yoon et al., 2007; Kapsak et al., 2011). Every year,

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Table 1. Formula of recipe in percent for preparation of pepper perilla oil sauce.

Ingredients	Onion pepper oil	Oil cake pepper oil	Shrimp pepper oil
Perilla oil	58.7	58.7	58.7
Red pepper powder	19	19	19
Fried onion	5.8	0	0
Perilla oil cake powder	0	5.8	0
Shrimp powder	0	0	5.8
Dried onion	3.1	3.1	3.1
Garlic flake	1.6	1.6	1.6
Onion powder	0.3	0.3	0.3
Garlic powder	0.3	0.3	0.3
Ginger powder	0.3	0.3	0.3
Sesame	3.0	3.0	3.0
Peanut powder	4.7	4.7	4.7
Salt	0.4	0.4	0.4
Ssamjang	2.8	2.8	2.8
Total (%)	100.0	100.0	100.0

different products of pepper oil sauce are being launched on the market. Different ingredients are being used to enhance the nutritional values and organoleptic properties of condiments like pepper oil sauce. Quality of pepper oil sauce is mostly affected by the quality of pepper and other factors including the ingredients used (Li et al., 2007).

Perilla (*Perilla frutescens*) is widely cultivated in Korea as vegetable oil crop. It contains 50 to 60% of ω-3 polyunsaturated fatty acid in the form of α-linolenic acid (Narisawa et al., 1994). The α-linolenic acid, a primary fatty acid in perilla oil, is attracting attention as it is believed to have many health benefits such as lowering blood pressure, thrombosis improvement, inhibition of cancer cell proliferation, and retinal and brain development (Lee, 1990). In another report, the quality of tomato sauce increased while the microbial activity was inhibited with the use of perilla leaf (Kim et al., 2013). In general, pepper oil sauces are prepared using different sources of edible oils like those from soybean and corn. Perilla is widely used for flavoring, food, medicine and oil in China, Korea and Japan (Lee et al., 2002). To the best of the authors' knowledge, perilla oil was not found to have use in making pepper oil sauces so far. Since the perilla is widely cultivated in Korea (Narisawa et al., 1994) and possesses many health benefits, the objective of the present study was to prepare a pepper oil sauce using perilla oil and investigate the physicochemical and sensory characteristics of the sauce in comparison with the commercially available pepper oil sauce.

MATERIALS AND METHODS

All the food ingredients were purchased from a retail store in Gyeongju, Korea. Formula of various materials used for preparing different types of sauce samples are shown in Table 1. The optimum amount of perilla oil and other ingredients (Table 1) used in preparing the perilla oil sauces were determined on the basis of their overall taste. The commercially available pepper oil sauce (KPO) was obtained from retail store in Gyeongju, Korea. The KPO was prepared using corn oil.

Sample preparation

The pepper oil sauce samples were prepared following Son (2004) and Koo and Kim (2004) with some modifications. The ingredients (Table 1) were added to the perilla oil heated to 110°C and thoroughly mixed. Three different perilla oil sauce samples: onion pepper oil (ONP), oil cake pepper oil (OIP) and shrimp pepper oil (SHP) were prepared separately. The pepper oil sauce samples were packaged in air-tight container and stored at refrigeration temperature (4°C) until needed for analysis. All the chemicals and reagents used in the present study were of analytical food grade.

Proximate composition and chemical properties

Contents of moisture, crude protein, crude lipid, ash, carbohydrate and sugar were evaluated according to AOAC (1995). Acid and peroxide values and fatty acid composition were determined following Eltayeib and Elaziz (2014) with some modifications. Calorie value was determined using bomb calorimeter (Parr Instrument Co., Moline, IL, USA). Soluble solid content expressed as degree Brix was determined by a hand refractometer (RX-5000α, Atago, Tokyo, Japan). The water activity was determined at 25°C using a CX–1 chilled-mirror dew-point water activity meter, Campbell Scientific, Ltd. (CX–1 water activity system: Instruction manual: Version 1/3.88).

Crude protein

Sauce sample (0.8 g) was underwent combustion in pure oxygen at 850°C. The amount of nitrogen was measured by thermal conductivity. Crude protein was calculated by multiplying the nitrogen value by 6.25.

Crude lipid

Sauce sample (2 g) was kept into a soxhlet extraction thimble and extracted for 8 h with a constant boiling range (40-60°C) hydrocarbon solvent. The hydrocarbon solvent was removed and the amount of oil was determined gravimetrically.

Ash and moisture content

The ash content was determined by incineration in a muffle furnace at 520°C. The moisture content of the sample was calculated based on weight loss after the sample was heated in an oven at 105°C.

Sugar and carbohydrate

The free sugars and carbohydrates in the extracts are examined using HPLC. The method was based on chromatographic separation of sugars and their retention time. The identification of sugars was done by comparing retention times of individual sugars in the reference vs. tested solution (qualitative analysis). The quantitative assays were made by the following carbohydrates: fructose, glucose, sucrose and maltose. Carbohydrates are separated on the basis of their differential adsorption characteristics by passing the solution to be analyzed through a column. Carbo-hydrates can be separated on the basis of their partition coefficients, polarities or sizes, depending on the type of column used.

Acid value

Three grams of the cooled oil sample was weighed in a 250 ml conical flask, 100 ml of freshly neutralized hot ethyl alcohol and 1 ml of phenolphthalein indicator solution were added, the mixture was boiled for 5 min, titrated while hot against standard alkali solution and shaken vigorously during titration. Acid value was calculated as follows:

Acid value = (56.1)V.N/W

where, V = volume in ml of standard potassium hydroxide; N= normality of the potassium hydroxide solution; W = weight in g of the sample.

Peroxide value

Five grams of the sample sauce were placed in 250 ml conical flask and fitted with ground-glass stopper. Thirty milliliter of a mixture of chloroform and glacial acetic acid (2:3 v/v) was placed in the conical flask, shake for a minute to dissolve the oil, 0.5 ml of saturated potassium iodide solution and 30 of water were added. The flask content was titrated with 0.01 N sodium thiosulphate, the titrant was added slowly with continuous vigorous shaking until the yellow colour was unchanged and a blank test under the same condition was carried. Peroxide value was calculated as:

Peroxide value = 10 $(n_1 - n_2)/m$

where, n_1 = volume in ml of standard sodium thiosulphate solution required for the sample; n_2 = volume in ml of standard sodium thiosulphate solution required for the blank; m = weight of sample

Sodium content

Sodium content was analyzed as described by Ehling et al. (2010) with some modifications. An Activa instrument (Horiba Jobin Yvon, Longjumeau, France) equipped with an autosampler AS500 (Horiba Jobin Yvon, Longjumeau, France), a tangential nebulizer (Miramist Peek Body), a cyclonic spray chamber, a radial torch, a Czerny-Turner monochromator, and an optical path purged with nitrogen was used. The daily calibration of the monochromator was performed by using the carbon emission lines and each operating wavelength was individually centered before the experiment began. Three wavelengths were chosen for Na analysis: 330.237, 588.995 and 589.592 nm. Samples were quantified with ICP-AES three times, first with external calibration of the 1/50 sample dilution, and then with the standard added procedure on the 1/50 sample dilution and 1/100 sample dilution.

Fatty acid composition

The fatty acid composition as fatty acid methyl esters (FAMEs) of the sauces was determined using gas chromatography (GC) following procedures described by Giacometti et al. (2002) with some modifications. Methylation was done with sodium methylate according to the European Union Commission modified Regulation EEC 2568/91. A chromatographic analysis (SHIMADZU set 17 A Series II gas chromatography) was performed using a capillary column (Stabilwax column, Restek Corporation, PA, USA). The column temperature was isothermal at 180°C and the injector at 230°C and detector temperature was 250°C. Fatty acids were identified by comparing retention times with standard compounds.

Sensory characteristics analysis

Analysis of sensory properties was performed using freshly made sauce. The aspects rated were for colour, flavour, and overall acceptability using scale (Mugisha et al., 2009) of 1 = very poor, 2 = poor, 3 = fair, 4 = good, and 5 = very good. All the sensory properties were evaluated by 20 semi trained volunteer panelists (10 women and 10 men) selected from the list of graduate students of College of Agriculture and Life Science of Kyungpook National University, Deagu, Korea. Mean values of 20 evaluations for each sensory property were reported as scores.

Statistical analysis

Data were subjected to analysis of variance (ANOVA) using SAS 9.4 (2013). Differences between means at $p < 0.05$ were analyzed using Tukey test.

RESULTS AND DISCUSSION

Proximate composition of sauces

The values of some of the proximate compositions were significantly different ($p < 0.05$) among the pepper oil sauces while others were not (Table 2). Moisture content of the KPO was not significantly different from all the other samples. Ash content of OIP was significantly high followed by SHP then KPO. The high value of ash in OIP might be due to the oil cake, which reported to contain high ash (Sharma, 2013) as compared to onion (Yahaya et al., 2010) and shrimp (Brasileiro et al., 2012). Carbohydrate content was significantly high in the KPO as compared to other samples. This might be due to

Table 2. Proximate composition and chemical properties of perilla oil and commercial pepper sauces.

Components	Sample[1]			
	ONP	OIP	SHP	KPO
Moisture (%)	4.0±0.5[a2]	4.8±0.4[a]	3.9±0.5[a]	4.2±0.2[a]
Ash (%)	2.0±0.1[c]	3.3±0.1[a]	2.8±0.2[b]	2.7±0.2[b]
Carbohydrate (%)	4.8±0.4[b]	3.7±0.3[c]	2.7±0.5[d]	17.0±1.8[a]
Crude protein (%)	4.0±0.8[d]	6.1±0.3[b]	7.1±0.6[a]	5.0±0.5[c]
Crude fat (%)	85.2±1.3[a]	82.1±1.2[b]	83.5±2.0[ab]	64.0±1.6[c]
Calorie (kcal)	802±11[a]	778±8[b]	791±15[a]	667.0±9[c]
Soluble solid (Brix°)	76.7±0.03[a]	76.7±0.04[a]	76.6±0.05[a]	73.4±0.03[b]
Water activity (Aw)	0.38±0.02[b]	0.42±0.01[a]	0.32±0.02[c]	0.33±0.02[c]
Acid value	0.9±0.1[b]	1.5±0.2[a]	1.4±0.2[a]	1.0±0.3[b]
Peroxide value (meq/Kg)	2.3±0.3[b]	2.5±0.2[b]	2.2±0.2[b]	5.4±0.1[a]
Sodium (mg/100g)	479.6±3.5[d]	727.7±5.5[b]	606.8±3.8[c]	912.0±6.9[a]
Sugars (%)	ND[3]	3.5±0.2[b]	2.5±0.1[c]	16.0±0.3[a]

[1]ONP: Onion pepper oil, OIP: Oil cake pepper oil, SHP: Shrimp pepper oil, KPO: Pepper oil purchased from at a local market in Korea. [2]Quoted values are means of triplicate measurements. Values followed by different superscripts in the same row are significantly different ($p<0.05$). [3]Not detected.

higher carbohydrate containing ingredients in the commercially available pepper oil sauce. Crude protein content of SHP was high as compared to all the other samples. This might be due to higher protein content in shrimp (Brasileiro et al., 2012) as compared to perilla (Gwari et al., 2014) and onion (Yahaya et al., 2010). Crude fat content of KPO was lower than the other three samples made using perilla oil. The calorie content of perilla oil sauce samples were higher than that obtained from the market. This might be due to higher fat content (DeClerck, 2016) of perilla oil containing sauces.

Chemical properties of sauces

The average soluble solids content in perilla oil sauces was higher than that of commercial sauce (Table 2). Measurements of soluble solids by a refractometer could be used to estimate the degree of protein hydrolysis during fermentation (Lopetcharat and Park, 2002).

Water activity (Aw) of OIP was the highest followed by ONP, KPO and SHP, respectively. Aw has been recognized as one of the primary factors influencing the thermal resistance of pathogens in low-moisture foods (Syamaladevi et al., 2016).

Acid value of the KPO was 1.0 which was in the range of perilla oil containing sauce (0.9 to 1.5). The acid value is an indicator of the aged food (Pennington and Hepburn, 1910) or whether the oil has been degraded or become rancid. The peroxide value of the samples corresponded with that of the acid value with the lowest for ONP. The acid and peroxide values are indicator of rancidity behaviour of the oils when properly stored in a container free from atmospheric oxygen and other contaminants (Ogungbenle, 2003). Sodium content of the KPO was about 25% higher than those of three perilla sauces. Excess sodium intake has negative effect on health (He and MacGregor, 2009) causing ventricular hypertrophy as well as fibrosis in the heart, kidneys and arteries (Frohlich, 2007). Sugar content of commercially available perilla oil sauce was significantly high as compared to perilla oil sauces. This might be due to high sugar containing ingredients in the commercially available pepper oil sauce.

Fatty acid composition of sauces

The fatty acid composition of perilla oil and commercial pepper oil sauces were significantly different (Table 3). The KPO contained higher amount of saturated fatty acids (SFA) and monounsaturated fatty acids (MUFA) but lower amount of polyunsaturated fatty acids (PUFA). In contrast, the perilla pepper oil sauces showed opposite results with highest value for PUFA of the total fatty acids (FAs). The dominant fatty acids in the perilla oil and commercial sauces were α-linolenic acid (C18:3 or omega-3) and linoleic acid (C18:2 omega-6), respectively. The perilla oil sauces contained almost 12 times higher omega-3 PUFA than that of KPO. The higher amount of PUFA in the perilla sauces was attributed to the presence of high α-linolenic acid (C18:3) content in perilla oil (Gwari et al., 2014). It is well stablished that omega-3 PUFA α-linolenic acid (C18:3) reduces cholesterol level (glyceride contents) in human blood as well as to inhibit colon cancer (Narisawa et al., 1994). The α-linolenic acid

Table 3. Fatty acid composition in percent of total fat content of perilla oil and commercial pepper sauces.

Fatty acid	Sample[1]			
	ONP	OIP	SHP	KPO
SFA[2]	8.9±0.2[5]	8.3±0.2	8.1±0.2	15.3±0.3
C12:0	0.5±0.1	ND	ND	ND
C14:0	0.2±0.1	ND	ND	ND
C16:0	5.9±0.2	5.9±0.1	5.8±0.2	10.5±0.3
C18:0	2.2±0.1	2.3±0.2	2.2±0.1	4.1±0.2
C20:0	0.1±0.1	0.1±0.1	0.1±0.1	0.4±0.1
C22:0	ND[6]	ND	ND	0.3±0.1
MUFA[3]	16.9±0.2	17.8±0.2	17.0±0.1	27.2±0.2
C14:1	ND	0.1±0.1	ND	0.1±0.1
C18:1	16.9±0.2	17.7±0.2	17.0±0.1	27.1±0.2
PUFA[4]	74.2±0.3	73.9±0.5	74.9±0.2	57.5±0.1
C18:2	13.4±0.3	15.3±0.3	14.0±0.1	52.5±0.1
C18:3	60.8±0.2	58.6±0.2	60.9±0.2	5.0±0.1

[1]ONP: Onion pepper oil, OIP: Oil cake pepper oil, SHP: Shrimp pepper oil, KPO: Pepper oil purchased from at a local market in Korea. [2)]Saturated fatty acids. [3)]Monounsaturated fatty acids. [4)]Polyunsaturated fatty acids. [5)]Quoted values are means±SD of triplicate measurements. [6)]Not detected.

Table 4. Sensory characteristics of perilla oil and commercial pepper sauces.

Characteristics	Sample[1]			
	ONP	OIP	SHP	KPO
Appearance	3.0±0.21[b2]	4.0±0.31[a]	4.5±0.22[a]	3.5±0.04[b]
Flavor	3.0±0.31[d]	4.5±0.03[a]	4.0±0.31[b]	3.6±0.02[c]
Overall acceptability	3.5±0.21[c]	4.0±0.31[a]	4.3±0.11[a]	3.8±0.03[b]

[1]ONP: Onion pepper oil, OIP: Oil cake pepper oil, SHP: Shrimp pepper oil, KPO: Pepper oil purchased from at a local market in Korea. [2]Quoted values are means±SD of triplicate experiments (n=20) based on 5 point scores (1, very poor; 2, poor; 3, fair; 4, good; 5, very good). Values followed by different superscripts in the same row are significantly different ($p<0.05$).

also has health benefits such as of lowering blood pressure, thrombosis improvement and retinal and brain development (Lee, 1990). The omega-3 fatty acids are mainly consumed by vegans for heart health (Calder, 2004). The results of the fatty acid composition indicate that pepper oil sauces prepared with the perilla oil could be a good option to enhance the value of the sauces with increased health benefits.

Sensory characteristics of sauces

Appearance value of two of the three perilla sauces was higher than that of the commercial sauce (Table 4). Values for OIP and SHP were significantly high as compared to ONP and KPO. The appearance value is not the only criteria for acceptance or rejection of pepper oil sauce unless it is noticeably unusual. Appearance could vary based on types and quantity of ingredients added during preparation (Ogundele et al., 2015). The proportion of ingredients in pepper oil sauce could be varied in accordance with the preference of the individual without severely affecting its originality.

Flavour value was also high for the samples which had higher colour value (Table 4). This might be because of the influence of an ingredient for both colour and flavour. OIP had the highest flavor value followed by SHP, KPO and ONP. Although, different sensory inputs like visual, olfactory, gustatory, tactile, or trigeminal are considered during food consumption (Prescott, 2004), the interaction between taste and odour, which jointly constitute the flavour value, is one of the decisive factors for food

evaluation (Delwiche, 2004).

Overall acceptability determines the general acceptance of the product considering all the discriminating sensory characteristics of the sample. Overall acceptability of OIP and SHP was significantly high as compared to other two samples. The ONP showed the least overall acceptability value out of the four samples (Table 4). The reason behind this might be the lower colour and flavour score for ONP that contained high amount of onion (Table 1). Although consumers are truly conscious about the nutritional characteristics (Bruhn et al., 1992), safety (Wilcock et al., 2004), and even the trademark (Guerrero et al., 2000) or price (Caporale et al., 2001) of the product, their benefits cannot outweigh the sensory properties of foods (Siró et al., 2008). The results of the sensory evaluation showed that pepper oil sauces prepared with the perilla oil could be a good option for high value sauce with increased organoleptic properties.

Conclusion

The pepper oil sauce prepared from perilla oil was found to be of superior quality in terms of nutritional value and overall acceptability. Perilla oil sauces contained about 12 times higher omega-3 polyunsaturated fatty acid content and 25% less sodium content than a commercially available pepper oil sauce. Moreover, the sensory characteristics in terms of overall acceptability of OIP and SHP were also higher than that of the commercial product. Results of the present study offer a good choice for production of high value perilla sauce.

Conflict of interest

The authors declare no conflict of interest.

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Evaluation of drying methods on the content of some bio-actives (lycopene, β-carotene and ascorbic acid) of tomato slices

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Tomato (*Solanum lycopersycum* L.) is one of the most important vegetables worldwide. As it is a relatively short duration crop and gives a high yield, it is economically attractive. Thus, the objective of this study was to evaluate the effect of drying method on the quality of the dried tomatoes based on three parameters viz; lycopene, ß-carotene and ascorbic acid contents. Thirty-six kilograms of tomatoes were sorted, cleaned, blanched and divided into three equal portions of 12 kg each. The tomatoes were sliced into 4, 6 and 8 mm, then sun, solar and hybrid dried, respectively. The value of lycopene content obtained for sun dried tomatoes ranged from 23.89 to 18.77 mg/100 g, solar dried ranged from 24.51 to 22.56 mg/100 g and hybrid dried ranged from 25.12 to 24.65 mg/100 g. The average value of β-carotene content obtained for sun dried tomatoes ranged from 4.12 to 3.72 mg/100 g, solar dried ranged from 4.94 to 4.25 mg/100 g and hybrid dried ranged from 4.98 to 4.65 mg/100 g. The values of ascorbic acid obtained for sun dried tomatoes ranged from 17.04 to 5.60 mg/100 g, solar dried ranged from 23.73 to 13.37 mg/100 g and hybrid dried ranged from 29.20 to 24.82 mg/100 g. Hybrid dried tomatoes slice showed higher retention of lycopene, ß-Carotene and ascorbic acid than both the solar and open sun dried methods.

Key words: Tomato, hybrid-photovoltaic dryer, solar dryer, sun drying, lycopene, β-carotene and ascorbic acid.

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) belongs to the family *Solanaceae*, the main vegetable grown and most widely consumed and is therefore of strategic importance (Celma et al., 2009). It is highly seasonal and available in large quantities at a particular season of the year (Lorenz and Maynard, 1997). The tomato crop is noted to be the second most important vegetable crop next to potato (FAOSTAT, 2010). Tomato fruits had a high moisture

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content (90 to 94%), makes the fruit highly perishable (Rajkumar, 2007; Al-Sananbani et al., 2013). This fruits are rich sources of potentially bioactive compounds as health functional constituents including red-coloured carotenoid lycopene, β-carotene, vitamins E and C, phenolics, organic acids and flavonoids (Kaur et al., 2002; Periago and Garcia-Alonso, 2009; Kalogeropoulos et al., 2012). Also, tomatoes are widely known for their outstanding antioxidant content, including their high concentration of lycopene and excellent amounts of other conventional antioxidants like vitamin C and tocopherols, additional carotenoids (β-carotene, lutein, and zeaxanthin), trace minerals (selenium, copper, manganese and zinc) and phytonutrients including flavonoids (naringenin, rutin, kaempferol, and quercetin) and hydroxycinnamic acids (caffeic, ferulic, and coumaric acid) (Capanoglu et al., 2010; Fernández-ruiz et al., 2011). High levels of antioxidants present in tomatoes and tomato products help prevent oxidative damage that is hazardous for humans. Moreover, it is widely recognized that the protective role of tomato consumption is due to the synergistic effect among the different classes of antioxidants. Aside from the genetic potential of the cultivar, agronomic and environmental conditions, ripening stage of fruit and post-harvest storage are known to affect the chemical composition of tomatoes (Garcia and Barrett, 2006; Hernández et al., 2007; Al-Sanabani et al., (2013).

Adejumo (2012) reported that a medium sized tomato contributes 40% of ascorbic acid (vitamin C) required in humans, which is important in forming collagen, a protein that gives structure to the bones, cartilage, muscle, and blood vessels and aids in the absorption of iron. Ascorbic acid is necessary for healthy teeth, gums and is essential for proper functioning of adrenal and thyroid glands. It is also an antioxidant and as such acts as a general de-toxicant. USDA (2010) reported that tomato fruits contained vitamin A (5%), vitamin C (17%), and vitamin E (4%), potassium (5%). Vitamin A is needed for maintenance of skin, mucous membranes, bones, teeth, hair, vision and reproduction processes. The chemical composition of the tomato fruit depends on factors such as cultivar, maturity and environmental conditions, in which they are grown (Davies and Hobson, 1981).

Recent studies have demonstrated that the regular intake of tomato, either fresh or processed, is associated with a reduced risk of inflammation, cancer, cardio-vascular diseases and obesity and can increase cell protection from DNA damage by oxidant species (Harms-Ringdahl et al., 2012; García-Valverde et al., 2013; Raiola et al., 2014). Other medicinal benefits of tomatoes include reduction of cholesterol, improvement of vision, maintenance of gut, lowering of hypertension, alleviation of diabetes, protection of the skin, prevention of urinary tract infections and gallstones. Lycopene is used in cosmetics and pharmaceutical products and is an excellent natural colorant in several food formulations (Arab and Steck, 2000; Egydio et al., 2010; Levelly and Torresani, 2011; Itziar et al., 2013).

Nigeria ranks as the 16th largest tomato producing nation in the world and has the comparative advantage and potential to lead the world in tomato production and exports (FAOSTAT, 2010). The production of tomatoes in Nigeria in 2010 was about 1.8 million metric tonnes, which accounts for about 68.4% of West Africa, 10.8% of Africa's total output and 1.28% of world output (FAOSTAT, 2010). Unfortunately, the country still experiences deficiency in critical inputs, lack of improved technology, low yield and productivity, high postharvest losses and lack of processing and marketing infrastructure. The demand for tomato and its by-products far outweighs the supply. With a population of over 170 million people, an estimated national population growth rate of 5.7% per annum, and an average economic growth rate of 3.5% per annum in the past five years, Nigeria has a large market for processed tomato products (Ugonna et al., 2015).

Again, tomato has a limited shelf life at ambient conditions and is highly perishable. The demand for a wide range of processed tomato products has increased remarkably both in the retail and the food ingredient markets (Verlent et al., 2006). To increase the shelf life of tomatoes, different preservation techniques are being employed; however the success of these methods depends on how it meets certain requirements of the product quality for consumption. Many developing countries still face enormous challenges of postharvest losses of tomatoes due to inadequate processing and storage facilities. Tomatoes produced in the peak seasons are either consumed fresh, sold at relatively cheap prices, or are allowed to go waste (Abano and Sam-Amoah, 2011).

Drying is a very common preservation method used in foodstuffs and the quality of the final products is strongly dependent on the technique and the process variables used (Doymaz, 2005). The reduction of water activity by moisture removal leads to significant reduction of weight and volume, minimizing packaging, transportation and storage costs (Okos et al., 1992). Drying also, alters other physical, biological and chemical properties of foods (Demirhan and Özbek, 2010). Hot-air drying is one of the most frequently used operations for food dehydration (Krokida and Maroulis, 1999; Youssef and Mokhtar, 2014). A major disadvantage associated with hot-air drying is that it takes long time even at high temperature, which may cause serious damage to the flavour, colour and nutrients in dried products (Jing et al., 2010; Youssef and Mokhtar, 2014). Sun drying is a well-known traditional method of drying agricultural commodities immediately after harvest since the existence of human. Adejumo (2012) reported that a large percentage of tomatoes are usually sun dried on the bear ground to avoid wastages but such methods results in products with unattractive attributes, since the

product is unprotected from the environmental factors and infestation by insects, rodents, animals etc.

It then becomes expedient to produce solar dryers that would have added advantage of longer period residence, increased productivity and reliability through its ability to augment available heat during days with limited radiation as well as ability to operate during the night. In a hybrid solar dryer, drying is continued during off sunshine hours by back-up heat energy or storage heat energy. Therefore, the product is saved from possible deterioration by microbial infestation (Hossain et al., 2010). Drying helps to extend the shelf-life, decrease product volume significantly, increase product diversity, increases product food applications and improved products qualities and increased economic benefit. However, drying can accelerate some reactions that can adversely affect the product quality too (Akanbi and Oludemi, 2004). The interest in the production of dried tomatoes is increasing because of the possibility of using them in different purposes and drying efficiencies alone may not be adequate in qualifying this dryer for acceptance, except when the quality of the dried product is comparable to other alternatives in terms of lycopene, ß-carotene and ascorbic acid. This study represents the first systematic analysis of the effects of three different drying methods (sun, solar and hybrid-photovoltaic solar drying) on lycopene, ß-carotene and ascorbic acid of tomato slices.

MATERIALS AND METHODS

Sample source and preparation

In this study, tomatoes were obtained from the Jimeta Modern Market Yola, Nigeria. Tomatoes were selected from the lot based on; firmness, colour and size uniformity. They were sorted, cleaned thoroughly by washing under tap water (Owusu et al., 2012). Thirty-six kilograms of tomatoes were washed, sorted, blanched (in boiling water 100^{o}C for 2 min to inactivate enzymes) and divided into three equal portions of 12 kg each. Then, each portion was sliced with Hand Tomato Slicer to a thickness of 4, 6 and 8 mm, respectively. The moisture content of the fresh fruits was immediately determined according to the AOAC (2000) method (number 934.01), and found to be 94.22 ± 0.21 g water per 100 g sample.

Drying method

Open sun drying method

Out of the first portion (12 kg and 4 mm thickness), 4 kg of the sliced was spread in a single layer on a four different wire meshes (1 kg on each wire mesh) and sun dried until equilibrium moisture content was achieved. The procedure was repeated for the second portion (12 kg and 6 mm thickness) and third portion (12 kg and 8 mm thickness). The drying time required to reach the equilibrium moisture content was 510, 630 and 840 min and the moisture content of the dried slices was 9.75 ± 0.21, 9.83 ± 0.10 and 9.91 ± 0.15 g water per 100 g slices dried with 4, 6 and 8 mm thickness, respectively. The average of atmospheric temperature was approximately 40 – 45^{o}C daily.

Solar drying method

The second portion (12 kg and 4 mm thickness) 4 kg of the sliced was dried in the constructed hybrid dryer (1 kg on each tray) by using solar collector as the heating source alone. This is the solar drying method; here the heating source is from solar collector alone. The heater was not working in this case but the solar energy from the panel was charging the battery. So if the weather changes with poor sun intensity especially when drying through the night, the stored energy in the battery will power the heater to generate heat to facilitate drying process. The procedure was repeated for the second portion (12 kg and 6 mm thickness) and third portion (12 kg and 8 mm thickness). The drying time required to reach the equilibrium moisture content was 420, 510 and 600 min and the moisture content of the dried slices was 8.63 ± 0.22, 9.56 ± 0.48 and 9.71 ± 0.51 g water per 100 g slices dried with 4, 6 and 8 mm thickness, respectively. The average of atmospheric temperature was approximately 40 to 45°C daily.

Hybrid-photovoltaic solar dryer

The residual quantity, (12 kg and 4 mm thickness) was also dried in the constructed hybrid dryer (1 kg on each tray) but by using both heating source together. The schematic diagram of the experimental system is shown in Figure 1. The procedure was repeated for the second portion (12 kg and 6 mm thickness) and third portion (12 kg and 8 mm thickness). The drying time required to reach the equilibrium moisture content 300, 360 and 420 min and the moisture content of the dried slices was 6.57 ± 0.32, 7.63 ± 0.60 and 8.57 ± 0.15 g water per 100 g slices dried with 4, 6 and 8 mm thickness, respectively. The average of atmospheric temperature was approximately 40 to 45°C daily.

Determination of lycopene and vitamins in the fresh and dried tomatoes

Lycopene analyses

Spectrophotometric determination of lycopene content was carried out by using Spectrophotometer (UV-VIS SPECORD Analytik Jena, Germany) as described by Alda et al. (2009). Lycopene in the fresh and dried tomatoes samples were extracted by adding 8.0 ml of the mixture of hexane–acetone–ethanol (2:1:1, v/v/v) wrapped with aluminum foil to exclude light. Tubes were cap and vortex immediately, and then incubate out of bright light. The mixture was extracted at room temperature for 30 min. This extract was reconstituted with 10 mL distilled water on a vortex mixer for 1 min. The samples were allowed to stand for 10 min so as to allow phases to separate and all air bubbles to disappear. The cuvette was rinsed with the upper layer from one of the blank samples, then using hexane as a blank to zero at 503 nm determine the A_{503} of the upper layers of the lycopene samples. Lycopene levels in the hexane extracts was calculate as follows:

$$Lycopene\,(mg/100g) = (A_{503} \times 537 \times 8 \times 0.55)/(0.10 \times 172)$$

Where: The molecular weight of lycopene = 537g/mole, The volume of mixed solvent = 8 ml, The volume ratio of the upper layer to the mixed solvent = 0.55, The weight of added tomato = 1.0 g, The extinction coefficient for lycopene in hexane = 172 mM^{-1}, The Spectrophotometer at 503nm = A_{503}.

βcarotene (Pro-vitamin A) analyses

Vitamin A determination was carried out by using the method

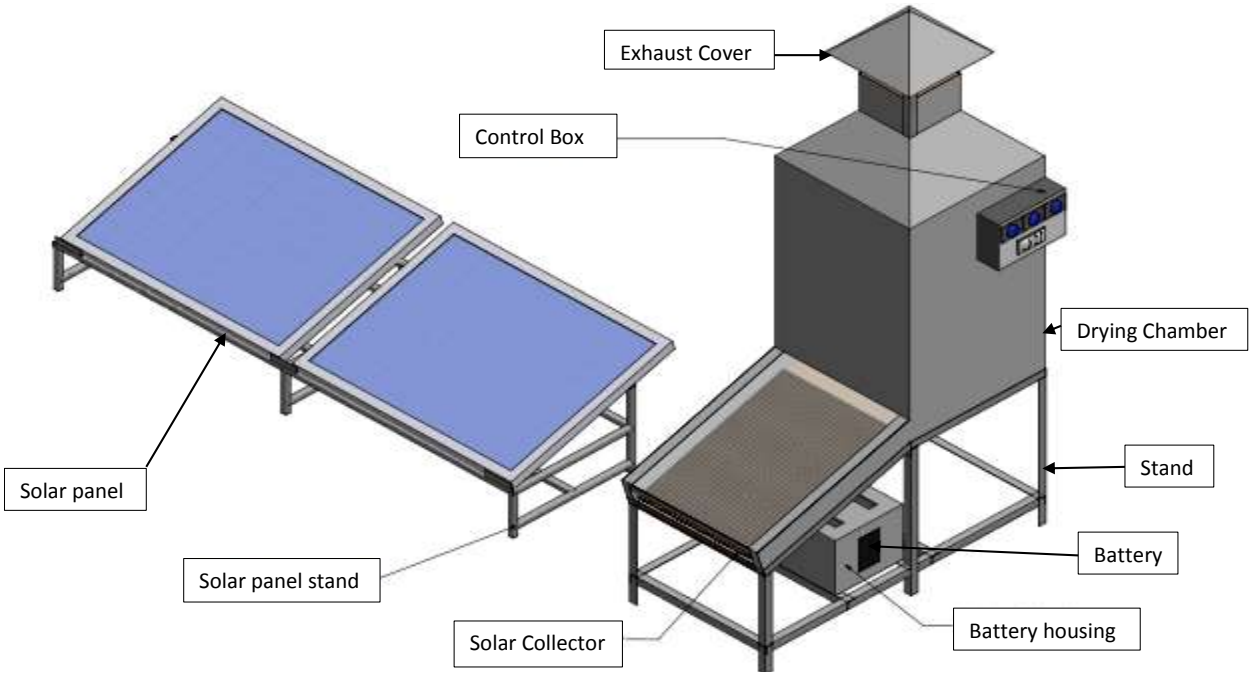

Figure 1. Isometric view of the hybrid dryer.

described by Onwuka (2005); this involves 200 µl of distilled water was placed in appropriate test tubes for blanks, samples and standard solution. Then 200 µl of alcoholic KOH was added to all tubes (including blanks) and mixed well on the vortex mixed for 10 to 20 s. Tubes were then placed in a water bath at approximately 55 to 60°C for 20 min. After 20 min, samples were cooled to room temperature and 200 µl of xylene- kerosene mixture was added. Retinol was extracted by vigorous mixing of each tube on the vortex for at least 30 s. Centrifugation was done for 5 min at 600 to 1000 xg. Xylene-Kerosene supernatant was withdrawn by means of a constriction micropipette connected to a rubber tube (for mouth sucking) and placing this sample extract in the spectrophotometer cuvettes. Readings were done at 328 nm for retinol and 460 nm for total carotenoids. Sample extract was transferred from the cuvette to glass tubes for irradiation. All the samples and blanks were irradiated for 35 min using an ultraviolet for source. The irradiated samples extract were transferred to cuvettes and their optical absorbance was read at 328 nm.

$$Retinol\ (\mu g/dl)\ =\ A^o\ (328)\ -\ A'\ X\ 637$$
$$Carotenes\ (\mu g/dl)\ =\ A^o\ (460)\ X\ 480$$

Where: A^o = Initial optical absorbance reading. A' = Optical absorbance after ultra violet irradiation.

Ascorbic acid analyses

Ascorbic acid was determined using the AOAC (2000) official titrimetry method. An aliquot (10 g) of the sample was diluted to a fixed volume (100 ml) with 3% HPO_3 and then titrated with 2, 6-dichlorophenolindophenol. A standard ascorbic acid solution of 5 mL was added to 5 mL of 3% HPO_3 and titrated with dye solution to a pink colour, which persisted for 15 s. Triplicate determinations were carried out and the result averaged. Ascorbic acid (mg/100 g) of reconstituted juice was calculated using the following formula:

$$Ascorbic\ acid\ (mg/100\ g) = \frac{T \times DF \times V_1}{V_2 \times V_3}$$

Where, T = titre; DF = Dye factor; V_1 = volume made up (100 ml); V_2 = aliquot of extract taken for estimation (10 g) and V_3= volume of sample taken for estimation (10 ml).

Statistical analysis

All experiments were performed in triplicate, and the results were expressed as means ± standard deviation (SD). Analysis of variance (ANOVA) was carried out to determine any significant differences in measurements using the SPSS statistical software (SPSS 20.0 for Windows; SPSS Inc., Chicago, IL, USA) and considering the confidence level of 95%. The significance of the difference between the means was determined using the Duncan Multiple range test, and the differences were considered to be significant at $p< 0.05$.

RESULTS AND DISCUSSION

Drying characteristics of tomato fruits

The change in moisture content (wet basis) of tomatoes slices with drying time (min) in open sun, solar and hybrid-photovoltaic solar dryer was showed in Figure 2. It was observed that the total drying time for 4, 6 and 8 mm thickness slices was 510, 630 and 840 min, respectively in open sun drying, 420, 510, 600 min, respectively; in solar drying and 300, 360, 420 min, respectively in hybrid-photovoltaic solar drying. All curves showed a clear exponential tendency with moisture content

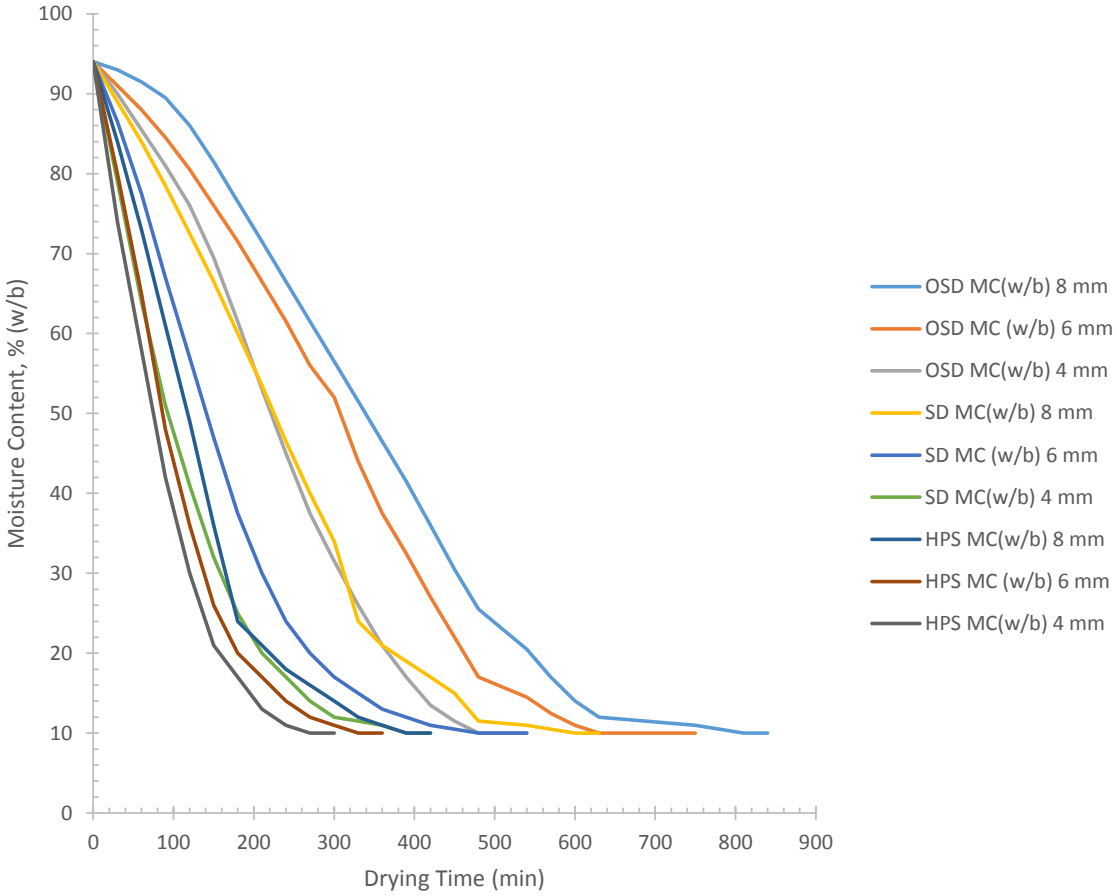

Figure 2. Drying curves for tomato slices at different thickness during for open sun, solar and hybrid-photovoltaic solar drying. OSD MC = Open Sun Drying Moisture Content, SD MC = Solar Drying Moisture Content, HPS MC = Hybrid-photovoltaic Solar Drying Moisture Content.

decreasing as the drying time increased. This shows that for a given thickness, the hybrid-photovoltaic drying method required shorter drying time when compared to solar and open sun drying. The drying followed a falling rate period and the decrease of thickness tomato slices accelerated the drying process. As thickness decreased, moisture removal also increased and ultimately resulted in the reduction in drying time. Drying time reduced from 840 to 510 min as the thickness tomato slices decreased from 8 to 4 mm (open sun-dryer), 600 to 420 min (solar dryer) and 420 to 300 min (hybrid-photovoltaic dryer). This means that there was significant savings in time as thickness decreased and type of dryer. The results agree with what reported by Sacilik et al. (2006) and Rajkumar (2007), The moisture content (wet basis, wb) of fresh tomato was 94.22 %, 9.83% (open sun dried tomato), 9.56% (solar dried) and was 7.63% (hybrid-photovoltaic dried). The results indicate that much moisture was removed in hybrid-photovoltaic drying method compared to sun and solar drying method within a short period of time. These results is in agreement with Toor and Savage (2006).

Influence of drying method on lycopene, ß-carotene and ascorbic acid content

Lycopene, the pigment of red tomatoes, determines the biological and curative value of dried tomatoes. It is a carotenoid belonging to the same group of β-carotene and gives the red colour to tomatoes. Among the most prominent phytochemicals in tomatoes are the carotenoids of which lycopene is the most abundant in the ripened fruit, accounting for approximately 80-90% of the total pigments (Helyes et al., 2009; Shi et al., 2009). This compound is not only a pigment but also a strong antioxidant, which neutralizes the free radicals, and, especially, the oxygen derived ones. Its ability to inhibit the oxidative activity of the active oxygen is twice higher than in case of β-carotene and 10 times higher than in case of α- tocopherol (Shi and LeMaguer, 2000). Lycopene is an important carotenoid from human plasma, but unlike β-carotene it does not have the activity of vitamin A. The biological role of lycopene in human body also consists in its capacity of preventing the oxidative reactions. It neutralizes the toxic compounds that are

Table 1. The effect of drying methods on the lycopene, β-carotene and ascorbic acid (mg/100g) of tomato slices.

Samples	Thickness (mm)	Lycopene (mg/100 g)	*ß*-carotene (mg/100 g)	Ascorbic acid (mg/100 g)
Fresh	-	15.51 ± 0.31^{d}	0.88 ± 0.02^{i}	40.15 ± 2.11^{a}
	4	23.89 ± 0.19^{a}	4.15 ± 0.03^{f}	17.04 ± 0.61^{e}
Sun dried	6	22.33 ± 0.90^{b}	3.96 ± 0.01^{g}	12.78 ± 1.05^{f}
	8	18.77 ± 0.77^{c}	3.72 ± 0.01^{h}	5.60 ± 0.95^{g}
	4	24.51 ± 0.30^{a}	4.94 ± 0.02^{b}	23.73 ± 1.05^{d}
Solar dried	6	24.00 ± 0.13^{a}	4.68 ± 0.01^{d}	18.25 ± 1.05^{e}
	8	22.56 ± 0.53^{b}	4.25 ± 0.01^{e}	13.37 ± 0.61^{f}
	4	25.12 ± 0.12^{a}	4.98 ± 0.02^{a}	29.20 ± 0.42^{b}
Hybrid dried	6	25.00 ± 0.14^{a}	4.79 ± 0.01^{c}	27.13 ± 0.42^{ab}
	8	24.65 ± 0.23^{a}	4.65 ± 0.01^{d}	24.82 ± 0.63^{cd}

Values are means of triplicate ±SD, Values in the same column bearing different superscripts are significantly different ($p<0.05$).

formed as a result of oxidative processes of the cell metabolism, thus protecting certain biomolecules (lipids, proteins and DNA). Lycopene in tomato is particularly effective in fighting prostate cancer, cervical cancer, cancer of the stomach and rectum as well as pharynx and oesophageal cancers (Harvard School of Public Health, 2010). The phyto-chemical composition (lycopene, beta-carotene and vitamin c content) of dried tomato slices are presented in Table 1. Fresh tomato contained lycopene, beta-carotene and vitamin C in varied concentrations as 15.51±0.31, 0.88±0.02 and 40.15±2.11 mg/100 g, respectively.

To compare the influence of drying methods (open sun, solar and hybrid-photovoltaic solar dryers) on lycopene, the dried tomato slices lycopene content were compared with that of the fresh (Table 1). The lycopene levels of the fresh tomatoes significantly ($p<0.05$) increased from 18.77±0.77 to 23.89±0.19 mg/100 g, 22.56±0.53 to 27.51±0.30 and 24.65±0.23 to 25.12±0.12 mg/100 g when dried with slice thickness 4, 6 and 8 mm, respectively. The result is similar to what was reported by Roldan-Gutierrez and Luque de Castro (2007) and Aktas et al. (2011). Studies have found consistent differences in lycopene concentrations between tomato varieties, which can be magnified by environmental conditions and agricultural practices, especially those affecting plant nutrient status (Abushita et al., 2000; Binoy et al., 2004). The content of lycopene depends on variety, cultivating area, variable climate conditions and cultivation technology. Red tomato is the richest source of lycopene and yellow tomato is rich in carotene (Butnariu and Samfira, 2012). The base phenomena, which result in changing lycopene during tomato processing, are isomerisation and oxidation. While oxidation is a process leading to lycopene decomposition, isomerisation has a positive effect. Lycopene is found in tomatoes in the *trans*-steric form. Thermal processes, including drying, lead to lycopene isomerisation and its change from *trans*-steric to *cis* form. The quantity of cis isomers grows once with the increase in temperature and duration of heat treatment. The bioassimilation of lycopene cis isomers is greater than of *trans*- isomers. Drying increases the lycopene bioassimilation by destructing the tomato cells and breaking the connection between lycopene and matrix, damaging the lycopene-protean complex and releasing free lycopene by cis isomerisation (Shi and LeMaguer, 2000). The results as presented in Table 1 shows that the lycopene and β-carotene content of fresh tomatoes increases with drying and drying method used. This could be due to concentration effect which is as a result of the reduction in the moisture content compared to the fresh tomatoes.

The lycopene content of open sun dried tomato slices was significant ($p<0.05$) with tomato slice (thickness, 4 mm) having the highest value (23.89 mg/100 g) and tomato slice (thickness, 8 mm) had the lowest value (18.77 mg/100 g). In hybrid-photovoltaic and solar-dried tomato slices (thickness 4, 6 and 8 mm) there were no significant ($p>0.05$) difference. Lavelli et al. (1999) have obtained analogical data for half tomatoes, demonstrating the insignificant difference between lycopene concentration in fresh and dried tomatoes at temperature of 80°C. This observation may be due to prolonged time of drying with uncontrolled temperature in the sun drying method, while in the hybrid-photovoltaic and solar drying methods the drying took place at temperature less than 60^{o}C with short period of drying time. The long exposure of the sun dried tomato to drying temperature might have resulted in higher degradation of its components including lycopene (Yusuf et al., 2013). This is also supported by a previous study, by Yusuf et al. (2013) which stated that increase in temperature and duration of heat treatment

caused lycopene degradation. Aktas et al. (2011) reported that the drying processes that were performed at higher temperature above 65°C may cause high loss of lycopene content, but we can also say from the result obtained that if exposure duration to drying process was long, the rate of degradation is expected to be higher too. All studied drying methods caused significant increase in β-carotene content of dried tomato slices. This result could be related to an increase in the extractability of such compounds.

The average value of *ß*-carotene content of fresh tomatoes before drying was 0.88 mg/100 g. The values obtained for sun dried tomatoes ranged from 4.12 to 3.72 mg/100 g, solar dried ranged from 4.94 to 4.25 mg/100 g and hybrid dried ranged from 4.98 to 4.65 mg/100 g. Similar results were observed by Muratore et al. (2008) and Yusuf et al. (2013). They reported that degradation of lycopene and β -carotene in tomatoes was highly influenced by the temperature and length of drying. The quantity and quality of phytochemicals detected in tomato fruits is known to depend greatly on genotype and environmental condition (Giuntini et al., 2005). The β-carotene content of open sun dried tomato slices was significant ($p<0.05$) with 4 mm thick tomato slice having the highest value follow by 6 mm thick and 8 mm thick. The same trends were also observed for hybrid-photovoltaic and solar drying methods. The β-carotene content of dried tomato decreased with increasing the period of drying and thickness of the tomatoes. Hybrid-photovoltaic dried tomatoes slices showed a higher retention of β-carotene than both the solar and open sun dried methods. This may be due to high rate of moisture loss within a short period of time. This high retention of lycopene and β-carotene by hybrid-photovoltaic drying method was suggested to retain the bright colour of hybrid-photovoltaic dried tomatoes than the solar and open sun dried ones. The selection of the drying techniques and the processing parameters seems to be essential in order to preserve high carotenoids concentrations; as carotenoids being sensitive to heat. Freeze-drying is therefore the leading candidates for this operation as it allows retaining 100% of carotenoids in the dried samples (Tran et al., 2008).

Tomatoes are a rich source of ascorbic acid (Abushita et al., 2000; Kaur et al., 2002); however, processing of tomatoes has been reported to have a very detrimental effect on their ascorbic acid content (Takeoka et al., 2001; Toor and Savage, 2006). Ascorbic acid is one of the most thermolabile components of food products, fact also confirmed at tomato drying. The value of the ascorbic acid content for the fresh sample was 40.15 mg/100 g. The values obtained for open sun dried tomatoes ranged from 17.04 to 5.60 mg/100 g, solar dried ranged from 23.73 to 13.37 mg/100 g and hybrid-photovoltaic dried ranged from 29.20 to 24.82 mg/100 g. It was observed that there was a continuous decrease in the value of ascorbic acid as the drying time and the temperature increased which was expected because of the sensitivity of ascorbic acid to heat (Rajkumar, 2007). From the results obtained, it was observed that the ascorbic acid was very sensitive to oxidative heat damages as the reduction was significant ($p < 0.05$). Hybrid-photovoltaic dried tomato slices showed a higher retention of ascorbic acid than solar and open sun dried tomatoes. Also solar dried tomato slices showed a higher retention of ascorbic acid than open sun dried tomatoes. This variation in retention of ascorbic acid was observed to due to variations in temperature, thickness and period of drying. This observation confirms with the results obtained by Giovanelli et al. (2002) that the reduction in ascorbic acid content was mainly due to the temperature, time of exposure to direct sun light, thickness and the presence of air. This reduction may also be due to leaching of the vitamin being water soluble and oxidation due to longer period of drying. This is in agreement with the works of Shi et al. (1999). Also, significant loss of ascorbic acid has been reported in the previous studies using higher temperature and longer drying time. Lavelli et al. (1999) reported about 88% losses in ascorbic acid when tomatoes were dried at 80°C for 7 h to 10% moisture content. The results of Toor and Savage (2006) have shown that drying tomatoes in quarters at 42°C during 18 h, led to ascorbic acid losses between 17 to 27%, according to tomato varieties. The increase of drying temperature results in deep decomposition of ascorbic acid.

A similar trend was also observed for tomatoes dried at 90°C for more than 8 h (Yusuf et al., 2013). This result supports the concept that nutrients are more sensitive to longer time of exposure than to higher temperature shorter times, which implies that a greater reduction in time at the cost of slight increase in temperature results in better retention of nutrients (Teixeira, 2012). Similar decline in ascorbic acid content was noticed in other studies with tomato by Kadam et al. (2012) and Qadri and Srivastava (2014). Hence, the higher drying exposure time, thickness and temperature resulted in considerable reduction in the values of nutrients in dried tomatoes.

Conclusion

Hybrid-photovoltaic dried tomatoes slice showed higher content of lycopene, ß-carotene and ascorbic acid than solar and open sun dried methods. The ascorbic acid was very sensitive to oxidative heat damages as the reduction was significant ($p < 0.05$) when the thickness of tomato slices increases for the three drying methods used. Lycopene, ß-carotene and ascorbic acid contents decreased with drying time. Therefore, hybrid drier can be ranked to be the best followed by the solar drying method for drying tomatoes in order to preserve its nutrient and prevent it from post-harvest losses.

Conflict of interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Evaluation of some nutritional and physicochemical properties of camel meat originating from Chad

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Camel meat presents high protein content. It is rich in vitamins and low levels of fat, globally comparable and similar to bovine meat. World production of camel meat has been regularly increasing, mainly in the Central African sub-region doubling during the past two decades. The purpose of this study was to investigate and evaluate some physicochemical and nutritional properties of camel meat by gender and age groups. Fifteen samples of meat were collected from N'Djamena and analyzed in the laboratories of the Centre for Research in Food and Nutrition of Yaoundé. The mean pH values were 5.70 and 5.86 for male and female, respectively and there was no significant difference between them. The mean crude proteins and water contents were 15.14, 16.60 and 76.55, 77.53% for male and female, respectively. However, the mean intramuscular total lipids values differed significantly (5.02% and 3.13%) for males and females, respectively. Total ash and dry matter contents were 0.97, 1.03 and 23.45, 22.47% for males and females, respectively. There was no difference in crude proteins, total ash, total lipids and water contents when comparing by age groups. Camel meat from Chad is rich in crude proteins and total minerals. This meat has a high nutritive value and the community should be encouraged to consume it especially as a source of protein. Camel meat has the potential to provide animal proteins and a reliable source of meat which is healthy for human consumption.

Key words: Nutritional properties, physicochemical properties, camel meat.

INTRODUCTION

Meat and meat products are essential components in the diets of humans. The red meat production in Central Africa reached 277 414 tons in 2009 (FAO, 2013). In 2011, Africa produced 62.2% of the world camel meat

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followed by Asia at 35.8%, while South America contributed 5.3% (Kadim et al., 2014). Nevertheless, the average consumption of these meats varies from one country to another. Camel meat production in Chad is more than 8 500 tons and bovine meat production is about 83 000 tons in Chad and 109 600 tons in Cameroon (FAO, 2013). The dromedary camel is one of the most important domestic animals in the arid and semiarid regions as it is equipped to produce high quality food (Parang et al., 2011). The general estimate of the camel world population is probably around 30 million heads (Faye, 2013). According to estimates of 2006, Chad has 1 822 781 heads of camels (PAFIB, 2013). About 88% of the camels are found in Africa. In the previous years, there has been a trend of growing numbers of camels in the world (Faye, 2013). In the Central African sub-region, camel meat production has been doubling during the past two decades, but only few investigations on the chemical composition and physical properties of this meat and their products have been published (Yam et al., 2016).

Camel meat is similar in taste and texture wih beef and it is sold in those countries in fresh or in processed form. Camel has unique physiological characteristics, including a great tolerance to high and low temperatures, solar radiation, water scarcity and poor vegetation. The morphological features of camels make them well adapted to the harsh environment. The camels can withstand long periods of time without any external source of water through a series of physiological adaptations that reduce feed (Ntiranyibagira et al., 2015). Meat is a source of protein that has an important place in our diet. It has a high protein content and contains all the essential amino acids, iron, zinc and vitamins A, B12, B6, D and E (Nfor et al., 2014). Proteins from meat have a high biological value, rich in lysine and are essential for the development of the organism. Meat is rich in fat and sugars (Tidjani et al., 2013). The camel meat contains low level of intramuscular fat and relatively high proportion of poly-unsaturated fatty acids, vitamins and calcium, globally comparable to that of beef meat. This is an important factor in reducing the risk of cardiovascular diseases, which is related to saturated fat consumption (Kurtu, 2004). The low proportion of fat is remarkable and presents an essential characteristic of camel meat (Faye et al., 2013). High in protein quality and low in cholesterol, camel meat is considered beneficial for health and is used in some countries as a medicine for some diseases such as diabetes, hyperacidity, hypertension, pneumonia and respiratory diseases (Yam et al., 2016; Kurtu, 2004).

In recent years, camel meat has become increasingly available in many countries. The main reason for camel meat consumption is connected to increase slaughter rate due to their population growth. These trends are observed locally where the consumption of camel meat grew three times faster than that of cattle on the N'Djamena market (Koussou and Amine, 2012) and gets to be consumed by a portion of the northern population of Cameroon. The purpose of this study was to investigate and evaluate some nutritional and physiochemical properties in the camel meat taken from the slaughterhouse of N'Djamena (Chad) whose very few studies have been made. Analyzing camel meat is a standard practice to ensure safety and quality of meat. This article discusses some nutritional and physiochemical properties of camel meat from Chad in Central African sub-region with its weak data and investigates whether there are any differences in these properties when considering the age groups and sex of the camels.

MATERIALS AND METHODS

The camel fresh meat was collected to N'Djamena in Chad from the meat production chain of the slaughterhouses and brought to the laboratories of the Centre for Research in Food and Nutrition from the Institute for Medical Research and Study of Medicinal Plants of Yaoundé.

Fifteen samples of camel fresh meats were collected from the *Longissormus dorsi* muscle (chop from the section dividing the thoracic and lumbar parts of the muscle), considered as the reference muscle and the least used muscle in camels. About 500 g of camel meat was sampled according to aseptic rules (ISO/DIS 18593/2005). Samples of camel meat were wrapped in aluminum foil, kept in sterile plastic bags and transported to the laboratories and kept between 0 and 4°C in a cooler (Keep Cold®) provided with refrigerant ice bag blocks and transported to the laboratories of Yaoundé for analysis. The sex and age of the camels were determined and given by veterinary officers from the slaughterhouse.

Analytical procedures

For the laboratory analysis and determination of minerals concentration, 500 g of sample were initially homogenized in a food processor BLENDER 7SBL-42 for 5 min. The following parameters were determined: pH, total lipids, crude proteins, total ash and moisture content. Two buffer solutions of pH 4 and 7 were used for calibration of the pH meter.

The pH of camel meat was measured by using a pH-meter probe (HI8484, HANNA) with a piercing pH electrode and temperature probe. The electrode was inserted at least 2 cm in the meat to give the pH value. For each measurement, the probe was inserted into the muscle at a similar depth. The determination of crude proteins was made by mineralization process in the flasks. 0.1 g of sample was introduced into the flask, 10 ml of sulfuric acid solution was added and heat for one hour. The distillation was by machine *VELP® Scientifica UDK 127* device, and titration relatively with the Kjeldahl method according to the AOAC (1990).

Total lipids were determined by the method of Soxhlet through the solubilization of lipids in an organic solvent, hexane. The samples weighed in Whatman paper. Each sample is treated with three Whatman papers and placed in extraction inners of the balloons ramp heating Bistabil BRAND 6 positions and heated for 12 h and then weighed (AOAC, 1990). Total ash was determined by the weight difference by incinerating the samples in the oven *electronic Heraeus* at 550°C for 24 h.

The dry matter was determined by the method of AOAC (1990) of drying. Samples of known weight were placed at 105°C for 48 h.

Table 1. The mean values of physical characteristics, nutritional contents and water content of meat according to gender.

Sex	Male (mean)	Female (mean)	Std male	Std female	p value*
pH (n=15)	5.70	5.86	0.21	0.14	0.15
Crude proteins (%) (n=15)	15.14	16.60	3.36	4.53	0.39
Total lipids (%) (n=15)	5.02	3.13	1.02	0.70	0.002
Total ash (%) (n=15)	0.97	1.03	0.11	0.10	0.33
Water content (%) (n=15)	76.55	77.53	1.64	0.61	0.28
Dry matter (%) (n=15)	23.45	22.47	1.64	0.61	0.28

Std: Standard Deviation, n: number of samples, *the Mann-Whitney U test was used to determine the significant difference between the mean physicochemical and nutritional properties by sex.

The water content was obtained by the difference of dry matter obtained.

Statistical analysis

The IBM SPSS v. 20 software was used to analyze the data. The data were analyzed using descriptive statistics. The Mann-Whitney U test was used to determine the significant difference between the mean physicochemical and nutritional properties by sex. The Kruskal-Wallis test was performed to determine the significant difference between the mean physicochemical and nutritional properties by age groups. The differences were considered significant at values of $p<0.05$.

RESULTS

The means values of pH were 5.70 for meat obtained from males and 5.86 for females (Table 1). It was found that sex did not influence the pH. There was no statistical significant difference in the meat pH of the two sexes. Results of means values of the crude proteins were 15.14% for meat obtained from male camels and 16.60% for females. The mean of the total ash meat obtained from male camels were 0.97 and 1.03% for females. The total lipids of the female meat camel, 3.13% were lower than those of the male, 5.02% (Table 1). The crude protein and total ash did not vary in relation to sex. However, the total lipids content of camel meat were significantly different between males and females (Table 1). The water content of the male meat camels (76.55%) was lower than that of the female (77.53%). The means were not different statistically between sexes. Sex did not influence the water content and dry matter content (Table 1). According to the sex, the values of total lipids were significantly different.

The different age groups did not have an influence on the pH. The means were not different statistically between age groups ($p = 0.12$). Therefore, the results in the present study did not establish a relationship between pH and age groups of camels (Figure 1).

According to the Kruskal-Wallis test, the various age groups do not influence the results of crude proteins, total ash and total lipids,dry matter and water contents(Table2)

DISCUSSION

The slight variation in pH values of camel meat in this study may be due to pre-slaughter stress of camel handling, post mortem treatments and muscle physiology as previously reported by Yam et al. (2016), Babiker and Yousif (1990) and (Kadim et al., 2008). The average pH values found for male and female are similar to those obtained by Faye et al. (2013) who obtained the average pH 5.71 and Kadim et al. (2008) who found in Arabian camel meat a pH of 5.89. Abdelhadi et al. (2015) found in Sudan camel meat ultimate pH in male (6.10) and female (6.18) muscles showing no significant differences. These results are similar for pH values found for this study. Likewise, all pH values between the different age groups and sex were agreed to Kadim. For crude protein, camels are a very good source of protein. Tsegay et al. (2015) reported the average value in raw beef was 16.10%. The averages crude proteins by age groups (14.54%; 16.55 and 16.27%) were below the values found by Chiabou (2005) with 22% of crude proteins and Faye et al. (2013) who found between 20 and 23% of crude protein. These results were explained by the high water content in the meat analyzed. Meat from young camels has similar protein content like meat of young cattle (Kadim et al., 2014). Crude protein did not vary in relation to sex and in relation to the age groups. The results of total lipids were significantly different in males and females ($p = 0.002$). However, the total lipids content of camel meat were not varied in relation to the age groups with averages of 4.04, 4.42 and 3.49%. These values were almost similar to the results of Nfor et al. (2014) who analyzed cattle beef from Yaoundé and found out 2.4, 2.1 and 2.2% of fatness. The fat or total lipids content of camels across camel muscles are dependent on the fatness of the animal; these values vary between 1.4 and 10% (Faye et al., 2013; Kadim et al., 2014). The average values fat of raw beef as observed by Tsegay et al. (2015) was 5.4%. These values are similar to those from red meat in Nigeria

Table 2. Crude proteins, total lipids, total ash and water content by age group.

Age	(8-10) years 0	(10-12) years 1	(12-14) years 2	Std	p value
Crude proteins (%) (n=15)	14.54	16.55	16.27	3.96	0.80
Total lipids (%) (n=15)	4.04	4.42	3.49	1.28	0.50
Total ash (%) (n=15)	1.03	0.96	1.04	0.11	0.63
Water content (%) (n=15)	77.06	76.87	77.32	1.26	0.89
Dry matter (%) (n=15)	22.94	23.13	22.68	1.26	0.89

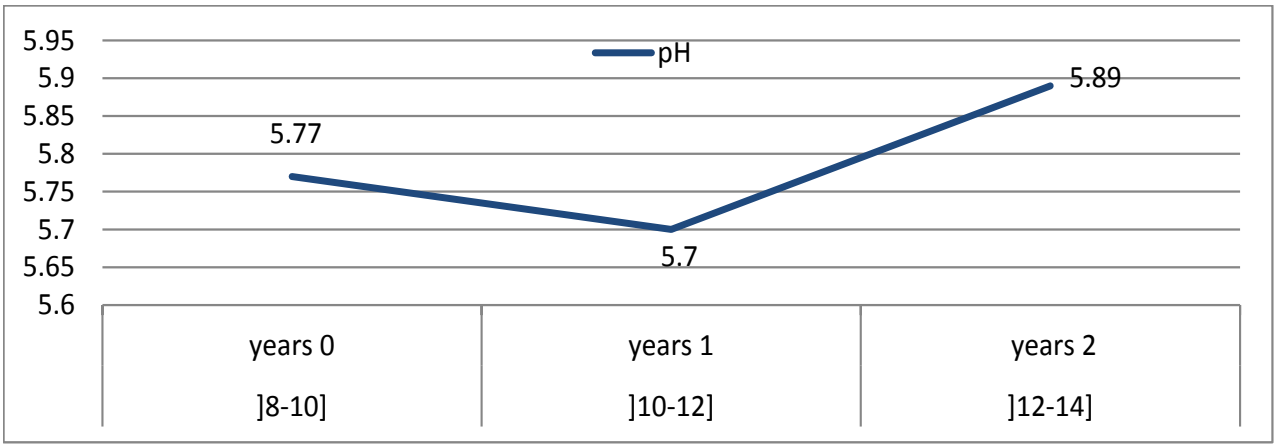

Figure 1. The mean values of pH by age group.

(Williams, 2007). The fat of camel is concentrated in its hump, whereas in other animals, it is stored in muscles; also, the fat content varies depending on species, origin, feeding system and the cut (Abdelhadi et al., 2015).

The results of total ash with the average of 1.03, 0.96 and 1.04% according to age groups were comparable with the results found between 0.9 and 1.5% and mainly composed of potassium, phosphorus, calcium, magnesium and sodium in camel meat (Raiymbek et al., 2013). The present result on ash content in camel meat is similar to the results published by Tsegay et al. (2015) in ash content in beef meat (1.2%) and the study of Kadim et al. (2006). The differences of mean values could be explained by the water content results that were different in the meat samples. According to Siham et al. (2015), the camel meat has a higher concentration of calcium, phosphorus, potassium, sodium, copper, manganese and magnesium as compared to beef.

Apart from the total lipid content, this data did not show any statistically significant influence of age and sex on the physicochemical and nutritional properties of these samples. This is consistent with the findings of Yam et al. (2016) on raw camel meat analyzed in Iran. The difference of total lipid with respect to sex could be due to the fact that in total lipid is included cholesterol. Studies like that of Javad et al. (2013) have shown that sex is highly correlated with cholesterol and triglyceride levels in camel meat.

Results of crude protein, total lipids and pH agreed with results of raw camel meat analyzed in Iran. The water contents with respect to sex, were 76.55 and 77.53% for males and females, respectively. There was no statistical difference in the water content when comparing both sexes.

The different age groups did not have a significant influence on the results of water contents (77.06, 76.87 and 77.32%) and dry matter (22.94, 23.13 and 22.68%), $p>0.05$. These results were similar to results obtained by Ouldel Hajj et al. (2002) on the water contents results and dry matter whose averages water content of meat were 77.07, 76.08 and 74.8%, respectively for different age groups of camels in Algeria. Results of moisture content in beef were almost in similar range with those reported by Nikmaram et al. (2011) who found 73.45% for raw meat. The moisture content widely varies in camel meat (63.0 to 79.0%), camel meat composition is an important indicator of its functionality (Kadim et al., 2014). The improvement in the water holding capacity could be due to the fact that camel meat had superior water content when compared with beef.

Camel meat has less fat and is low in cholesterol when compared with beef, sheep and goat meats. It was rich in mono and polyunsaturated acids and calcium (Kadim et al., 2008). This can also reduce the risk of cardiovascular disease and atherosclerosis since it reduces the percentage of cholesterol in the blood (Raiymbek, 2013).

Conclusion

Camel meat, rich in crude proteins, total minerals and low intramuscular total lipids could provide a reliable source of healthy meat with a high nutritive value for consumers. The results showed that only the total lipids content of camel meat were significantly different between males and females. The mean values of physicochemical and nutritional properties were not different statistically between age groups. Camel meat should be valorized in the Central Africa sub region. At the end of this study, the camel meat from Chad was rich in crude proteins and total minerals should be valorized in the Central Africa sub region. The community should be encouraged to consume it especially as a source of protein. This study contributes to the fact that camel meat is the least studied type of meat and is wrongly believed to be of lower nutritive value and quality than other types of red meat. Camel meat consumption would permit access to animal proteins for the most disfavored populations often and would ensure that meat camel have competitiveness in the market.

Conflict of Interests

The authors declare that there is no conflict of interests.

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Comparative evaluation of mineral compositions of green leafy vegetables consumed in South Eastern Nigeria

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Ten green leafy vegetables commonly consumed in South East, Nigeria were analysed for mineral composition. The presence of Fe, Cu, Zn, Cr and Mn were analysed using Atomic Absorption Spectrophotometry, Ca and Mg were analysed by the Versenate EDTA complexometric method, K and Na were analysed by Flame Photometery, total nitrogen was analysed by semi-micro Kjeldahl distillation and P was analysed by the Vanado Molybdate yellow. The vegetables analysed were *Telfaria occidentalis* (ugu), *Gnetum Africana* (ukazi), *Pterocarpus mildbreadii* (oha/ora), *Amaranthus viridis* (inine), *Curcubita maxima (ugboghoro)*, *Solanum melongena (anara)*, *Vernonia amygdalina (onugbu)*, *Ocimum gratissimum* (nchuanwu), *Piper guineense* (*uziza*), *Gongronema laifolium* (*utazi*), and *Talinum triangulare* (water leaf). Each of the vegetables contained mineral constituents which were different when compared with other vegetables. Green leafy vegetables are a good source of macro/micro nutrients.

Key words: Minerals, macro nutrients, micro nutrients, leafy vegetables, South East Nigeria.

INTRODUCTION

Green leafy vegetables are important items of diet in many Nigerian homes and they are valuable sources of nutrients especially in rural areas where they contribute substantially to minerals, vitamins and other nutrients which are usually in short supply in daily diets (Mosha and Gaga, 1999).

Leafy vegetables play a vital role in human wellbeing. It has been established that greens contribute significantly to the daily dietary requirements of Ca and Fe among children within the ages 2 to 5 years (Faber et al., 2007). Leafy vegetables are used to improve the quality of soup and also for their dietary purposes (Sobukola and Dairo, 2007).

Fresh green leafy vegetables serve as a very important protective food and also used for maintenance of health, prevention and treatment of diseases. They contain both

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essential and toxic metals (D'Mello, 2003).

Nigeria has rich resources of cultivated, semi-wild and wild species of crops being used as traditional vegetables and different types are consumed by various ethnic groups for different reasons (Mensah et al., 2008). Vegetables are mostly consumed as part of a meal rather than as a whole meal. These herbaceous plants have different tastes and characteristics ranging from soft to hard, tasteless, aroma and bitterness (Edema, 1987). Herbaceous plants (soft stem) are sources of edible vegetables which are rich in nutrients. Some vegetables, such as bitter leaf, fluted pumpkin, *Piper guineense*, scent leaf and utazi leaf also possess some medicinal properties (Oyenuga and Fetuga, 1975).

The composition of nutrients is different in various leafy vegetables and these are due to differences in climate, soil, post-harvest handling and the use of fertilizers (Fasuyi, 2006). Environmental pollution has caused the contamination of soil and also waste water irrigation resulted in the significant mixing of heavy metal contents of agricultural land (Mapanda et al., 2005). The main cause is the water ways through which heavy metals are leached out to the soil and are taken by the vegetation. If plants decay, these toxic metals are distributed back and as a consequence, their abundance in the agricultural soil occurs; bioaccumulation may result as a result of the entrance of these heavy metals to the ecosystem. Then long term waste water irrigation leads to build up of heavy metals in soil and food crops (Khan et al., 2008).

Polluted sewage water is found to be rich not only in organic water and nutrient and also in heavy metals like Ld, Ni, Cd, Cr, etc., that finally reach to the soil of agricultural area and leads to food chain contamination as crops and vegetables absorb them from the soil. Heavy metals are not easily biodegradable and it leads to their accumulation in human vital organs causing different degrees of illness on acute and chronic exposure (Ward et al., 1995). However, some metals are essential and their deficiency results in the damage of biological functions. When present in excess, essential metals known to have essential functions may give rise to toxic manifestations (Friberg and Norberg, 1986). Heavy metals inputs need to be as small as possible because some metals are indispensable for life (Alloway, 1990).

Vegetables are important ingredient of human diet that contains essential nutrients (Abdulla and Chmielnicka, 1990). The utilization of leafy vegetable is part of African cultural heritage and they play important roles in the traditions and food culture of the African household. Nigeria is provided with a variety of traditional vegetables and different types are consumed by the various ethnic groups for different reasons (Fasuyi, 2006).

In most local Nigeria diets, approximately half of the leafy vegetables consumed are from indigenous sources constituting significant micronutrients sources especially in times of drought and famine (Lockett et al., 2000; Grivetti and Ogle, 2000). Leafy vegetables alleviate the problems of micronutrient malnutrition dominant in tropical Africa (Ejoh et al., 2005).

The objectives of this work were to determine the mineral compositions of some selected green leafy vegetables consumed in South Eastern Nigeria and to compare the levels of these minerals in the vegetables.

METERIALS AND METHODS

Sample collection

Ten fresh green leafy vegetables were purchased from Ahia-Ohuru Market in Aba South Local Government Area, Abia State, Nigeria. They were identified at the Department of Food Science and Technology, Abia State Polytechnic, Aba, Nigeria. The green leafy vegetables were rinsed with water to remove dust particles and then were air dried for one week to retain the green colouration of the leaves. The dried samples of vegetables were ground into fine powder using an electric mill and were stored in a sample container for wet-acid digestion.

Determination of minerals in the leafy vegetables

The mineral elements (Na, Ca, Mn, K, N, Fe, Cu, Zn, Ld, Cr, Mg, and P) were determined with some modifications according to the methods described by Association of Analytical Chemists (AOAC, 1990).

The heavy metals were determined from the digestion using the Atomic Absorption Spectrophotometer (AAS) method. K and Na were determined using the flame photometer method. Ca and Mg were determined by the versenate EDTA complexometric method. P was determined by the Vanado Molybdate yellow method using the spectrophotometer. While the total nitrogen was determined using the semi-micro Kjeldahl distillation method (AOAC, 1990).

RESULTS AND DISCUSSION

The result of mineral elements of the ten leafy vegetables is shown in Table 1. There were generally high Ca levels in all the leaves. The high Ca levels observed in the vegetables show that all the leaves are very nutritious. The result of the present study can be attested to that observed by different authors (Asaolu et al., 2012, Mohammed and Sharif, 2012; Iheanacho and Udebuani, 2009; Angela et al., 2010) who reported similar findings. *Ocimum gratissimum* (Nchuanwu) contained the highest level of Ca (2.87 ± 0.04 g/100 g) which is well above the 800 to 1200 mg/day recommended Ca standard for adults. Asaolu et al. (2012) also reported high content of Ca in some leafy vegetables including *O. gratissimum* (Nchuanwu). Small amount of the plants should be taken so as to ingest the optimum level of Ca intake of about 1000 mg/day (FAO, 2001). The difference in calcium level could be from the soil. Ca is a major factor for sustaining strong bones and plays a part in muscle contraction and relaxation, blood clotting, coordination of inorganic elements present in the body (Brown and Kane, 1994). *Amaranthus viridis* (Inine) had the highest level of magnesium (1.20 ± 0.02 g/100 g), while *P. guineense*

Table 1. Mineral composition of major green leafy vegetables consumed in South East Nigeira.

Vegetable	Mineral composition of leafy vegetable mg/100 g											
	Ca	Mg	K	Na	P	N	Fe	Cu	Zn	Pb	Mn	Cr
Ugu	2.55±0.15	0.94±0.07	0.76±0.03	0.25±0.04	0.53±0.02	2.84±0.05	184.2±1.76	0.36±0.03	1.75±0.05	0.014±0.002	5.79±0.18	$0.0014±4×10^{-4}$
Ukazi	1.53±0.16	0.64±0.05	0.66±0.02	0.39±0.01	0.49±0.003	2.47±0.31	255.6±9.10	0.66±0.004	1.96±0.04	0.009±0.001	4.20±0.1	Trace
Oha	2.18± 0.11	0.95 ±0.06	0.85±0.05	0.45±0.03	0.57±0.03	1.94± 0.1	264.7±8.10	0.35±0.001	2.08±0.02	0.022±0.001	2.13±0.03	$0.001±1×10^{-4}$
Inine	2.30±0.16	1.20±0.02	0.53±0.04	0.28±0.03	0.38±0.01	3.92±0.20	550.6±17.90	0.42±0.03	0.95±0.04	0.015±0.001	2.73±0.06	$0.003±1×10^{-4}$
Ugboghoro	1.81±0.04	0.47±0.04	0.15±0.14	0.19±0.01	0.53±0.01	3.15±0.10	244.1±14.03	0.14±0.03	1.25±0.05	0.058±0.003	1.72±0.02	$0.001±5×10^{-5}$
Onugbu	2.32±0.07	0.96±0.06	0.74±0.03	0.11±0.01	0.24±0.002	2.56±0.04	582.1±12.38	0.15±0.002	1.32±0.02	0.104±0.005	1.25±0.02	Trace
Nchuanwu	2.87±0.04	1.00±0.04	1.73±0.05	0.45±0.06	0.55±0.05	2.34±0.10	583±10.12	0.49±0.01	1.61±0.02	0.011±0.001	1.37±0.01	0.014±2×103
Uziza	1.78±0.06	0.46±0.06	0.63±0.02	0.29±0.01	0.60±0.05	3.46±0.52	270.7±14.49	0.15±0.003	0.63±0.06	0.008±0.001	0.8±0.04	$0.004±1×10^{-4}$
Utazi	1.82±0.02	0.66±0.04	0.70±0.09	0.30±0.02	0.28±0.02	2.37±0.07	235.4±16.14	0.11±0.004	0.65±0.01	0.023±0.008	1.15±0.03	$0.0014±3×10^{-4}$
Water leaf	1.52±0.10	0.61±0.03	1.03±0.03	0.35±0.05	0.40±0.01	4.20±0.1	453.9±2.98	0.25±0.03	0.49±0.01	0.032 ±0.001	3.80±0.02	$0.002±3×10^{-3}$

Values are means of triplicate determinations ± SEM.

(Uziza) had the lowest level of Mg (0.46 ± 0.06 g/100 g). Mg is important in treating of diarrhea and other gastrointestinal defects when taken in about 470 mg/day. It also has the ability to treat duodenal cancers when 1200 mg/day is ingested, secondary coronary heart diseases and congested heart failure when about 384 mg/day is taken. The Mg RDAs ranges between 26 and 260 mg/day for the various human categories (FAO, 2001). The values of magnesium are significantly different from those reported in this work; the difference might due to soil compositions and the rate of uptake of minerals by individual vegetables (Anjorin et al., 2010).

Magnesium is good by human health as it is known to reduce blood pressure (Fasuyi, 2006). The level of K ranges from 0.53 ± 0.04 to 1.73 ± 0.05 mg/100 g with *O. gratissimum* (Nchuanwu) having the highest K content (1.73 ± 0.05 mg/100 g) and *A. viridis* (Inine) had the lowest potassium content (0.53 ± 0.04 mg/100 g). Increasing dietary potassium has lowered blood pressure in humans, which by itself should reduce the risk of stroke; however, some of the protective effects of K appear to extend beyond its ability to lower blood pressure (Brown and Kane, 1994).

N is the major source of protein in nutrition; it is needed for the replacement of body tissue. The range of nitrogen in the vegetables is 1.94 ± 0.1 to 4.20 ± 0.1 mg/100 g.

Fe is important in the diet especially for pregnant and nursing mothers as well as infants. It is also needed by the elderly to reduce cases of diseases associated with deficiency of iron such as anemia (D'Mello, 2003). Fe had a range of 184.2 ± 1.76 to 583.7 ± 0.12 mg/100 g with *O. gratissimum* (Nchuanwu) having the highest composition of 583.7± 0.12mg/100g while *Telfaria occidentalis* (Ugu) had the lowest composition of 184.2 ± 1.7 mg/100 g. Fe is needed in haemoglobin formation (Fasuyi, 2006). *Gnetum* Africana (Ukazi) had the highest level of copper (0.11 ± 0.004 mg/100 g), which is adequate for normal growth; the estimated daily intake of Cu from food is 1.0 to 1.3 mg/day or 0.014 to 1.019 kg/day for adults (Akinyele and Osibanjo, 1982).

Zinc is important for nerve function and male fertility. It is important for normal sexual development especially for the development of testes and ovaries, it is also essential for reproduction (Ayoola et al., 2008). It is also essential for healthy functioning of heart and normal growth. The level of Zn ranges from 0.49 ± 0.01 mg/100 g to 2.08 ± 0.02 mg/100 g with *Pterocarpus mildbreadii* (Uha) having the highest content (2.08 ± 0.02 mg/100 g), while *Talinum traiangulare* (Water Leaf) had the lowest content (0.49 ± 0.01 mg/100 g). The amount of Zn reported in this work is significantly different with the estimated average daily dietary zinc intake range from 5.6 to 13 mg/day in infants and children and from 8.8 to 14.4 mg/day in adults aged 20 to 50 years (FAO, 1990). Regular consumption of leafy vegetables may assist in preventing the adverse effect of zinc deficiency which results in retarded growth and delayed sexual maturation, because of its role in nucleic acid metabolism and protein synthesis. Most of these effects are treatable with adequate amounts of zinc (Barminas et al., 1998). Ld had a

range of 0.008 ± 0.001 mg/100 g to 0.104 ± 0.005 mg/100 g, *Vernonia amygalina* (Onugbu) has the highest ld content (0.104 ± 0.005 mg/100 g), while *P. guineense (Uziza)* had the lowest content (0.008 ± 0.001 mg/100 g). The maximum allowable limit for lead is 0.3 mg/kg. The level of lead reported in this work was found within the maximum limit of the recommended value. Ld concentration in plants depends on the environment where the plant is cultivated. Areas of high level concentration such as highways, industrial areas may lead to high levels of lead in plants. Dietary supplement of iron, Ca and vitamin C has been recommended in preventing lead poisoning.

Mn has the range of 0.88 ± 0.04 to 5.79 ± 0.18 mg/100 g with *T. occidentalis* (Ugu) having the highest content (5.79 ± 0.18 mg/100 g), while *P. guineense* (Uziza) had the lowest content (0.88 ± 0.04 mg/100 g). These findings varied with that reported by Asaolu et al. (2012) who in their study reported a lower concentration in *T. occidentalis* (Ugu) compared to *A. viridis*. Such variation could possibly be due to the differences in soil composition in the plant source. Mn is very important for normal and proper activity of the nervous system. Each of the vegetables contains mineral constituents which are different when compared with other vegetables.

Conclusion

This research work reported the evaluation of mineral composition of green leafy vegetables consumed in South Eastern Nigeria. The result showed that the vegetables are rich source of mineral (Macro and Micro elements). The findings of this research work indicated that the vegetables studied could make significant contributions to the recommended dietary allowances for the nutrients and also provide essential health requirements to the consumers. Minerals are needed in the body because they form structure of the body and help the body systems work effectively. Green leafy vegetables are a good source of macro/micro nutrients.

RECOMMENDATION

Green leafy vegetables are good sources of mineral nutrients. It is recommended that the consumption of these studied green leafy vegetables could provide several essential health benefits and pharmacological uses. Leafy vegetables may be rich in heavy metal accumulation depending on the soil type and environmental activities around the farms where such vegetables are grown; it is therefore recommended that vegetables should not be grown in farms irrigated with water contaminated with heavy metals and sewage water.

Adequate policy should be put in place by various governments especially in Africa to control heavy metal discharge into farm lands through industrial effluents.

Conflict of Interests

The authors have not declared any conflict of interest.

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Chemical composition, functional and sensory properties of maize-based snack (Elekute) enriched with African oil bean seed (*Pentaclethra macrophylla* benth)

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This research work was carried out to evaluate the physicochemical properties of Elekute enriched with African oil bean seed. Elekute (a maize-based snack in West Africa) was substituted with oil bean seed in the ratio 90:10, 80:20, 70:30 and 60:40 with 100% Elekute as control. Results revealed higher protein content with increased substitution (highest was 23.14% in 60:40). Mineral composition as well as the phytic acid, oxalate and tannins in the samples also increased with higher substitution level. There was significant difference among the samples in bulk density, water absorption capacity, oil absorption capacity, emulsion capacity and stability and foaming capacity but no significant difference in gelation capacity. Enrichment of Elekute snack by incorporating African oil bean seed improved the nutritional quality of this maize-based snack with high level of acceptance from the taste panelist.

Key words: Elekute, African oil bean seed (*Pentaclethra macrophylla*).

INTRODUCTION

Maize (*Zea mays* L.) is the most important staple cereal crop in sub-Saharan Africa. It contains approximately 72% starch, 10% protein and 4% fat, supplying an energy density of 365 Kcal/100 g and is grown throughout the world (Ranum et al., 2014). Maize can be processed into a variety of food especially, snacks, such as Aadun (maize pudding), Kokoro (Corn cake), Donkwa (maize-peanut ball) and Elekute (sugared/salted maize flour) (Idowu and Aworh, 2014). Nutritionally, maize is an excellent source of energy (rich in carbohydrate, fat and fibre) and provides many of the vitamins and essential minerals for people in the tropics but low in protein (especially lysine and tryptophan), vitamin B12, vitamin C and niacin. Consumers of these maize-based snacks in large quantity are faced basically with a large intake of carbohydrate but risk malnutrition and

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vitamin deficiency diseases as well as pellagra which is common in maize-consuming areas (Oyetoro et al., 2007; Lasekan and Akinola, 2002). The need to enrich maize- based snacks with inexpensive quality protein therefore cannot be overemphasized (Idowu and Aworh, 2014).

Elekute is a snack common to West Africa and is produced locally by milling roasted maize into a fine powder to which salt or sugar is added. When oil is added it is known as “Aadun” (Abdurrahman and Kolawole, 2006).

The African oil bean seed (*Pentaclethra macrophylla*: Benth) is a popular tropical tree plant in Nigeria, locally called “ugba” in the eastern part. The Africa oil bean (seeds) is often used to complement carbohydrate foods, vegetables and other foods in Nigeria because it is known to contain a high proportion of protein and the 20 amino acids (Enujiugha and Akanbi, 2005). The oil bean seed is used to supply adequate essential amino acids (protein) needed in diets. The oil bean seed also contains high quantity and quality protein as well as 77-78% unsaturated and 22- 33% saturated fatty acids (Osagie-Eweka and Alaiya, 2014).

African oil bean seed is also known to contain high concentration of phytates, tannins and oxalates (Enujiugha and Olagundoye, 2001) which reports have shown exhibit some favourable effects such as anticarcinogens (Vucenik and Shamsuddin, 2003). Also, Odoemelam (2005) reported high protein content (36.2%) for African oil bean seed. Therefore, incorporating African oil bean seed (AOBS) into maize snack will improve the snack nutritionally.

Producing snack using maize and AOBS will add variety to the existing list of snack food as well as improve the underutilization of AOBS which can substitute other plant protein sources. Therefore, if snacks such as Elekute can be enriched with high protein flour, it will help to increase the amount of protein intake from the snacks consumed and can even serve as daily substitute for food among children (Adebowale et al., 2007).

This study was carried out to evaluate the chemical composition, functional and sensory properties of Elekute (maize-based snack) enriched with Africa oil bean seed flour.

MATERIALS AND METHODS

Raw materials and treatment

The quality protein maize flour and uncultivated African oil bean seeds were purchased from Oja-oba market in Akure, Ondo State, Nigeria.

The African oil bean seeds were sorted, weighed, washed, soaked, dehulled manually and dried (60°C) in an oven. The seeds were milled using hammer mill (model ED-5 Thomas Wiley, England) and sieved with 500 µm mesh sieve. The maize samples were also sorted and milled using 750 µm mesh size. Parts of the maize flour (MF) was substituted with 10, 20, 30 and 40% African oil bean seed flour (AOBSF) by weights. Each blend was separately mixed in a Philip blender (HR2611 model) for three minutes at high speed. The various blends were mixed with salt and packed separately in 100 µm polythene bags and kept in airtight plastic containers under ambient conditions (temperature: 28±2°C, relative humidity: 60%) till needed.

Proximate analysis

Samples were analyzed for moisture, crude protein, total ash, crude fibre and carbohydrate contents by AOAC (2000). Crude protein content was determined by the Kjeldahl-Nitrogen analysis procedure, using 6.25 as a conversion factor, while the crude fat was determined using the Soxhlet extractor. The carbohydrate content was obtained by difference (AOAC, 2000). All analyses were carried out in triplicates

Mineral elements analysis

Mineral content (sodium, potassium, calcium, magnesium, iron, copper and zinc) of the flour samples was determined using an AOAC (2005) method. Sodium (Na) and potassium (K) were determined using the standard flame emission photometer. Phosphorous was determined colorimetrically using the Spectronic 20 (Gallenkamp UK) Kirk and Sawyer (1991) with KH_2PO_4 as the standard. Calcium and magnesium were determined using atomic absorption spectrophotometer (AAS Model SP9, Pye Unicam Ltd, Cambridge, UK). All values were expressed in mg/100 g and determinations were carried out in triplicates (Bamidele et al., 2014).

Functional properties determination

Water and oil absorption capacity was determined by the method described by Abbey and Ibeh (1998). The foaming capacity and stability of the samples were determined using method described by Desphande et al. (1982). Emulsion stability was determined by the method described by Mempha et al. (2007). The method of Onwuka (2005) was adopted in the determination of gelation capacity. A sample suspension of 2.20% (w/v) in 5 ml of distilled water was prepared in test tubes and heated for 1 h in a boiling water bath followed by rapid cooling under cold tap water and later in ice water for 5 min to accelerate gel formation. All tubes were held at 4°C for 3 h. Least gelation concentration was determined as the concentration above which the sample remained in the bottom of the inverted tube.

The bulk density was determined using the procedure of Narayana and Narasinga (1984) with slight modification. Graduated cylinder tubes were weighed and flour sample filled to 5 ml by constant tapping until there was no further change in volume. The contents were weighed and the difference in weight was determined. The bulk density was computed as grams per millilitre of the sample.

Pasting properties determination

The pasting property of the sample was determined according to the Newport (1998) procedure based on 100% dry matter. 3 g of sample was dissolved in 25 ml of water in a sample canister. The sample was thoroughly mixed and fitted into the Rapid Visco Analyser (RVA Super 3, Newport Scientific Pty. Ltd, Australia) as recommended (Newport Scientific, 1998). The slurry was heated from 50 to 95°C with a holding time of 2 min followed by cooling to 50°C with another 2 min holding time. The 12 min profile was used

Table 1. Proximate analysis of enriched Elekute.

Sample	Total Ash	Crude Fibre	Crude protein	Crude fat	Carbohydrate
100:0	3.37±0.03^{d}	3.51±0.04^{c}	5.32±0.15^{b}	4.16±0.03^{c}	78.43±0.02^{c}
90:10	2.06±0.04^{e}	7.92±0.04^{a}	8.26±0.03^{d}	6.53±0.02^{d}	70.13±0.06^{d}
80:20	5.23±0.03^{a}	3.85±0.05^{d}	15.12±0.08^{c}	9.35±0.03^{c}	64.75±0.02^{c}
70:30	4.64±0.04^{b}	5.75±0.04^{b}	19.13±0.03^{b}	10.88±0.03^{b}	55.83±0.03^{b}
60:40	3.76±0.23^{c}	4.67±0.05^{c}	23.14±0.04^{a}	14.28±0.03^{a}	50.39±0.02^{a}

Values are Mean ± SEM; Values with different alphabet within the column are significantly different P<0.05. 100% Elekute (control), 90:10 (Elekute: oil bean), 80:20 (Elekute: oil bean), 70:30 (Elekute: oil bean), 60:40 (Elekute: oil bean).

Table 2. Phytochemical composition of enriched Elekute.

Sample	Phytate (mg/100 g)	Oxalate (mg/100 g)	Tannin (mg/100 g)
100:0	3.90±0.07^{e}	0.21±0.04^{d}	0.05±0.02^{b}
90:10	5.10±0.04^{d}	0.61±0.04^{c}	0.20±0.08^{a}
80:20	6.30±0.04^{c}	0.62±0.03^{c}	0.21±0.03^{a}
70:30	7.40±0.08^{b}	0.75±0.05^{b}	0.24±0.05^{a}
60:40	8.10±0.05^{a}	0.94±0.02^{a}	0.25±0.03^{a}

Values are mean ± SEM; Values with different alphabet within the column are significantly different P<0.05. 100% Elekute (control), 90:10 (Elekute: oil bean), 80:20 (Elekute: oil bean), 70:30 (Elekute: oil bean), 60:40 (Elekute: oil bean).

and the rate of heating and cooling was at a constant rate of 11.25°C/min. Corresponding values for peak viscosity, trough, breakdown, final viscosity, setback, peak time and pasting temperature from the pasting profile were read from a computer connected to the RVA (Ocloo et al., 2010).

Phytochemicals determination

The phytic acid and tannins were determined using the procedure described by Markkar et al. (1993), while AOAC (1990) method was used to determine oxalate. All procedures were carried out in triplicates.

Sensory evaluation

Quality attributes of the "Elekute" made from 100% maize flour substituted with 10, 20, 30 and

40% AOBSF respectively were assessed by a sensory panelist. The panelists were supplied with forms and asked to score the sample using 9-point Hedonic scale with respect to taste, colour, texture, aroma and overall acceptability.

Statistical analysis

All determinations were carried out in triplicate and error reported as standard deviation from the mean. All data were subjected to analysis of variance (ANOVA) and significance accepted at p≤0.05. The means were separated using Duncan new multiple range test with SPSS package (version 17.0).

RESULTS AND DISCUSSION

Proximate properties

The results of the proximate analysis are presented in Table 1. This showed that the crude protein and crude fat increased with increase in the proportion of the AOBSF level in the 'Elekute' samples. The results indicated that there was a significant difference *(p<0.05)* in the entire samples for all the proximate parameters. Sample 60:40 had the highest protein content of 23.14% and crude fat of 14.28% with corresponding lowest carbohydrate (50.39%), while sample 100:0 (that is, 100% maize) had the least crude protein and crude fat (5.32 and 4.16%, respectively). This is in line with the report of Ayinde et al. (2012) where defatted beniseed was used to enrich a maize based snack. Crude fibre is known to aid the human digestive system. 100:0 had the least value of crude fibre, 3.51% and sample 90:10 had the highest crude fibre content. Ash content of the samples ranged between 2.06 and 5.23%. The low ash content is reflective of the low mineral content of African oil bean seed (Enujiugha and Ayodele-Oni, 2003)

Phyto chemical analysis

This is as presented in Table 2. The phytate, oxalate and tannin contents increased with higher substitution of African oil bean seed ranging from 3.90 to 8.1, 0.21 to 0.94 and 0.05 to 0.25 mg/100 g, respectively with significant difference (p<0.05). Phytic acid in cereal based foods inhibit Fe absorption, while high oxalate level in food has been implicated as a cause of kidney stones. Tannins also form insoluble complexes with protein, thus reducing its bioavailability (Chai and Liebman,

Table 3. Pasting properties of enriched Elekute.

Sample	Peak	Trough	Breakdown	Final viscosity	Setback	Peak time	Pasting temperature
100:0	111.08	67.50	43.58	89.33	21.83	5.57	84.35
90:10	118.92	71.50	47.42	94.58	23.08	5.33	83.65
80:20	101.92	69.17	32.75	102.75	33.58	5.42	84.18
70:30	96.08	52.67	43.42	70.75	18.08	4.20	84.85
60:40	141.75	112.33	29.42	165.67	53.33	5.63	85.63

100% Elekute (control), 90:10 (Elekute: oil bean), 80:20 (Elekute: oil bean), 70:30 (Elekute: Oil bean), 60:40 (Elekute: oil bean).

Table 4. Mineral analysis of enriched Elekute (ppm)

Sample	P 100:0	Na	K	Fe	Zn	Cu	Mn	Ca	Mg
100%	0.34±0.01^{e}	150.0±1.00^{a}	54.67±4.04d	0.68±0.01^{e}	0.43±0.03^{e}	0.02±0.01^{a}	0.07±0.01^{b}	1.40±0.01^{e}	0.50±0.01^{c}
90:10	0.46±0.07^{d}	145.0±6.56^{ab}	65.0±3.61^{c}	1.07±0.06^{d}	0.55±0.03^{d}	0.02±0.06^{a}	0.12±0.02^{a}	1.50±0.01^{d}	0.60±0.01^{b}
80:20	0.57±0.09^{c}	145.7±2.08^{ab}	74.0±2.65^{b}	1.36±0.03^{c}	0.66±0.03^{c}	0.03±0.01^{a}	0.12±0.03^{a}	1.70±0.01^{c}	0.69±0.01^{a}
70:30	0.65±0.06^{b}	148.0±1.00^{ab}	74.0±2.00^{b}	1.47±0.06^{b}	0.74±0.04^{b}	0.04±0.06^{a}	0.13±0.04^{a}	1.80±0.01^{b}	0.69±0.01^{a}
60:40	0.72±0.04^{a}	143.0±3.61^{c}	98.68±0.03^{d}	1.66±0.04^{a}	0.84±0.02^{a}	0.03±0.02^{a}	0.13±0.03^{a}	1.99±0.01^{a}	0.69±0.01^{a}

Values are Mean± SEM; Values with different alphabet within the column are significantly different P<0.05. 100% Elekute (control), 90:10 (Elekute: oil bean), 80:20 (Elekute: oil bean), 70:30 (Elekute: oil bean), 60:40 (Elekute: oil bean).

2004). Thus, the phytate/oxalate/tannin contents of Elekute enriched with African oil bean seed was highest at 60:40, in line with the report of Enujiugha and Ayodele–Oni, (2003) and Enujiugha and Akanbi (2005) that African oil bean seeds are high in tannins, phytates and oxalates but thermal processing may cause a decrease in the levels of these phyto chemicals. Less than 20% level of substitution with African oil bean seed is therefore desirable.

Pasting properties

The result of the pasting properties of Elekute enriched with African oil bean seed as presented in Table 3 showed that sample 60:40 had the highest peak viscosity (141.75), final viscosity (165.67), setback (53.33), peak time (5.63 min) and pasting temperature (85.63°C). This indicate higher gelatinization temperature and longer cooking time. However, for technical and economic reasons, starches/flours with lower pasting time and temperature may be more preferred when all other properties are equal (Iwuoha, 2004; Baah et al., 2009). A low set back is also an indication that the starch has a low tendency to retrograde or undergo syneresis during freeze/thaw cycles (Ikujenlola and Fashakin, 2005). Thus, sample 70:30 with lowest peak viscosity (96.08), final viscosity (70.75), setback (18.08) and lowest peak time (4.20 min) may be of higher caloric density per unit volume and a preferred choice when pasting properties are being considered in food processing.

Mineral composition

The result of the mineral composition of Elekute substituted with African oil bean seed as shown in Table 4 revealed a corresponding increment in concentration of mineral contents with increase in substitution with AOBS. An earlier report by Enujiugha and Agbede (2000) had concluded

Table 5. Functional properties of enriched Elekute.

Sample	Loose (g/ml)	Pack (g/ml)	WAC (ml/g)	OAC (ml/g)	LGC (%)	EC &S (%)	FC&S (%)
100:0	0.49±0.01^{b}	0.75±0.01^{c}	2.30±0.01^{c}	1.20±0.01^{b}	3.60±0.01^{a}	1.58±0.01^{c}	5.20±0.01^{e}
90:10	0.51±0.01^{a}	0.79±0.01^{a}	2.50±0.01^{a}	0.99±0.05^{c}	3.60±0.01^{a}	1.59±0.01^{c}	7.07±0.06^{d}
80:20	0.52±0.01^{a}	0.77±0.01^{b}	2.40±0.01^{b}	1.00±0.00^{c}	3.59±0.01^{a}	2.30±0.01^{a}	3.90±0.01^{c}
70:30	0.44±0.01^{c}	0.75±0.01^{c}	2.20±0.01^{d}	1.03±0.06^{c}	3.60±0.00^{a}	1.85±0.01^{b}	5.90±0.10^{b}
60:40	0.43±0.01^{c}	0.73±0.01^{d}	2.40±0.01^{b}	1.30±0.01^{a}	3.60±0.01^{a}	1.90±0.01^{b}	10.30±0.05^{a}

Values are mean ± SEM; Values with different alphabet within the column are significantly different P<0.05. 100% Elekute (control), 90:10 (Elekute: oil bean), 80:20 (Elekute: oil bean), 70:30 (Elekute: oil bean), 60:40 (Elekute: oil bean). Bulk density (loose and pack), water absorption capacity (WAC), oil absorption capacity (OAC), least gelation concentration (LGC), emulsion capacity and stability (ECS), foaming capacity and stability (FCS).

Table 6. Sensory evaluation of enriched Elekute.

Sample	Colour	Taste	Aroma	Texture	Overall acceptability
100:0	8.40±0.97^{a}	7.90±0.01^{a}	7.60±2.01^{a}	8.10±0.99^{a}	8.60±0.52^{a}
90:10	7.40±0.69^{a}	6.30±2.06^{b}	6.90±1.45^{a}	7.20±1.75^{ab}	7.30±0.68^{b}
80:20	5.70±1.25^{b}	5.20±1.23^{b}	6.20±1.14^{a}	6.40±1.35^{ab}	6.10±1.29^{c}
70:30	5.70±1.70^{b}	3.00±1.41^{c}	6.40±1.65^{a}	6.40±2.11^{b}	5.00±1.56^{d}
60:40	5.40±1.71^{b}	3.50±1.27^{c}	6.20±1.62^{a}	6.90±1.73^{b}	4.90±1.45

Values are mean ± SEM; Values with different alphabet within the column are significantly different P<0.05. 100% Elekute (control), 90:10 (Elekute: oil bean), 80:20 (Elekute: oil bean), 70:30 (Elekute: oil bean), 60:40 (Elekute: oil bean).

that African oil bean seed contain appreciable amount of important minerals and this has corroborated with this study. There was significant difference among the samples for phosphorous (P), sodium (Na), potassium (K), iron (Fe), zinc (Zn), calcium (Ca) and magnesium (Mg) while there was no significant difference among the samples for copper and manganese.

Functional properties

Functional properties of food materials are very important for the appropriateness of diet, particularly for growing children (Omueti et al., 2009). Nutritionally, a loose bulk density promotes easy digestibility of food (Osundahunsi and Aworh, 2002), thus from Table 5, the result showed the highest loose bulk density and lowest foaming capacity in sample 80:20 (0.52 g/ml and 3.90%) and lowest bulk density but highest foaming capacity in 60:40 (0.43 g/ml and 10.3%). There is significant difference among samples for all the properties except for least gelation capacity.

Sensory evaluation

As presented in Table 6, the results showed there was no significant difference in aroma for all the samples evaluated but sample 100% Elekute and 90:10 had better colour appeal, while 100% Elekute was rated better for taste, texture and overall, acceptability. Thus, control sample had the best appeal and most acceptable to the panelists. Sample 90:10 is a close substitute as a result of the minimal level of substitution with AOBSF.

Conclusion

Enrichment of Elekute with AOBSF is un-desirable beyond 90:10 level of substitution. The effects of the anti-nutrients inherent on the

oil bean seed can however be reduced via thermal processing taking advantage of the high protein and mineral contents of the African oil bean seed.

Conflict of Interests

The authors have not declared any conflict of interest.

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Indigenous technical knowledge and formulations of thick (*ugali*) and thin (*uji*) porridges consumed in Kenya

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Thick (*ugali*) and thin (*uji*) porridges are important sources of nutrients for millions of Kenyans. They are made from unblended or composite flours of cassava and whole milled maize, finger millet or sorghum. *Ugali* is eaten as a main meal at lunch or dinner whereas *uji* is taken as a refreshing drink any time of the day. *Uji* is also an important complementary food for children. In addition, some formulations of *ugali* and *uji* are used to manage non-communicable diseases such as cardiovascular diseases and type II diabetes. The aim of this study was to document indigenous technical knowledge on *ugali* and *uji* in Kenya. Primary information was collected through Focus Group Interviews in ten counties in western Kenya and corroborated with secondary literature. Unblended whole milled white maize and finger millet are the preferred flours for making *ugali* and *uji*, respectively. Whole milled maize, finger millet and sorghum are recommended for preparing *ugali* and *uji* for people suffering from non-communicable diseases. *Uji* prepared as a complementary food for child-feeding is usually supplemented with plant or animal proteins in order to improve its nutritional quality. The indigenous technical knowledge provided by the interviewees show that several opportunities exist for product innovations and quality and safety improvements.

Key words: Kenya, maize, finger millet, sorghum, cassava, *ugali, uji*.

INTRODUCTION

Maize (*Zea mays* L.), sorghum (*Sorghum bicolor* (L.) Moench), finger millet (*Eleusine coracana* (L.) Gaertn) and cassava (*Manihot esculenta* Crantz L.) are important raw materials for the production of thick (*ugali*) and thin (*uji*) porridge in Kenya. However, production of these crops is less than the demand and hence considerable quantities have to be imported (Table 1). White semi-dent maize is the premier staple food crop in Kenya (KSC, 2016) with an annual production of about 3.6 million tons (Table 1). It is grown by 98% of rural farm households

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Table 1. Production and utilization of maize, finger millet, sorghum and cassava in Kenya[a].

Food item	Area planted (1000 ha)	Domestic supply (1000 metric tons)				Domestic utilization (%)					Per capita consumption (kg/person/year)
		Prod.[b]	Imp.	Exp.	TDS	Food[c]	Feed	Seed	Waste	Other	
Maize	2100	3591	112	6	3697	92	3	2	2	1	76
Sorghum	210	139	104	6	237	79	10	2	11	0	3
Finger millet	140	64	8	0	72	78	8	3	11	0	1
Cassava	64	1112	4	0	1116	97	0	0	3	0	24

[a]Adopted with modifications from FAOSTAT (2016). [b]Production plus stock changes (grains released by the government from national grain reserves). [c]Food: Refers to amount directly used as food and processed into food products. Prod.: production; Imp.: imports; Exp.: exports; TDS : total domestic supply.

and makes a large share of households' crop income (FTF, 2011). Despite the importance of maize as a national food security crop, several production constraints (Ndwiga et al., 2013; Ouma and De Groote, 2011) result in insufficient production to meet national demand (FAOSTAT, 2016). The productivity of sorghum in Kenya is about 1.7 t/ha (USAID, 2010), which is below the genetic potential of 3 to 4 t/ha (KSC, 2016). Improved sorghum varieties like Serena, Seredo, Gadam and E1291 with higher genetic potentials are increasingly being adopted by farmers (KSC, 2016).

The average mean yields of finger millet in Kenya is 2.9 t/ha (USAID, 2010). Improved varieties such as P224 and Katumani with yields reaching up to 3.3 t/ha are also being promoted by Kenya Seed Company (KSC, 2016). Cassava is an important food security crop in the semi-arid regions of Kenya (USAID, 2010), because the planting material is easily accessible; and it is drought tolerant, has a high production potential per unit of land and high return of food calories per unit energy input in its cultivation. The average cassava yield in Kenya is 15 to 20 t/ha against a potential yield of over 50 t/ha (MoA, 2010; USAID, 2010).

Thick (*ugali*) and thin (*uji*) porridges are important sources of calories and several other nutrients for millions of Kenyans. The porridges are made from unblended or composite flours of cassava and whole-milled grains of maize, finger millet or sorghum. When the flours are heated in excess water, the starch-rich slurry transforms into porridge as a result of gelatinization of starch. The main difference between *uji* and *ugali* relates to the amount of flour that is required to make the products. Less flour (about 10% w/v) is required to make *uji* than *ugali* (about 30% w/v) and hence the former can be drank or eaten with a spoon, whereas the latter is a solid paste that must be chewed before it can be swallowed (Onyango, 2014).

Uji is normally consumed as a breakfast meal or refreshment drink at any time of the day. It helps to improve appetite and, thus, is recommended for consumption a few hours before the main meal. It is an important source of energy and nutrients for complementary feeding of children below five years. *Uji* is the preferred food for invalids because they are weak and cannot consume food that requires a lot of energy to chew and swallow. In poor households, especially during famine, per capita consumption of *uji* is high because only a small amount of flour is required to make a large volume of the product, which can be consumed throughout the day. *Ugali* is eaten as the main dish for lunch or dinner with accompaniments such as vegetables and meat. Local communities also use certain recipes of *ugali* and *uji* as functional foods for the management of some non-communicable diseases, especially cardio-vascular diseases and type II diabetes.

The recipes used to make *ugali* and *uji* are variable and are dependent on the cultural practices, predominant crop grown in the area, and the price and availability of raw materials. The raw materials for making these porridges are largely prepared at home or in small-scale processing plants using rudimentary equipment and techniques.

The products have variable quality parameters due to the lack of raw material, process and product specifications. Consumption of these porridges is declining due to increasing competition from ready-to-drink beverages, such as tea and coffee; and other staple carbohydrate-rich food crops, such as rice and wheat. The aim of this study was to document indigenous technical knowledge on the preparation and utilization of *ugali* and *uji* in Kenya.

METHODOLOGY

Focus group interviews

Focus Group Interviews were used to determine ethnic practices associated with preparation and consumption of *ugali* and *uji* in ten counties in western Kenya (Siaya, Migori, Kisumu, Homa Bay, Nyamira, Kisii, Bungoma, Busia, Kakamega and Vihiga). Purposive sampling was used to select groups of 8 to 10 women in each county to participate in the Focus Group Interviews. The interviews were conducted in the months of May and June, 2016. The discussions focused on the following issues: (i) describe the preparation of flours from maize, finger millet, sorghum and cassava; (ii) identify the main unblended and composite flours used to prepare *ugali* and *uji*; (iii) describe the quality characteristics of *ugali* and *uji;* and (iv) identify *ugali* and *uji* recipes for complementary feeding of children and people suffering from non-communicable diseases such as cardiovascular diseases and type II diabetes.

Description of study site and interviewees

The administrative structure of the Kenyan state is composed of a central government and 47 county governments (Constitution of Kenya, 2010). In this study, Focus Group Interviews were conducted with women from ten counties in western Kenya. The predominant ethnic groups in these counties are the Luo in Siaya, Migori, Kisumu and Homa Bay counties; the Kisii in Nyamira and Kisii counties; and the Luhya in Bungoma, Busia, Kakamega and Vihiga counties. Other major indigenous communities that are native to these counties include the Suba and Kuria in Migori county; the Teso in Busia and Bungoma counties; and the Sabaot in Bungoma county. According to the latest Kenya Population and Housing Census data of 2009 (KNBS, 2016), the population of these counties was 9.8 million, which constituted 25% of the national population (38.6 million). The sample size of respondents in this study was 134 people. The age group distribution of the interviewees was 26, 44 and 30% for <30, 30-50, and >50 years, respectively. The ages of the interviewees were considered an important input variable in the discussions because of anticipated variability due to the influence of society, peers, culture, and experience.

Focus Group Interviews were used to collect the data in order to capture the diversities of porridges in the counties and to evaluate consumer preferences. The western region of Kenya was selected for the study, because the wide variety of recipes and techniques used to make porridges in this region can provide a representative view of the national consumption pattern. Purposive sampling was used to select respondents with knowledge and experience on past and current practices of making and consuming *ugali* and *uji*. Only women were interviewed, because they play a major role in meal planning and preparation in most families; nurse and feed children; and select food for invalids and people suffering from non-communicable diseases such as cardiovascular diseases and type II diabetes.

RESULTS AND DISCUSSION

Consumption of maize, sorghum, finger millet, and cassava in Kenya

Maize is not an indigenous crop in Kenya, but several government policies have ensured that it is the primary staple food in the country (Smale and Jayne, 2003). Maize accounts for a significant portion of dietary protein intake in the country despite the fact that it is deficient in essential amino acids like lysine and tryptophan (Nuss and Tanumihardjo, 2011). Nutritional interventions like the use of Quality Protein Maize (QPM) that is bio-fortified with tryptophan and lysine have been tried and accepted in Kenya (De Groote et al., 2014). White semi-dent maize is the most popular variety for making food products in Kenya, but local landraces of yellow and coloured dent maize are also widely produced.

Maize is eaten in many forms in Kenya. Whole-milled or sifted maize flour is used to make *ugali* or *uji*. The whole cob can be boiled or roasted and eaten directly from the cob. Maize grains can also be mixed with pulses and boiled in water to make *githeri*. African bread (*estata*) is made from maize flour and ripe banana. The dough is moulded into round balls, which are then wrapped in cooked banana leaves and steamed over a pot of boiling water. Another ready-to-eat maize snack is called *makhalange* in Bungoma and Busia counties or *zimbare* in Kakamega and Vihiga counties. Whole-milled maize is soaked in water to make a thick paste, which is fermented for 3 days. The paste is then slightly roasted and sun-dried. It is eaten as a dry snack or gruel after reconstitution in warm water. The fermented paste can also be made into an opaque alcoholic beverage (*busaa*) by adding sorghum or finger millet malt.

The national per capita consumption of finger millet is 1 kg/person/year (Table 1). More than 75% of finger millet produced in Kenya is used as human food (Table 1). Finger millet flour is preferentially used to make *uji* rather than *ugali*, because its supply is limited and hence it fetches a higher market price. The limited supply and high cost of finger millet is because few farmers grow it, because its production and processing is more demanding than for maize, sorghum or cassava. Manual weeding of the crop and cleaning of the grains is tedious and time-consuming. Finger millet malt (*kimera*) is used to make *busaa*, an opaque alcoholic beverage (Kirui et al., 2014). The grains can also be exposed to high temperatures by stacking them in heaps when they are still moist. As the grains respire, they produce heat, which raise their temperature to about 80°C. This process changes their colour from red to black (*emifuname*) and improves the colour and taste of *ugali* made from this flour. This product is made in Vihiga, Kakamega and Bungoma counties. This treatment may also improve the nutritional and health properties of the grain. Gahlawat and Sehgal (1994) reported that finger millet subjected to high temperature treatment has improved iron bio-availability, whereas Pushparaj and Urooj (2014) and Pradeep and Guha (2011), noted improved antioxidant activity.

The national per capita consumption of sorghum is 3

kg/person/year (Table 1). More than 75% of sorghum produced in Kenya is used as human food (Table 1). Sorghum is whole milled and composited with maize, finger millet or cassava, which is then used to make *uji* or *ugali*. Most farmers grow tannin-rich sorghum varieties that are bitter-tasting and have poor malting properties. Nonetheless, some malted grain can be used to make *makhalange* or *zimbare* as described earlier. Roasted and milled sorghum is also used as an alternative beverage to caffeine-containing tea and coffee. Roasting sorghum at high temperatures (161 to 179°C) changes its rheological attributes and gives the flour low shear-thinning character, which is ideal for making beverages (Ranganatham et al., 2014). Sorghum rice is made in a similar manner to normal rice by boiling or steaming the dehulled or soaked whole grains until they are soft.

The national per capita consumption of cassava is 24 kg/person/year (Table 1). Almost all cassava (97%) produced in Kenya is used as food (Table 1). Both the bitter and sweet varieties of cassava are grown in the western region of Kenya. The bitter variety is preferred in Busia and Siaya counties because it is high yielding and produces more tubers (8 to 12) per plant than the sweet variety. Sweet cassava varieties are peeled and washed then eaten raw or boiled before eating. They can also be peeled, chipped, sun-dried and milled into flour (*abeta*); or heap-fermented, dried and milled into flour (*akuoga*). Bitter cassava varieties are not eaten raw or after boiling due to their high content of cyanogenic glucosides, which can cause acute toxicity and death (Montagnac et al., 2009b). They must be heap-fermented before they are dried and milled into flour. *Anyonga* is another type of cassava flour, which is made by heap-fermenting cassava roots to make *akuoga*, which is then mixed with *abeta* cassava. The blended chips are once again heap-fermented for 3 days, before they are sundried and milled. *Abeta*, *akouga* or *anyonga* cassava flours are blended with maize, finger millet or sorghum flours and used to make *ugali* or *uji*. Heap fermentation of cassava roots is dominated by moulds (*Rhizopus stolonifer* and *Neurospora sitophila*) and lactic acid bacteria (*Leuconostoc pseudomesenteroides, Leuconostoc mesenteroides, Enterococcus faecium* and *Weissella cibaria*), which decrease the total cyanogenic content and pH; and slightly increase the protein content of the roots (Tivana et al., 2007).

Ugali formulations

Maize, finger millet, sorghum and cassava flours are the main flours used to make *ugali*. The flours are used either singly or as composite flours (Table 2). White semi-dent maize is the most widely used unblended flour for making *ugali*, because the grain is cheap and readily available and has been intensively promoted by the government as the premier national food security crop (Smale and Jayne, 2003). Other popular maize varieties are yellow maize and pigmented maize. Finger millet *ugali* is only made during special occasions, such as wedding ceremonies, because it is almost twice as expensive as the same amount of maize or sorghum. This is because its cultivation and processing is tedious and time-consuming. A special kind of *ugali* (*kuon anang'a)* is made from finger millet and fermented milk, instead of water, and is normally eaten with ghee. Sorghum is the least preferred unblended cereal grain for making *ugali*. It is mainly consumed in poor households, especially during famine, when maize stocks are low. In order to improve the taste of *ugali* made from finger millet or sorghum, the grains are usually roasted before they are milled.

Unblended *abeta, akuoga* or *anyonga* cassava flours are not commonly used to make *ugali* because they give a gummy product. Cassava *ugali* is difficult to form into a ball when it is kneaded in the palm of the hand prior to eating. Furthermore, it has a soft and slippery texture in the mouth, a characteristic that is not associated with normal *ugali*. Despite these negative textural properties of cassava *ugali*, the product is found in Busia and Migori counties where cassava is an important household food security crop. However, even in these counties cassava *ugali* is only made when household reserves of maize, finger millet and sorghum are low or have been exhausted a common occurrence during famine. When a choice has to be made between the kind of cassava product that should be used to make *ugali*, then *akuoga* or *anyonga* cassava are preferred over *abeta* cassava. This is because smaller quantities of the former flours are required to make *ugali*, and the product has better texture. Also, during cooking, it is easier to knead *ugali* made from *akuoga* or *anyonga* than that made from *abeta* cassava. *Ugali* made from *akuoga* or *anyonga* cassava is firmer, less stringy and has better colour, smell and taste than *ugali* made from *abeta* cassava. In terms of taste, the respondents said that *ugali* made from *akuoga* or *anyonga* cassava is sweeter than that made from *abeta* cassava.

Generally, composite flours (Table 2) are preferred over unblended flours for making *ugali* because they have better sensory properties. Cassava (preferably *akuoga* or *anyonga)* flour decreases the firmness and cohesiveness of *ugali* containing cereal flours. On the other hand, the cereals mitigate the gummy texture associated with gelatinized cassava. The types and amounts of flours used to make composite flour is dependent on the desired sensory attributes, cultural practices, and the availability and cost of the raw materials. Finger millet or sorghum grains are commonly roasted before blending with cassava or maize, in order to improve the taste of *ugali*. Sorghum is used in small amounts in most recipes because polyphenols in the grain give the product a bitter and astringent taste, and

Table 2. Major composite flours used to make *ugali* in ten counties in western Kenya.

County	Composite flour	Ratio
Bungoma	Finger millet: cassava	2:1
	Maize: cassava	4:1
	Sorghum: maize (*otwaka*)	1:1
	Cassava: finger millet: sorghum (*saba lulala*)	6:4:1
	Maize: sorghum: cassava	2:2:1
Busia	Cassava: sorghum	6:1
	Cassava: finger millet:	6:1
	Cassava: finger millet: sorghum	10:1:1
	Maize: sorghum: cassava	10:1:4
	Maize: sorghum: cassava	2:1:10
Homa Bay	Maize: sorghum (*kuon cham* or *odongo oher*)	4:1
	Sorghum: cassava	4:1
Kakamega	Finger millet: cassava	2:1
	Maize: sorghum (*otwako*)	3:1
	Maize: cassava	2:1
	Cassava: sorghum	4:1
	Finger millet: sorghum: cassava (*saba lulala*)	4:2:1
Kisii	Finger millet : sorghum	2:1
	Finger millet: sorghum: cassava	2:1:1
Kisumu	Sorghum: finger millet: cassava	2:2:1
	Maize: sorghum: cassava	4:1:1
Migori	Cassava: sorghum	5:1
	Finger millet: cassava	5:1
Nyamira	Finger millet: cassava: sorghum	4:1:1
Siaya	Maize: sorghum	8:1
	Cassava: sorghum	8:1
	Maize: cassava: sorghum	8:4:1
Vihiga	Maize: sorghum (*otama*)	10:1

an intense red-brown colour. Sorghum is also used in small amounts in the composite flour recipes, because it has a high water absorption capacity, which gives dense and compact *ugali*. For instance, *ugali* made from maize and sorghum (*otwako*) in Kakamega County, is liked because the consumer gets satisfied after eating only a very small amount. This recipe is commonly used during famine when poor households cannot afford to eat more than one meal per day. Other recipes that are essential in guaranteeing household food security during lean times are *otwaka* and *otama* in Bungoma and Vihiga counties, respectively; and the 8:1 maize: sorghum recipe in Siaya County.

The *saba lulala* recipe in Kakamega and Bungoma counties, which means ‘eat only once per day’ or ‘wash your hands only once a day to eat’ also aptly shows the association of this recipe with household food security during lean times.

Preparation and quality characteristics of *ugali*

The flour to water ratio required to make *ugali* is about 30% w/v (Onyango, 2014). Water is brought to boil in a cooking pot before adding about 30% flour. Heating is continued without any intervention until boiling resumes. The remaining flour is then added and the gruel is mixed using a flat wooden stick to develop a stiff inelastic, non-flowing paste. Mixing is continued intermittently for the next 7 to 10 min. At the end of cooking, *ugali* should not simmer, which signifies that excess moisture has been driven off. Well-cooked *ugali* should be a single cohesive mass without unhydrated flour particles or lumps of ungelatinized starch (*chimbunda* in Luhya or *chintobe* in Kisii). A hard crispy layer of gelatinized starch remains on the inner surface of the cooking pot. Most *ugali* recipes have a bland starchy taste, neutral pH and slightly burnt aroma. When roasted finger millet or sorghum is used, *ugali* acquires a lightly roasted aroma. *Ugali* made from yellow maize kernels is not popular because it has a distinct strong smell. Poorly-cooked *ugali* has a wet appearance (exudes water), is tasteless, has a gummy texture and sticks in the upper palate of the mouth during chewing. *Kuon anang'a ugali* has a sour taste because it is made with fermented milk instead of water.

The colour of *ugali* is dependent on the colour of flour used to make it. *Ugali* has a white or yellow colour if it is prepared from white or yellow maize kernels, respectively. Whole-milled white maize gives creamish-white non-glossy *ugali*, whereas *ugali* made from dehulled and degermed maize has a bright white colour and glossy appearance. *Ugali* made from pigmented maize kernels is white in colour since the white kernels are dominant in the cob. *Ugali* made from unblended *abeta* cassava has a bright white colour, whereas that made from *akuoga* or *anyonga* cassava has a cream colour. *Ugali* made from cassava and white or yellow maize has a white or yellow colour, respectively. *Ugali* made from unblended finger millet or sorghum or from composite flours containing either of these cereals has a red-brown colour.

Consumers have developed several simple tests to evaluate the texture of *ugali*. The 'wall-test', which is used to know if *ugali* is well-cooked, is done by throwing a piece of *ugali* to a wall. If it sticks on the wall (that is, it is adhesive) it is not well-cooked; if it falls down, it is well-cooked. The texture of *ugali* can also be evaluated by lightly pressing the middle finger into the product. The finger should not puncture or leave a depression in *ugali* that has a firm texture. Well-cooked *ugali* should be moist and have a firm texture that is easy to knead in the palm of the hand into a ball when it is still warm. *Ugali* should not stick on the palm of the hand (that is, should not be adhesive) during kneading into a ball. Poorly cooked *ugali* tends to disintegrate in the hand during kneading and has an adhesive character. *Ugali* should have a mealy, non-adhesive texture in the mouth. *Ugali* made from cereal flours has a rough mouthfeel due to sharp-edged bran and endosperm particles. The texture of this *ugali* is made smoother by incorporating cassava flour in the composite flour. The respondents described poorly cooked *ugali* as being bitter and having a rough texture in the mouth, probably due to ungelatinized starch particles and bran. Objective methods have also been used to evaluate the texture of *ugali*. Onyango (2014) used a Texture Analyser to evaluate the texture of *ugali* and found that the peak force required to cut through a block of maize *ugali* at 55°C ranging from 40 to 80 Newton (N), whereas the total shearing force ranged from 400 to 800 Ns.

Ugali should preferably be consumed when it is still hot, usually within an hour after cooking. Firmness increases whereas the ease of kneading in the hand decreases as *ugali* cools over time due to starch retrogradation. These textural changes make it less appealing and unpalatable after long-term storage. In Kisii and Nyamira counties, staling of *ugali* is delayed by storing it in a traditional hotpot known as *ekee* (calabash-shaped container made from finger millet straw with the lower end covered with cow hide, which acts a sponge to pad on the head during carrying and prevents *ugali* from cooling) and covered with *omonyaboga* leaves, which act like foil paper. Prior to putting *ugali* in the *ekee*, it is sprinkled with flour to reduce adhesion to the container and the leaves. The *ugali* is stuffed tightly and hermetically sealed to prevent any loss of heat. This preservation technique can prolong the shelf-life of *ugali* for up to one week.

***Uji* formulations**

Uji is prepared from unblended or composite flours of maize, finger millet, sorghum or cassava, which may be fermented or unfermented. When making the fermented product, naturally occurring microorganisms, rather than pure cultures, are allowed to develop spontaneously in the slurry. The initial stages of the fermentation are dominated by coliforms and fungi, while lactobacilli are a minor constituent (Masha et al., 1998). As fermentation progresses, contaminant microorganisms are replaced by homofermentative and heterofermentative lactobacilli (Masha et al., 1998). Although lactobacilli are the predominant bacteria, yeasts also play an important role in fermentation by supplying the fastidious lactic acid bacteria with nutrients and degrade raffinose and stachyose (Jespersen, 2003) and impart desirable taste and flavour (Mugula et al., 2003). Commercial processors make chemically-soured *uji* because it is cheaper and less time-consuming. These processors simply add citric acid powder (about 8,000 ppm) to the flours to create the sour taste. Acidulants, such as lemon (*Citrus limon* (L.) Burm. f.) juice extract, tamarind seeds (*Tamarindus*

Table 3. Major composite flours used to make *uji* in ten counties in western Kenya.

County	Composite flour	Ratio
Bungoma	Maize: sorghum	8:1
	Finger millet: maize: cassava	8:1:1
Busia	Finger millet: maize	16:1
Homa Bay	Cassava: finger millet	8:1
Kakamega	Finger millet: sorghum	2:1
	Maize: sorghum	3:1
Kisii	Finger millet: sorghum	2:1
Kisumu	Finger millet: sorghum: cassava	2:1:1
Migori	Cassava: sorghum	10:1
Nyamira	Finger millet: cassava: sorghum	4:1:1
Siaya	Finger millet: cassava	2:1
	Finger millet: cassava: sorghum	8:2:1
Vihiga	Finger millet: sorghum: cassava	4:1:1
	Finger millet: sorghum: cassava: maize	8:1:1:1

indica) or the young shoot of the camel foot plant (*Piliostigma thonningii* (Schum.) Milne-Redh) are also used to make *uji* in several households.

Unroasted finger millet and sorghum are the preferred unblended flours for making *uji*. Unblended maize is only used to make *uji* when finger millet and sorghum are unavailable. The sensory attributes of unblended cassava porridge are poorer than those of cereals. Consequently, unblended cassava is not used to make *uji* (except in Migori County where *anyonga* cassava is used), because the product has bland taste and flavor; and a jelly-like, rather than a free-flowing consistency. Generally, composite flours are preferred over unblended flours for making *uji*, because they give products with better sensory properties. The flour blend used depends on the desired sensory properties. Finger millet is the most preferred grain, whereas maize is the least preferred grain, in composite flours for making *uji* (Table 3). Sorghum is used in small amounts in composite flours because it gives the product a bitter and astringent taste. Cassava (preferably *abeta*) is used in several recipes to give *uji* a smooth texture and decrease grittiness caused by the cereal endosperm and bran particles.

Cereal malt is not used in Kenya as an ingredient in the preparation of *uji*. However, the Kuria in Migori County use finger millet malt to make *togwa. Togwa* is a thin porridge that is widely consumed in Tanzania (Kibatake et al., 2003; Mugula et al., 2003). It is not surprising that the Kuria are aware of this technology since they live along the Kenya-Tanzania border and have acquired this food culture from Tanzania. The Kuria make *Togwa* by adding finger millet malt to cooked *uji,* which is prepared from unblended cassava flour or composite flours of cassava/finger millet/maize; cassava/sorghum/maize; cassava/sorghum; or cassava/maize. The mixture is left to spontaneously ferment for about 8 h before it can be consumed.

Preparation and quality characteristics of *uji*

Fermented *uji* is made by mixing unblended or composite flours with water to obtain liquid slurry (30 to 40 g/100 ml). The slurry is left to spontaneously ferment in a warm place (25 to 35°C) for 24 to 48 h. The pH of the slurry falls from about 6.5 to 4.0 as it develops a sour aroma (Masha et al., 1998). Fermentation is speeded up by using warm water (30 to 35°C) instead of cold water,

adding sugar to the slurry, or inoculating the fresh slurry with previously fermented material (back-slop culture). Back-sloping is a highly effective technique for speeding up the natural acidification process because the inoculum is enriched with lactobacilli (Masha et al., 1998). Fermented *uji* has a short shelf-life, usually less than 48 h, and will rapidly deteriorate if it is not cooked and drank immediately. If fermentation is allowed to continue, the product becomes too sour, and could be contaminated with moulds. The shelf-life of the fermented product can be extended by refrigeration or dehydration. The dried flour can be stored at room temperature and reconstituted in water when required. It can also be used as starter culture for the next batch of *uji* slurry that is to be fermented.

Uji is prepared by first bringing a given amount of water to boil. Separately, cold water is mixed with an equal amount of the flour to make a slurry. The cold suspension is added to the boiling water while stirring until a viscous paste is obtained and there is no foaming. The final suspension has flour to water concentration of about 8 to 10% w/v. The suspension is continuously stirred for the first few minutes of cooking to ensure that all the flour gelatinizes and does not clump. Cooking is continued for 10 to 15 min or until the product is smooth and thick. When *uji* is removed from the cooking pot, a thick layer remains at the bottom of the cooking container. The container must be soaked in water for some time to enable this layer to completely dissolve. The same cooking procedure applies to fermented and dried flour, which is first reconstituted in cold water. If the starting point is fermented slurry, it has to be diluted to about 8 to 10% w/v before adding it to the boiling water. For *uji* made from unblended *anyonga,* the dried cassava pieces are first soaked in water then sieved and the filtrate is used to make *uji*.

Uji should have a viscous but free-flowing consistency. Onyango et al. (2004b) found that *uji* made from maize/finger millet, maize/sorghum, cassava/finger millet or cassava/sorghum blends had free-flowing consistencies at viscosities of 1000 to 1500 cP (40°C; shear rate 36 to 64 s^{-1}). In another study Onyango (2014), used a Texture Analyser to evaluate several textural attributes of *uji*. He found that the firmness, consistency, cohesiveness and index of viscosity of maize *uji* ranged between 0.2 and 1.3 N, 6 and 34 N·s, -0.2 and 1.5 N, and -0.3 and 2.1 N·s, respectively. Fermentation does not reduce the viscosity of *uji* (Onyango et al., 2004a; Masha et al., 1998).

The mouth-feel of *uji,* which depends on the particle size of the flours, ranges from coarse and gritty to smooth and creamy. A gritty mouthfeel is due to bran and endosperm particles from coarsely milled cereals. Grittiness can be reduced by milling the flour in successive cycles or using sieves with smaller pores. Generally, sieves with smaller pores are used when milling small grains, such as sorghum and finger millet, while sieves with larger pores are used when milling bigger grains, such as maize. The colour of *uji* largely depends on the colour of finger millet (red or brown) or sorghum (red) used to prepare it. *Uji* made from finger millet is dark brown; that from sorghum and finger millet is red-brown; and that from finger millet and maize is light brown in colour. Poorly cooked *uji* has an uncooked flavour and undergoes syneresis when left to stand. It drains out completely from a cup, whereas well-cooked *uji* leaves a thick layer of the gruel attached to the side of the cup.

Many consumers prefer fermented *uji* over the unfermented product. Unfermented *uji* has a bland, cooked-starchy taste, whereas the fermented product has a pleasant sour taste due to the aroma compounds produced by lactic acid bacteria (Masha et al., 1998). The microorganisms produce enzymes that digest polysaccharides, proteins and lipids in the substrate and produce compounds that contribute to the flavour and aroma. Lactic acid is the main non-volatile aroma compound in fermented *uji,* and is supplemented with other aroma compounds such as branched alcohols, carboxylic acids, esters and aldehydes (Masha et al., 1998; Onyango et al., 2004b). If desired, the sour taste of fermented *uji* can be complemented with sugar to create a sweet-sour flavour.

Other than improving the sensory properties of foods, consumption of fermented foods has several nutritional and health benefits. Fermentation destroys undesirable and harmful compounds in the food, preserves the food, improves its nutritional value and reduces the energy and time required to cook the food (Blandino et al., 2003; Steinkraus, 2002; Hotz and Gibson, 2007). Fermented products are also important sources of lactic acid bacteria with probiotic value. Fermentation improves the safety of foods by producing antimicrobial compounds, produce nutraceuticals with increased bioavailability of nutrients, improve intestinal microbial balance, improve immune system modulation, play a role in management of type II diabetes, and lower serum cholesterol levels (Mokoena et al., 2016; Franz et al., 2014).

Ugali and *uji* as functional foods for management of non-communicable diseases

Kenya among other countries in sub-Saharan African is faced with a tremendous increase in the prevalence of non-communicable diseases such as cardiovascular diseases and type II diabetes (Dalal et al., 2011). Since medications for controlling these conditions are expensive, dietary approaches are more cost-effective. Nutrition epidemiology shows that a diet rich in whole-grain based foods assist in health maintenance and lowers the risk of developing non-communicable diseases. Whole grain foods contains several bioactive

substances and phytochemicals that contribute to gut health, increase satiety and help to control body weight (Fardet, 2010; Stefoska-Needham et al., 2015; Saleh et al., 2013; Truswell, 2002). Consumption of high fiber diet slows digestion and retards release of sugar into the blood stream, which improves glycaemic control and reduces the risk of developing non-communicable diseases such as type II diabetes and coronary heart disease (Roberts and Liu, 2009; Hardy et al., 2010). Consumption of millet increases levels of high density lipoprotein in the blood stream and may be useful in managing insulin resistance and cardiovascular disease in type II diabetes (Nishizawa et al., 2009). Furthermore, bioactive compounds in whole grains have anti-oxidant and anti-inflammatory properties that suppress tumors and have anti-carcinogenic properties (Fardet, 2010; Stefoska-Needham et al., 2015; Saleh et al., 2013; Awika and Rooney, 2004; Truswell, 2002).

In this study, the researchers reported that whole-milled maize, finger millet and sorghum grains are recommended for making *ugali* and *uji* for people suffering from cardiovascular diseases and type II diabetes. Mlotha et al. (2016) studied the glycemic index of a thick porridge (*nsima*) in Malawi, which is similar to *ugali*, and found that *nsima* prepared from fermented maize grits has a lower glycemic index than that prepared from whole maize flour or unfermented maize grits. They recommended that fermented flours should be used to prepare maize-based foods for diabetics. By contrast, cassava is not recommended in food recipes for diabetics because it is rich in rapidly digestible starch (Yessoufou et al., 2006), which can cause a sudden spike in blood sugar levels. However, cassava starch digestibility can be decreased by converting it into resistant starch (Lertwanawatana et al., 2015), and hence it is possible to develop cassava-based nutritional products for the management of non-communicable diseases.

Uji as a complementary food for children

Unfermented *uji* is an important food for complementary feeding of children (children are not fed fermented *uji* because they are unfamiliar with the sour taste and hence consume very small amounts). However, because only a small amount of flour (less than 10% w/v) is required to make the product, it has a low energy density (0.3 kcal/g) (Onyango et al., 2004a), which is below the minimum recommended energy density of thin porridge (0.8 kcal/g) for complementary feeding (WHO/UNICEF, 1998). Consequently, children weaned exclusively on un-supplemented thin porridge have inadequate energy intake and suffer from energy malnutrition (Kulwa et al., 2015). Furthermore, the overall inadequate nutrient intake exposes children to other dietary-related illnesses, such as stunting and wasting (Kulwa et al., 2015).

Simply increasing the flour concentration in order to increase the energy density of porridge for child-feeding is not effective because the product will be too thick and a child will find it difficult to chew and swallow (Onyango et al., 2004a). The energy-density of thin porridges for complementary feeding can be increased by adding amylase-rich malt flours (Thaoge et al., 2003) or microbial amylases (Onyango et al., 2004a) to the slurries. The amylases hydrolyse starch to maltose and low molecular weight dextrins, which have low water binding capacities, do not gelatinise when cooked and produce low viscosity porridges with potentially high energy densities provided the recommended amount of flour is used (Onyango et al., 2004a). Thaoge et al. (2003) showed that sorghum malt flour (5%) can be used to make thin porridge (2,500 to 3,000 cP) with a high (30% w/v) solids content. Microbial amylase can also be used to increase the amount of flour required to make *uji* (20% w/v) and obtain a product with a high energy density (2.51 to 3.35 kJ/g) and appropriate viscosity 1000 to 2000 mPa.s (Onyango et al., 2004a). Despite widespread academic knowledge on the positive influence of malt on the energy density of porridge, this technology has not been adopted in Kenya, except by the Kuria in Migori County, who use malt flour to make *togwa*.

Maize, finger millet, sorghum and cassava are good sources of dietary energy because of their high carbohydrate content. The carbohydrate content in cereals is about 75% (Mckevith, 2004) and in cassava is 80 to 90% on dry-weight-basis (Montagnac et al., 2009a). However, these foods have low protein contents. The protein content of cereals is about 6 to 15% (Mckevith, 2004), whereas cassava roots have 1 to 3% (Montagnac et al., 2009b). Cereals are deficient in lysine and tryptophan but are rich in cysteine and methionine (Mckevith, 2004). Cassava root is deficient in methionine, cysteine and tryptophan (Montagnac et al., 2009a). Many respondents said that they improve the quality and content of protein in *uji* for complementary feeding with legumes (Table 4), such as soybean (*Glycine max* (L.) Merr), amaranth (*Amaranthus cruentus* L.), common bean (*Phaseolus vulgaris* L.), groundnuts (*Arachis hypogaea* L.) or sesame (*Sesamum indicum DC*). Legumes are rich in lysine but are deficient in sulphur containing amino acids (Blandino et al., 2003). Hence, supplementing cereal/cassava porridges with legumes improves the content and quality of proteins in the porridges (Ejigui et al., 2007; Anyango et al., 2010; Muoki, 2013). The bioavailability of nutrients in plant foods can be further improved by other pretreatments, such as soaking, germination, fermentation and thermal treatment, which reduce the levels of anti-nutrients, improve mineral absorption and reduce the incidence of common infections in children (Gibson et al., 2006). Animal proteins such as milk or silver cyprinid

Table 4. Major composite flours used to make *uji* for complementary feeding of children in ten counties in western Kenya.

County	Composite flour mixture	Ratio
Bungoma	Finger millet: soybeans: groundnuts: common bean	16:8:2:1
	Sorghum: finger millet: soybeans: groundnuts: beans: silver cyprinid	2:2:1:1:1:1
Busia	Finger millet: maize: soybeans: groundnuts: beans: cassava: amaranth: silver cyprinid	32:4:1:1:1:1:1:1
Homa Bay	Cassava: finger millet	8:1
Kakamega	Maize: groundnuts: soybeans	32:1:1
	Finger millet: groundnuts: soybeans	32:1:1
	Finger millet: maize: groundnuts: soybeans	8:4:1:1
Kisii	Finger millet: groundnuts: beans: soybeans: green bananas: silver cyprinid	4:1:1:1:1:1
Kisumu	Finger millet: sorghum: groundnuts: soybeans: simsim: amaranthus: green gram	4:1:1:1:1:1:1
Migori	Cassava: sorghum: beans: groundnuts	8:2:1:1
	Finger millet: soybeans: groundnuts: silver cyprinid	4:1:1:1
Nyamira	Finger millet: sorghum: soybeans: groundnuts: cassava	4:1:1:1:1
Siaya	Finger millet: groundnuts: soybeans: sorghum: cassava	4:1:1:1:1
Vihiga	Finger millet: sorghum: cassava: groundnuts (or soybeans)	4:1:1:1

(*Rastrineobola argentea;* locally known as *omena* or *dagaa*) may also be used to improve the content and quality of protein in *uji*.

The choice of protein material used to improve the nutritional quality of *uji* for complementary feeding is determined by several factors such as affordability, sensory properties and its functional properties. Milk is not commonly used because it is expensive. Undesirable sensory properties of foods may limit the energy and nutrient intake of the food by children. Silver cyprinid is used in small amounts because it gives *uji* a distinct off-flavour that is unappealing to children. Acceptability of cereal porridges blended with high contents of legumes may be limited due to the beany flavour (Asma et al., 2006; Obatolu et al., 2000). Mosha and Bennink (2005) found that *uji* made from extruded corn-bean-sardine meal or sorghum-bean-sardine meal had better texture, colour and taste relative to *uji* made from maize meal. In terms of product functionality, Anyango et al. (2011) showed that addition of cowpea to sorghum decreases the peak viscosity and cool paste viscosity of *uji*. They attributed the textural changes to the increase in protein content and the concomitant decrease in starch content in flour as a result of cowpea addition.

Conclusion

Maize, finger millet, cassava and sorghum are the basic raw materials for the production of thick (*ugali)* and thin *(uji)* porridges in Kenya. The flours are used either singly or as composites. *Ugali* is principally eaten for lunch or dinner as the main meal whereas *uji* is consumed as a refreshing drink any time of the day. The flours can also formulated to meet the nutrient requirements of special categories of consumers such as children, invalids and people suffering from non-communicable diseases. The nutritional quality of *uji* for child-feeding is improved by adding plant or animal proteins. People suffering from non-communicable diseases are fed ugali and uji made from whole-milled cereal flours. The products are largely made at home and hence product quality is extremely diverse. Several opportunities exist to improve the quality and safety of these products. Cereal malt could be utilized to improve the energy density of *uji.* The products could be made into ready-to-eat porridges that require little energy and time to prepare at home. Opportunities for further product development and commercialization of novel products such as gluten-free African bread (*estata*), *makhalange* (*zimbare*), *emifuname*, sorghum rice, and

caffeine-free sorghum beverage also exist. Microbial strains with unique technological and functional properties could be identified in *uji* and *togwa* and used to develop probiotic foods. Finally, industrial production of these porridges based on scientific principles and in commercial quantities can contribute to improved food and nutrition security in the country.

Conflict of interests

The authors have not declared any conflict of interests.

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