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Review

Bio-based packaging used in food processing: A critical review

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Food packaging plays an important role in ensuring the global quality of the food consumed by people. Technological progress has been achieved in recent years in the food packaging sector, leading to a great diversity of food packaging, including bio-based packaging. This review highlights the different types of biodegradable polymers that are used for food packaging production, their characteristics and effects on food quality. Three categories of bio-based packaging are classified according to the origin of the materials: Polymers directly extracted from natural materials, polymers synthesized from bio derived monomers, and polymers produced by microorganisms. Bio-based food packaging has various properties and is increasingly used to limit the use of plastic packaging produced with petroleum resources. Several types of interactions occur between food and bio-based packaging such as permeation, migration and sorption. Depending on the properties of the material used for production, bio-based packaging contributes differently to the preservation of packaged food.

Key words: Biopolymers, food packaging, food quality, renewable material, biodegradable packaging.

INTRODUCTION

Food packaging plays an important role in food security by reducing losses, but also to ensure food safety and to strengthen trade, one of the keys to the development of various economies (Carocho et al., 2015; Gontard et al., 2017; Meenu et al., 2017; Ribeiro-Santos et al., 2017; Robertson, 2006). As part of key factors in loss reduction and ensuring food safety, food packaging presents some

environmental benefits. Indeed, each ton of food waste contributes to avoiding 4.2 tons of food emissions carbon dioxide that would have been associated with the waste (Quested et al., 2011). The use of food packaging started a long time ago, and at that time, leaves and skins of animals were used to hold, transport or preserve food (Mustafa et al., 2012). This traditional packaging continues

to be used in Africa and Asia, and occupy an important place in the food industry (Hounhouigan, 2000; Onzo et al., 2013). Since the twentieth (20th) century, many advances have been made in the field of food packaging (Risch, 2000). Thus, the detailed functions of food packaging including containment, protection and conservation, marketing, identification, information and comfort of use are widely reported in literature (Risch, 2000). Advances in this sector have led to the use of various materials for the manufacture of food packaging and the production of modern types of packaging such as intelligent packaging or smart packaging (time-temperature indicators, gas, microwave cooking indicators, radio frequency identification and others) and active packaging (oxygen sensors, moisture absorbers and antimicrobials) (Brody et al., 2008). These innovations have further improved food quality, food safety and shelf life (Han, 2018), and are in particular due to scientific research which allows understanding the various reactions which take place within food and the interactions of food with its packaging. These interactions are diverse and vary from one packaging material to another (Yam et al., 2005). Several studies carried out in recent years have clarified the diverse effects of the packaging material on environmental and consumer health, depending on its origin. Non-biodegradable packaging, especially plastic has become very bulky in nature, thus posing serious health, environmental and land degradation problems (Adejumo and Ola, 2008). Consequently, bio-based packaging is perceived nowadays as a good alternative to non-biodegradable packaging. In this area, one approach consists in using and structuring bio-based materials on a micrometric or nanometric scale in order to obtain packaging with specific properties to meet the requirements of food packaging while respecting environmental constraints (Davidovic, 2007; Hijazi, 2014; Peelman et al., 2013; Siracusa et al., 2008). Providing sustainable and economically viable food packaging while maintaining key packaging's characteristics requires continuous technology development and innovation. There are several reported studies on packaging produced from natural and biodegradable resources. The purpose of the present review was to highlight the new development in food packaging with a focus on bio-based packaging and technical advances in the field including interactions between bio-based packaging and food. Particular interest was given to future prospects of bio-based food packaging development in Africa.

FUNCTIONS OF FOOD PACKAGING

Food packaging provides two important functions: logistical function (container, protection and preservation) and information function (marketing, convenience, identification) (Lee and Lye, 2003).

Food container

Packaging is the container used to keep one or more products until complete use or transfer to another container. The characteristics of the packaging (structure, shape, size, material, etc.) depend on the type of product for which it is intended. Depending on the product nature (liquid, solid, hot, cold, large, small, etc.), the packaging will be different. This container function integrates derived sub-functions such as transport, storage, warehousing and handling (Rocher, 2008). Considering the product distribution channel, packaging ensures its delivery from the production places to the point of sale without damage. In addition, as a container, it should not become harmful after use of the product but can also be useful in ensuring storage possibilities for the consumer (Lee and Lye, 2003).

Protection and preservation

Another function of packaging is to protect and preserve the product, to maintain its highest level of quality as long as possible. Packaging provides physical, chemical and biological protection for the product (Robertson, 2006). At the physical level, it protects food from mechanical damage including shock and vibration during distribution. Chemically, it minimizes changes in both nutritional (preserving nutrients) and organoleptic (color, texture, taste) composition caused by environmental influences such as exposure to gas (oxygen), humidity (loss or gain), or light (visible, infrared or ultraviolet). Biologically, packaging provides a barrier against both pathogenic and spoilage microorganisms, insects, rodents and other animals, thereby preventing contamination and spoilage of the food (Marsh and Bugusu, 2007). Protective function that packaging provides implies properties such as:

i) Mechanical resistance: Solidity of the packaging to ensure physical and biological protection;
ii) Impermeability: Ensuring chemical protection and avoiding the exchange of microorganisms and matter between the product and the outside environment;
iii) Opacity: Protecting the product against the effects of light
iv) Integrity: Remaining unharmed so as not to compromise the quality of the product it contains.

Marketing

Before discovering the product, the component the consumer first comes in contact with is the packaging. It is a real means of communication between the producer and the consumer. It should inform consumers and appeal to them. Packaging attraction is based on different

Figure 1 diagram:

Bio-based

Examples:

Bio-based Polyethylene Terephthalate (Bio-PET), Biopolyethylene (Bio-PE), Bio-propylene (Bio-PP), Bio-polyamide (Bio-PA)

Examples:

Polylactic acid (PLA), Polyhydroxyalcanoate (PHA), Polybutylene succinate (PBS), Lignin, Hemicellulose, Cellulose, Starch, Chitosan

Not biodegradable   **Biodegradable**

Conventional plastics

Examples:

Polyethylene (PE), Polypropylene (PP), Polystyrene (PS), Polyethylene Terephthalate (PET)

Examples:

Polycaprolactone (PCL), Polybutylene adipate terephthalate (PBAT)

Petrochemical-based

Figure 1. Types of packaging materials used in food packaging. Source: Hijazi (2014), Lackner (2015), and Rameshkumar et al. (2020).

elements (color, shape, graphics and material) (Draskovic, 2007). The ability of consumers to instantly recognize products through a distinctive brand and labeling makes it easy for supermarkets to sell (Ampuer and Vila, 2006; Robertson, 2006). This marketing function includes a set of elements (Ampuer and Vila, 2006; Robertson, 2006):

i) Visual impact (or alert function): It is important for packaging to be spotted easily.
ii) Recognition: When looking at the packaging, consumers who already know the brand recognize it easily, without even having to read its name.
iii) Expression of positioning: The packaging must, by its shape or decoration, evoke the salient and distinctive features that the producer has decided to confer on the brand.
iv) The impulse to buy: A package must arouse or reinforce the desire to buy.

Identification and information

Packaging provides consumers all the information they may need: type of product, composition, quantity, manufacture date, expiration date for consumption, nutritional value, manufacturers, indications for optimal use, precautions for use, storage handling, etc. (Robertson, 2006). It gives information about the specific characteristics of the product, so as to avoid misuse (Draskovic, 2007).

User convenience

Food packaging is an integral part of the product. It should allow consumers to access the food with some convenience and allow easy use of the food (Robertson, 2006). For certain technologies, the packaging used confers organoleptic characteristics to food and leads consumers to prefer one packaging over another (Onzo et al., 2015). The packaging, intimately linked to the food product which it contains, contributes to the quality of this food by facilitating its use and its conservation by the consumer.

DIVERSITY OF BIO-BASED FOOD PACKAGING MATERIALS

The term "bio-based" designates polymers whose raw materials are wholly or partially derived from the plant, animal or microbial biomass (Hijazi, 2014). They may or may not have a biodegradable character (Figure 1). The term biodegradable is used to show the ability of a material to be decomposed under the action of enzymes produced by microorganisms (Hijazi, 2014; Jiang et al., 2006).

Depending on the origin of bio-based and biodegradable materials, they are classified into three main categories: polymers directly extracted from natural materials, polymers classically synthesized from bio-derived monomers and polymers produced by microorganisms (Figure 2).

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                                    ┌─────────────────┐
                                    │   Biopolymers   │
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│ extracted from      │          │ from bioderived     │          │ microorganisms      │
│ natural materials   │          │ monomers            │          │                     │
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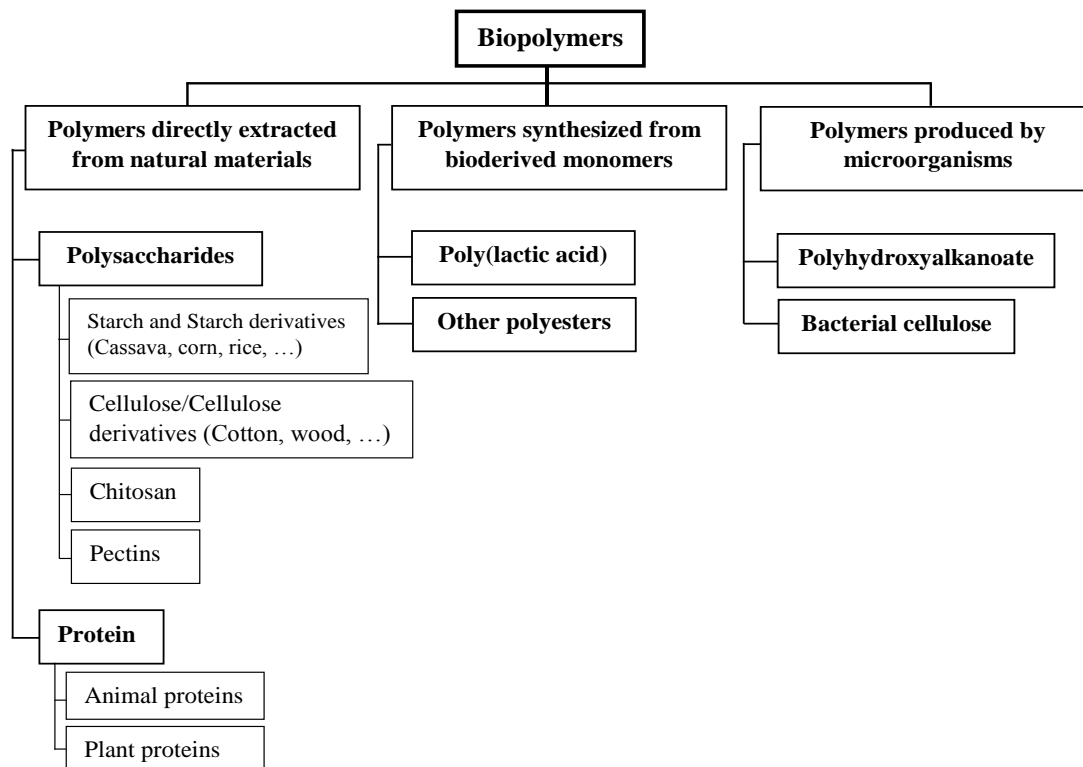
Figure 2. Categories of bio-based materials.
Source: Guzman et al. (2011) and Robertson (2008).

Polymers directly extracted from natural materials

Natural polymers are those obtained from animal, agricultural and marine resources, which include polysaccharides (starch, cellulose, chitosan, gums, etc.) (Robertson, 2008). There are also vegetable proteins (zein, gluten, soy, etc.), animal proteins (casein, collagen, gelatin, etc.) and lipids. They can be used alone or mixed with a biodegradable synthetic polymer such as polycaprolactone (PCL) or other biodegradable polyesters such as polylactic acid (PLA) (Guzman et al., 2011; Rameshkumar et al., 2020). These materials used in the production of food packaging have good gas barrier properties (Avérous and Pollet, 2012). However, due to their hydrophilic and crystalline character, they present some limits during the heat treatments which are carried out on packaged foods (Avérous and Pollet, 2012).

Starch is a less expensive and renewable plant material (Sadeghizadeh-Yazdi et al., 2019). It is obtained from various sources such as cassava, potato, corn, wheat, rice, sweet potato (Whistler and BeMiller, 2007). It is composed of amylose and amylopectin which ratios vary with the source of the starch (Guzman et al., 2011). Several studies have shown that starch is a thermoplastic material (TPS) and can be used to replace polystyrene (PS) which is a non-biodegradable compound. Thanks to

the restructuring, starch can be converted into thermoplastic material by means of treatment at high temperature (Avérous and Pollet, 2012; Guzman et al., 2011). In this process, water and glycerol are generally used and play the role of plasticizers (Guzman et al., 2011; Wertz, 2011). However, its affinity for humidity limits its ability to be used alone for the production of food packaging suitable for foods with a high water content (Guzman et al., 2011; Peelman et al., 2013; Sadeghizadeh-Yazdi et al., 2019). In order to improve the characteristics of biodegradable starch-based packaging, it is mixed with synthetic biopolymers with the desired properties (Rutot and Dubois, 2004; Yadav et al., 2018). These technologies for improving the properties of bio-based packaging are developed by some researchers. As an example, corn starch enriched with chitin nano-whiskers has been used to produce food packaging with antimicrobial properties against *Listeria monocytogenes* (Qin et al., 2016).

Cellulose-based bioplastics are also used as food packaging with a significant market share worldwide (Peelman et al., 2013). Cellulose derivatives can be produced by derivatization of the cellulose from the solved state, via esterification or etherification of the hydroxyl group. These cellulose-derived forms are used to produce biodegradable packaging (Majid et al., 2018; Rutot and Dubois, 2004). In order to increase its moisture

barrier properties, the incorporation of hydrophobic compounds such as fatty acids is carried out in the cellulose ether matrix to develop a composite film (Morillon et al., 2002).

Like starch and cellulose, chitosan or chitin is used for the production of biodegradable packaging. It is a semi-crystalline polymer of the polysaccharide type obtained by deacetylation of chitin. The second most common polysaccharide in the world after cellulose (Rinaudo, 2006), chitin is one of the constituents of the exoskeleton of arthropods, the cuticle of insects or the cell wall of fungi and yeasts (Majeti and Ravi, 2000). Chitosan has excellent mechanical and antimicrobial properties which reduce the oxidation process and are beneficial in increasing the shelf life and quality of food products (Gemili et al., 2009). It is mainly used as an edible coating to extend the shelf life of fresh fruits and vegetables (Clarinval and Halleux, 2005).

Proteins are also used in the production of biodegradable food packaging. They are complex structures made up of amino acids and are obtained from plant (gluten, zein, soy protein, etc.) and animal (casein, whey, gelatin, etc.) sources (Dean and Yu, 2005). Although they are biodegradable, renewable, and with better gas barrier properties, they have limitations due to their hydrophilic nature. Like starch-based polymers, proteins must be mixed with other polymers or must be chemically or microbiologically modified (Majid et al., 2018). Applications of proteins in the packaging field are in particular in the form of edible films (Mohareb and Mittal, 2007). Protein materials are widely studied as food packaging materials with recent improvements in properties, but a breakthrough leading to commercialization has yet to be assessed (Guilbert et al., 1997). One reason is the high cost of protein materials (Bhattacharya et al., 2005).

Polymers classically synthesized from bio-derived monomers

Synthetic polymers are polymers resulting from chemical reactions from renewable materials. Obtained by the fermentation route, they are called synthetic or chemo-synthetic polymers because of their method of manufacture (Meena et al., 2017). This method consists of a polycondensation (heating) of natural monomers. Synthetic polymers are produced by conventional chemical synthesis of bio-based monomers. These synthetic polymers are obtained from renewable resources such as corn, sugar beets and potato starch (Koutinas et al., 2007). There are several types of these polymers and the most used is polylactic acid (PLA). Polylactic acid (PLA) is one of the most available and exploited bioplastics (Montes et al., 2018). It has become a good alternative to conventional plastics due to its biodegradable nature. It has also been shown that PLA,

in many circumstances, performed better than that of synthetic plastics (Auras et al., 2005). It is produced by conversion of the raw material (carbohydrate source) into dextrose followed by fermentation into lactic acid. Following this conversion, PLA pellets are obtained by direct polycondensation of lactic acid monomers or by ring-opening polymerization (Södergård and Stolt, 2002). Several types of treatment can be carried out with this material to produce biodegradable food packaging (Rasal et al., 2010; Xiao et al., 2012).

Polymers produced by microorganisms or bacteria

This polymer category includes polymers synthesized from the microbial fermentation of polysaccharides (Sudesh and Doi, 2005). It includes polymers, such as polyhydroxyalkanoates (PHA) and microbial polysaccharides such as pullulan, bacterial cellulose, curdlan, xanthan etc. (Bielecki et al., 2003). Among polymers produced by microorganisms, the most common are polyhydroxyalkanoates (PHA) (Bielecki et al., 2003). PHA are linear biopolyesters produced biologically by microorganisms from carbon substrates, in unbalanced living conditions, in a proportion which can sometimes reach 80% of their dry mass (Avella et al., 2005; Matsumoto et al., 2001). The chemical structure of these polymers varies according to the bacterial sources, the metabolism and the substrates used, which influence the molecular mass and the properties of the polymer. With the development of biotechnology, it has become possible to synthesize a wide variety of PHAs (Noda et al., 2004; Steinbüchel, 1995). However, PHA polymers are very expensive (5 to 10 times more expensive than for petro-based polymers) because of being obtained from microorganisms and the purification is still in very restrictive steps (Suriyamongkol et al., 2007), which explains the high cost of PHA polymers. PHAs are biodegradable, thermoplastic, biocompatible and thermostable with a melting temperature of around 180°C (Hijazi, 2014). PHAs are bio-based materials which have high biodegradation kinetics under natural conditions. They are optically active and have good gas barrier properties to flavors and odors (Castilho et al., 2009; Narancic et al., 2020). They are also resistant to grease and oil, temperature stability and are easy to dye, which improves its applications in the food industry (Tripathi et al., 2014).

INTERACTIONS BETWEEN BIO-BASED PACKAGING AND FOOD PRODUCTS

By nature, food bio-based packaging materials are not inert; they can have consequences on physical, chemical, microbiological and organoleptic characteristics of the food. Furthermore, the contact between bio-based
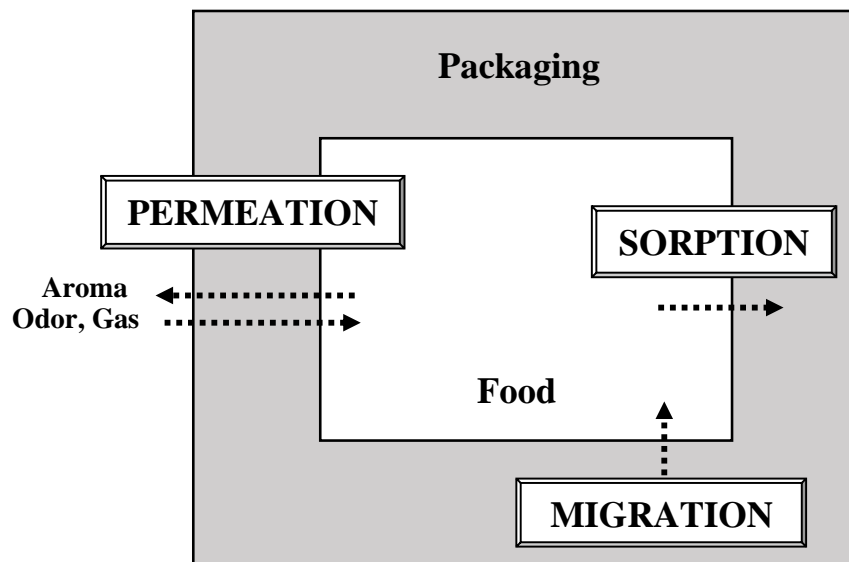
Figure 3. Interactions between packaging-food products.
Source: Bach (2012) and Severin et al. (2011).

packaging and food can also influence the mechanical properties of the packaging (Ebrahimzadeh Mousavi, 1998; Lezervant, 2007). There are three types of interactions between the environment, packaging and food: permeation, sorption and migration (Figure 3).

Permeation

Permeation is characterized by the transfer of volatile molecules between external environment and food through packaging. Oxygen (O_2) passes from the surrounding environment to the packaged product; while CO_2 and other volatile compounds (water vapors, aroma compounds) are transferred from the product to the outside of the packaging, or in some cases, from the environment to the product (Perazzo et al., 2014; Severin et al., 2011). Permeation could lead to oxidation reactions, microbiological contamination, loss of aroma, change in color, texture, etc. As a result, the quality of the food may decrease (Severin et al., 2011). As in the case of migration and sorption, permeation is greater in amorphous materials and rubbery materials than in crystalline or glassy materials (Zaki, 2008). In general, permeability depends on the materials used for the production of the packaging, the thickness of the packaging, the type of product packaged and the storage conditions.

Sorption

Sorption is the assimilation of the food constituents by the packaging followed by their penetration in the packaging (Bach, 2012; Severin et al., 2011). It can cause physical

ageing of the packaging which results in a slow and irreversible deterioration of its properties. Furthermore, the structural modifications caused by these phenomena can lead to the production of newly formed substances. These uncontrolled substances can in turn migrate to food, constituting a danger for the consumer. Thus, on the one hand, these phenomena can lead to the deterioration of the packaging, and on the other hand, they can affect the quality of the food (Severin et al., 2011). In addition, the increase in temperature promotes the sorption of aroma compounds in packaging materials. By passing for example from 4 to 40°C, the total sorption of the aroma compounds, after 28 days of storage, was multiplied by 13 in a polyethylene terephthalate (PET) bottle (Coulier et al., 2007). The sorption of the aroma compounds increases the permeability of the packaging to oxygen which is detrimental to the quality of the content (Coulier et al., 2007; Van Willige et al., 2001).

Migration

Migration corresponds to the transfer of components from packaging to food (Berlinet, 2006). In general, this transfer of material can occur during production, transport, storage, cooking or even during consumption of food. Different factors are involved in the migration process: the nature of the material, the elements concerned, but above all, the physical and chemical characteristics of the packaged food. Depending on whether the food is more or less pasty, solid or liquid, the migration process varies (Simoneau, 2008). In addition, factors such as the temperature and the lipophilic nature of food remain the main factors of compound migration (Ebrahimzadeh Mousavi, 1998; Simoneau, 2008).

BIO-BASED PACKAGING MATERIAL EFFECTS ON FOOD QUALITY

Food packaging produced with biological and renewable resources has properties that are directly linked to the nature of the biopolymer that constitutes them (Auras et al., 2005). The main properties of bio-based packaging are barrier to water vapor, oxygen, and fats and antimicrobial function. All biopolymers do not have the same properties and for the same property, the level of performance differs from one biopolymer material to another. Recent studies have developed bio-based packaging with incorporation of active biological substances in order to give antimicrobial and antioxidant activities to packaging (Table 1).

Effects of bio-based packaging on the physico-chemical characteristics of food

The effects of bio-based packaging on the physico-chemical characteristics of food vary according to the type of food and the packaging material. Packaged food products contain various types of substances and their interaction with bio-based materials can affect the mechanical properties of the packaging and also the overall quality of the food (Auras et al., 2005). In the food industry, the performance of bio-based packaging in terms of barrier to oxygen, air, light, water, water vapor, grease and oil is very important (Lavoine et al., 2012; Leminen et al., 2013). Several studies have evaluated the effects of bio-based packaging on the quality of food. The research of Kantola and Helen (2001) on ability of bio-based packaging (polylactic acid, PHA and polyhydroxybutyrate, PHB) to preserve fresh tomatoes has shown that, although bio-based materials offer the same protection against quality change as -based plastic packaging, tomatoes have lost more weight in bio-based packaging than in conventional plastic packaging. The evaluation of the effect of yam starch films on the conservation and quality of strawberries, carried out by Mali and Grossmann (2003), showed that these films made it possible to considerably reduce fruit rot compared to the control. But compared to yam starch films, PVC exhibited the best behavior in maintaining fruit weight and firmness. Other studies have shown that the water vapor transmission of a PLA film used to package mushrooms is about four times higher than that of conventional plastic film (Holm and Mortensen, 2004). The water vapor barrier is also shown to be a factor in shelf life and is limited when using bio-based materials for cheese packaging (Holm et al., 2006b). In PLA packaged cheese, moisture loss was the predominant process due to higher internal relative humidity, generated by the high water activity of the cheese (Holm et al., 2006a). The evaluation of the performance of bio-based packaging against lipid oxidation has been investigated by certain authors. The work carried out on cheese packaged in a modified atmosphere bio-based packaging (PLA) and conventional plastic packaging (PET) has shown that there is no significant difference between the proportion of lipid oxidized in each type (Holm et al., 2006b). The study of the effect of PLA on the oxidation of vitamins in food revealed a good protection of ascorbic acid in orange juice (Haugaard et al., 2002) and of α-tocopherol in vinaigrette (Haugaard et al., 2003) compared to polystyrene packaging and other types of conventional plastic packaging. PLA packaging generally had weaker light transmission than the reference packaging (petro-based plastic), which may explain the protection against loss of vitamins (Haugaard et al., 2003). Likewise, more pronounced degradation of riboflavin was observed in yogurt packaged in polystyrene packaging than in PLA. This observation has been attributed to differences in light transmission (Kristensen et al., 2000). Although bio-based packaging has properties necessary for food packaging, it has been proven that these properties are sometimes weak and do not always favor food storage over a long period (Gan and Chow, 2018; Qin et al., 2016; Silva-Pereira et al., 2015). Several studies have therefore been carried out with the aim of improving the properties of bio-based packaging and making it able to preserve food for relatively long period. Various types of packaging from composite bio-based materials with additives have been developed (Table 1). Kanatt and Makwana (2019) have produced food packaging from cellulose incorporated with citric acid and Aloe vera. These authors have found that the packaging produced has antioxidant activity and good mechanical properties. Bio-based food packaging with antioxidant activity has also been developed by Schreiber et al. (2013) from chitosan enriched with gallic acid, which type of packaging significantly reduces peroxidation and rancid reactions during the conservation of ground peanuts. Other technologies have made it possible to develop intelligent bio-based packaging, pH indicator, using natural additives such as red cabbage extract and mulberry extract (Ma et al., 2018; Silva-Pereira et al., 2015) and blueberry powder (Luchese et al., 2017). These studies have shown that bio-based materials can be used in combination with other natural compounds (essential oils, polyphenols, etc.) to produce bio-based packaging with beneficial effects on physicochemical characteristics of foods (Woranuch et al., 2015) and on their conservation (Ma et al., 2018; Schreiber et al., 2013; Silva-Pereira et al., 2015).

Effect of bio-based packaging on the microbiological characteristics of food

Packaging materials play an important role in protecting food from microbial contamination (Faseyi, 1996). Their ability to act as a barrier to microorganisms differs,

Table 1. Synthesis of recent studies performed on effects of bio-based food packaging on food quality.

Bio-based packaging materials	Constituents	Effect of developed bio-based packaging on food characteristics and quality	Reference
Chitosan	Grafting of gallic acid on chitosan	Effect on peanut powder preservation by reducing the levels of thiobarbituric acid-reactive substances, peroxide, and conjugated trienes.	Schreiber et al. (2013)
Starch and chitosan	Chitosan-starch films containing red cabbage extract and mulberry extract for fresh fish conservation	Visual colorimetric indicators of edible films which change color when the pH accompanying deterioration changes.	Silva-Pereira et al. (2015) and Ma et al. (2018)
Chitosan	Chitosan film modified by ferulic acid	Decreased moisture content, water sorption capacity, and mechanical properties but improved oxygen barrier property and antioxidant activity, as well as decreased water vapor barrier property and extensibility	Aljawish et al. (2016) and Woranuch et al. (2015)
PLA (Polylactic acid), lignin and cellulose	PLA based films containing lignin nanoparticle (LNP) and/or cellulose nanocrystal (CNC)	Synergistic effect of the LNPs and CNC which improve antibacterial activity against *Xanthomonas axonopodis pv. vesicatoria* and *X. arboricola pv. pruni bacteria* (bacteria negatively affecting tomato and pepper crops)	Yang et al. (2016a)
Starch and chitosan	Maize starch-based films enriched with chitin nano-whiskers	Antimicrobial activity against *Listeria monocytogenes*	Qin et al. (2016)
PLA	PLA packaging reinforced with cellulose nanocrystals and lignin nanoparticles	Showed an antibacterial activity against *P. syringae pv. tomato*	Yang et al. (2016b)
PLA and cellulose	Addition of acetylated or crystalline nanocellulose as a filler material for PLA films	Improve the barrier properties. reduces oxygen transmission rate (OTR) better than water vapor transmission rate (WVTR). Cellulose nanofillers (reinforcements) act as obstacles to the passage of gases through composite PLA films independently of the shape and source of cellulose nanofillers.	Trifol et al. (2016)
PLA and Cellulose	PLA films with *Zataria multiflora Bioss* essential oil, propolis ethanolic extract and cellulose nanofiber	Antibacterial effect in composite PLA films compared to pure PLA films	Rezaeigolestani et al. (2017)
Starch	Film produced with corn starch, glycerol and blueberry powder (with or without prior fruit bleaching)	Blueberry powder has a potential to be used as pH indicator for intelligent food packaging or even for sensing food deterioration	Luchese et al. (2017)
PLA and chitosan	Polylactic acid with chitosan nanoparticles using polyvinyl alcohol as a plasticizer and polyethylene glycol as crosslinking agent	Increase tensile strength and antimicrobial activity against aerobic microorganisms	Fathima et al. (2018)
PLA and Cellulose	Cellulose nanocrystal containing PLA films	Antimicrobial effect against *Aspergillus niger*	Montes et al. (2018)
Cellulose	Carboxymethyl cellulose-poly vinyl alcohol (CMC-PVA) incorporated with citric acid 4% and *Aloe vera* 1%	Antioxidant and antimicrobial activities against both Gram-positive organisms (*S. aureus, B. cereus*) and Gram-negative organisms (*E. coli, S. oslo, S. weltevreden, S. dysentery, P. fluroscenes, Y. enterocolitica*). Which activities induce shelf life extension during meat conservation.	Kanatt and Makwana (2019)
Chitosan and arabic gum	Chitosan-arabic gum films enriched with cinnamon and clove essential oils	Improve moisture resistance and antimicrobial activity against *Escherichia coli* and *Staphylococcus aureus* compared to pure film of chitosan and the incorporation of these essential oils separately.	Xu et al. (2019)
PLA and cellulose	PLA films containing propolis ethanolic extract, cellulose nanocrystal and Tanacetum balsamite L. essential oil.	Higher antimicrobial effect on vacuum-packed cooked sausages inoculated with Gram-positive bacteria (*Bacillus cereus*) compared to samples inoculated with Gram-negative bacteria	Khosravi et al. (2020)

depending on the material (Almenar et al., 2008). Koide and Shi (2007) reported the effects of a PLA film compared to a conventional plastic film on the microbial quality of green peppers. These authors observed a low coliform load for the samples of green peppers packed in PLA compared to the samples packed in plastic packaging. However, another study reported that vegetables packaged in PLA showed higher fungal development than those packaged in a Polyethylene Terephthalate (PET) (Almenar et al., 2008). Some authors have reported that chitosan-based food packaging materials have good antimicrobial activity. As a result, the shelf life of a food packaged in a chitosan-based package could be extended compared to petro-sourced package. The use of chitosan was examined during storage of mangoes packed in cellulose-based packaging with an upper surface covered with a film of chitosan for some and of conventional plastic for others (Srinivasa et al., 2002). The results showed an extended shelf life of up to 18 days with no microbial growth and no change in flavor. Thus, these authors concluded that chitosan films are a useful alternative to synthetic films for the storage of certain fruits. Furthermore, the addition of starch to conventional plastic films has not increased the growth of bacteria in meat products or on the surface of packaging materials (Bennett and Leitch, 2005; Kim and Pometto, 1994; Strantz and Zottola, 1992). In order to give better antimicrobial activity to bio-based packaging, several recent studies were carried out on the incorporation of antimicrobial agents in bio-based packaging (Table 1). These studies identified migratory and non-migratory systems as the two main types of packaging systems with incorporation of antimicrobial agent (Brody et al., 2001). Migratory system is a system that contains an antimicrobial agent capable of migrating within the package, while non-migratory system contains an antimicrobial agent immobilized on the bio-based packaging. In the case of bio-based packaging with immobilized antimicrobial agent, microbial growth is inhibited when food and packaging material are in direct contact (Appendini and Hotchkiss, 2002; Brody et al., 2001). It has been proven that antimicrobial agents are effectively integrated into bio-based packaging mainly if it derived from polymers such as starch-based and protein-based polysaccharides (Hotchkiss, 1997; Vermeiren et al., 2002). The forms of biodegradable packaging systems with antimicrobial agent are primarily designed to extend the shelf life of food by greatly reducing spoilage reactions and the multiplication of microorganisms (Fathima et al., 2018; Rutot and Dubois, 2004; Xu et al., 2019).

Effect of bio-based packaging on the organoleptic characteristics of food

The ability of bio-based packaging to preserve the organoleptic characteristics of packaged food is an important element and depends on several parameters such as the transmission of gases, odors and light through the packaging (Robertson, 2006). These material transfers induce changes in the sensory profile (color, taste, aroma, texture) of packaged food. The monomers of the bio-based material or the additives incorporated into the polymers can migrate into the food, with organoleptic consequences (Severin et al., 2011). This migration phenomenon is closely linked to the composition of the packaged product (nature, volatility, concentration of molecules). The sorption of certain molecules from food by polymer materials can cause loss of aroma and aromatic imbalance (Zaki, 2008). The capacity of PLA to protect orange juice (Haugaard et al., 2002, 2003), and yogurt (Frederiksen et al., 2003) against discoloration was evaluated in comparison with samples conditioned in polystyrene. It was found that PLA gave better protection against color changes than the references (polystyrene). These results are due to the low light transmission of bio-based packaging (Lennersten and Lingnert, 2000). Bio-based packaging offers protection against changes in the organoleptic characteristics of food comparable to conventional plastics, sometimes even better than plastics (Haugaard et al., 2003; Lennersten and Lingnert, 2000).

ADVANTAGES, LIMITATIONS AND PERSPECTIVES OF BIO-BASED PACKAGING

The responsible use of petroleum resources as well as the reduction of greenhouse gas emissions are essential. This is why it is important to analyze the advantages and disadvantages of bio-based packaging and to use it as much as possible. Packaging made from renewable organic raw materials reduces waste production and protects environment (Naveena and Sharma, 2020). Indeed, bio-based and biodegradable packaging has advantage of being consumed by microorganisms and helping life cycle to continue because they are made of natural materials. When they decompose, they do not release harmful chemicals or gases into the atmosphere, which reduces the carbon footprint. Likewise, they quickly disappear or are recycled for re-use (Asgher et al., 2020, Naveena and Sharma, 2020). However, the mechanical and barrier properties of biodegradable films are low compared to the properties of most petroleum-based food packaging. The properties of these films are improved by the addition of several other biopolymers in the form of composites (Asgher et al., 2020). At the present stage of science, there is very little scientific data on the disadvantages of biodegradable packaging. But it is important to point out that currently, in many countries in the world, food packaging, even if it is biodegradable, does not often go into suitable composting systems, but rather in landfills, without adequate conditions for its decomposition. This phenomenon could also lead, in the

future, to health risks. Furthermore, it is very difficult for consumers to distinguish biobased packaging from those which are not biobased. Thus, for the good development of biobased packaging in all countries of the world, it is necessary to implement good management and recycling systems for food packaging. Likewise, industrial production of biobased food packaging must increasingly focus on agricultural waste and non-food plant resources in order to avoid a negative impact on food availability and food prices.

The great diversity of bio-based materials and the search for an efficient packaging solution with several functions have led scientists to make great progress in the field of bio-based food packaging. Various types of modern packaging have therefore been developed, including active packaging (Oxygen Scavengers, Antimicrobiol) and Modified Atmopheric Packaging (Intelligent packaging, Smart packaging) (Avella et al., 2005; Hijazi, 2014). Active packaging is the incorporation of certain additives/agents into packaging systems with the aim of maintaining or extending the quality and shelf life of the product. Intelligent packaging is a packaging system capable of performing intelligent functions such as detection, tracing, recording and communication (Brody et al., 2008). These functions facilitate decision-making to extend shelf life, improve quality, enhance security, provide information and give warnings about potential problems. Smart packaging is a recent type of food packaging resulting from nanotechnology. It has the capabilities of both intelligent and active packaging. Smart packaging in fact, monitors changes (intelligent function) in the product or the environment and acts on these changes (active function) (Schaefer and Cheung, 2018).

Nanotechnology is one of the recent techniques used for the production of modern packaging such as smart packaging and active packaging. It is a technique that use small particles (materials) of the order of a nanometer (Avella et al., 2005). These nanoparticles present in certain types of modern packaging are sometimes released into food environment and play protective functions for the food. Thus, it is important for science to pay more attention to toxicological effects and the migration of nanoscale reinforcing agents from bio-based packaging materials to food. Likewise, it is necessary for each country to establish regulatory frameworks for the manufacture and marketing of this new generation of packaging solutions.

FUTURE OF BIO-BASED PACKAGING IN AFRICAN CONTEXT

Analysis of the future of bio-based packaging used in food industry in Africa takes into account factors that favor their success and the provisions necessary for their development.

Factors favorable to the success of bio-based food packaging in Africa

Bio-based food packaging offers great opportunities for African countries, especially in the context where food demand continues to increase each year. An appropriate use can promote sustainable socio-economic development in African countries and bring environmental benefits. The prospects for growth in the use of biodegradable packaging in African countries are excellent for the coming years. Several factors favor the success of biodegradable food packaging in Africa.

Legislation: In the aim to reduce plastic pollution, several African countries have put in place regulatory provisions to reduce the use of plastic packaging. Out of 54 African countries, 34 have already passed laws banning plastics. The rest of the continent is making significant efforts to reduce the use. These regulatory provisions implemented in Africa constitute a favorable factor for a successful use of biodegradable packaging in this continent.

Biodiversity and availability of under-exploited biodegradable resources: The whole of Africa and its island had a very rich biodiversity for many decades. It consists of various habitats extended over a vast territory (FAO, 2019). It is therefore possible to produce and use non-food biomass for the manufacture of bio-based packaging. In addition, in many African countries there are traditionally used leaf packaging and under-exploited plant resources such as water hyacinth, cashew apple, post-harvest losses and pineapple residues. These plant resources, which are still under-exploited, can be used in the production of biodegradable food packaging.

The availability of cultivable space for the production of agromaterials: Africa has significant land potential which is still unused (NEPAD, 2013). In 2014, estimates of unexploited arable land were 200 million hectares in sub-Saharan Africa (FAO, 2019). According to the FAO (2019), Africa is the continent with the largest area of uncultivated arable land. The cultivable land (excluding forest areas) in Africa is three times the size of the land cultivated (NEPAD, 2013). These available land resources constitute exploitable factors for the production of agromaterials used in the manufacturing processes of biodegradable food packaging.

A workforce seeking employment: The World Economic Forum's Human Capital Index (2017) finds that Sub-Saharan Africa currently only captures 55% of its human capital potential, compared to a global average of 65%. With more than 60% of its population under the age of 25 years, Sub-Saharan Africa is the world's youngest region. By 2030, the continent's working-age population is set to increase by two-thirds, from 370 million adults in

2010 to over 600 million in 2030 (World Economic Forum, 2017). Therefore, Africa has the workforce that can be trained and educated to participate in the development of the continent. In the context where the employment rate is estimated around 40% among young people on the continent (World Economic Forum, 2017), the biodegradable packaging production chain constitutes then an opportunity to create employment for youth.

Growing consumer food market: Most African people eat a diet generally made of traditional foods, produced by processors and small farmers across the continent (NEPAD, 2013). According to Bricas et al. (2016), the local food market in African countries is not just urban. The rural market is now far from negligible and accounts for almost half of the food market in African countries. This trend is still growing with demography and offers a large market for food products. Thus, this is a factor that could contribute to promoting the use of bio-based food packaging in Africa.

Provisions necessary for the development of bio-based packaging in Africa

The successful development of bio-based materials applicable to food packaging in Africa will offer the opportunity to start a new sector of bio-based packaging and to replace existing conventional packaging. This will contribute to food security in an environmentally friendly way. However, to achieve this successfully on a large scale, an enabling environment is necessary and everyone in the community must play a role. As is already the case in 34 countries in Africa, the decision makers (executive and legislative) of the remaining African countries (20 countries) must apply laws aimed at limiting or stopping the use of packaging made from non-biodegradable resources such as plastic bags. Also, the public authorities of African countries must ensure the proper dissemination and application of the laws that are passed. African states must promote innovation in this field by encouraging the development of companies for bio-based food packaging production. They should also finance research on biodegradable packaging in our different universities. For example, taxes may be created on imported non-biodegradable packaging to support research on biodegradable packaging. Moreover, there must be good collaboration between research and innovation institutions in the field of biodegradable packaging in African countries. The continental initiative called "African Packaging Organization (APO)" could be supported by Non-Governmental Organizations (NGOs) in each country on the continent. These organizations should have representatives in each country and work for the promotion of biodegradable food packaging. Researchers should focus on innovative research by using locally available renewable resources to produce bio-based packaging. Consumers should also be aware of the negative impacts of imported non-biodegradable packaging and should increasingly use biodegradable food packaging.

CONCLUSION

Bio-based packaging is increasingly studied by scientists and there is a large variety of biological materials to be used for the production of food packaging. Among the materials that are available for the production of bio-based food packaging, chitosan and PLA are the most used and have better properties in comparison with other bio-based materials. Depending on the biological materials, these packages interact with the food and can contribute to physicochemical, microbiological and organoleptic changes. At present, the studies that have been carried out on the effects of bio-based packaging on food quality have focused mainly on some types of food (fruits, vegetables, drinks, dairy products, seafood and meat products). Thus, the effects of bio-based packaging on foods such as dough of corn, cassava or cereal, legume and oil mixes need to be documented. The effects of bio-based packaging on these types of food which are widely consumed in Africa must be studied. This could allow the promotion of bio-based food packaging which may not have a negative impact on human health and the environment. Furthermore, the adoption of these types of packaging for food requires appropriate studies mainly on the interaction between food components and biopolymers during and after the treatments that are applied to food.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Application of wedge fracture test for texture analysis in boiled sweetpotato (*Ipomoea batatas*)

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Several instrumental texture analysis methods have been developed for use in sweetpotato. However, there are very few reports on the use of the wedge fracture test. The purpose of the study was to develop a texture analysis method using a wedge fracture and evaluate its performance against compression test in assessing sweetpotato varieties with different cooking times. The optimal cooking time (OCT) of five sweetpotato varieties was determined by boiling 2.5 cm^3 cubes until soft. Samples for texture analysis were prepared under four conditions: 85°C for 10 and 15 min; and 95°C for 5 and 10 min. Peak positive force (firmness) and total work done (toughness) were determined using the wedge fracture texture analysis. The correlation between the OCT and texture measurements was evaluated, and samples incubated at 85°C for 15 min had the highest correlation with OCT (R^2 = 0.725). Using this heat treatment, texture measurements from the wedge fracture were compared to those obtained from a compression test. The wedge fracture test gave significant discrimination of sweetpotato varieties (p ≤ 0.05) while the compression test did not. The wedge fracture test is thus recommended for determining the instrumental firmness of boiled sweetpotato varieties with different cooking times.

Key words: Texture, wedge fracture test, orange-fleshed sweetpotato, optimal cooking time.

INTRODUCTION

Sweetpotato, *Ipomoea batatas* (L) Lam, is ranked as the 5th most important food crop after rice, wheat, maize, and cassava in the developing countries, and ranked seventh in the world food production (FAO, 2016). There is an abundance of white-fleshed sweetpotato (WFSP) varieties across SSA but over the past two decades, the breeding focus has been on producing biofortified orange-fleshed sweetpotato (OFSP) varieties which have enhanced β-

carotene (pro-vitamin A) contents. OFSP is a proven, cost-effective method of providing vitamin A to vulnerable populations, especially children and pregnant women (Low et al., 2007, 2017; Sanginga, 2015). Consumer acceptance of new sweetpotato varieties is a major challenge for adoption in both fresh and processing markets and is dependent on the quality and utilization attributes (Tomlins et al., 2004).

Optimal cooking time (OCT) is an important processing factor. Fast cooking varieties are preferred because they utilize less energy, minimize preparation time, and make more nutritious products since there is less time for nutrient loss, conversion to non-bioavailable forms, and undesirable changes in structure and colour. OCT is commonly determined by probing samples with a fork/knife during boiling (Sjölin et al., 2018). This method is subjective but has been successfully applied by other researchers studying potato and sweetpotato because it is easy to perform, without affecting the cooking process in the rest of the batch (Blahovec and Esmir, 2001; Coelho et al., 2007). It is, however, imperative to calibrate the operators to exert the same amount of force while assessing the extent of cooking, and to minimize fracture of the samples as this will change the heating dynamics and cause a bias in the rate of cooking. OCT has also been determined as the time taken to reach a core temperature of 94 to 96°C (Leighton et al., 2010; Sjölin et al., 2018). This temperature, however, is not a widely accepted indicator for cooking and varies with product. Whichever method of choice, it is important to assess the reproducibility and discriminative power when analyzing a large sample set.

The most common preparation methods in sweetpotato are boiling, steaming, roasting, and frying (Oke and Workneh, 2013). In such cooked products, texture is one of the most important sensory attributes determining consumer acceptance (Laurie et al., 2013; Nwosisi et al., 2019; Tomlins et al., 2004). Texture impacts mouthfeel properties (hardness, gumminess/chewiness, moistness, mealiness, smoothness, and stickiness) and is correlated with several physical properties including dry matter content (mainly starch content) and distribution, starch swelling pressure, cell size, cell wall structure, and composition, and the breakdown of the cell wall middle lamella during cooking (He et al., 2014; Kitahara et al., 2017; Ross et al., 2011).

The sensory texture is commonly assessed by quantitative descriptive analysis (QDA) using a panel of trained individuals. However, QDA is inherently low throughput and relatively expensive to implement (Ross et al., 2010). Several instrumental analysis methods have been developed to correlate and complement sensory evaluation because they are less expensive and have a higher throughput. Texture analysis instruments conduct uniaxial tests in which a single or double compression (texture profile analysis; TPA) is performed. During TPA, the instrument simulates mastication by partially compressing the sample twice, to imitate the first two bites taken, while measuring the changes in force over time (Peleg, 2019). Several textural parameters such as hardness, brittleness, chewiness, gumminess, elasticity, adhesiveness, cohesiveness, and springiness are extrapolated from the texture profile. Laurie et al. (2013) reported that instrumental measurements from a TPA curve can reliably predict sensory textural properties. The single compression tests in sweetpotato have been used successfully by Sato et al. (2018) but also been reported to inadequately predict the sensory response (Leighton et al., 2010).

A wide range of special texture measurement devices and probes have been developed. Flat end cylindrical probes of various diameters have been applied for texture analysis of cooked sweetpotato (Ellong et al., 2014; He et al., 2014; Sajeev et al., 2012; Sato et al., 2018). Blade/Shear probes such as the Kramer cell (multiple blades), Warner Bratzler (single blade) and razor blades have mostly been reported for meat products, with a few reports of their use in sweetpotato (Gallego-Castillo and Ayala-Aponte, 2018; Leighton et al., 2010; Sajeev et al., 2012). A wedge fracture/shearing test first developed by Vincent et al. (1991) utilizes an acrylic blade to cut through a cooked sample. This method is relatively easy to perform, and the acrylic blade is affordable. The test was developed to measure peak force and the total work done. The peak force is the maximum force at the onset of an unstable crack, or the force required for the wedge to initially cut and then force the tissue apart and propagate a crack in the cube ahead of the wedge (Ross et al., 2011; Vincent et al., 1991). This relates to the fracturability of the product; the lower the peak force, the more brittle or crunchy the sample is. Total work done refers to the total energy required to penetrate to a pre-determined distance. This is equated to toughness and is represented by the area under the curve. Newer texture analysis protocols include hardness, which is determined as the peak positive force or the maximum force recorded during the test. In some products, peak force and peak positive force coincide at the same point.

There are few reports on the use of the wedge fracture test in the analysis of sweetpotato texture. Therefore, the objectives of this research were to: (i) develop a wedge fracture test suited for determining firmness/hardness in boiled sweetpotato, and (ii) assess the reliability of the

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wedge fracture against compression test.

METHODOLOGY

Development of a wedge fracture test for firmness determination

Sweetpotato roots were harvested at maturity, from an experimental field trial at the National Crops Resources Research Institute (NaCRRI), Namulonge, Uganda. Five varieties were selected and analyzed 3 days after harvest; Ejumula (orange-fleshed), Kyambogo (white-fleshed), NASPOT 8 (pale orange-fleshed), NASPOT 11 (cream-fleshed), and NAROSPOT 1 (pale yellow-fleshed). Three damage-free, representative sized roots were selected, washed under running tap water to remove surface debris and air-dried.

Optimal cooking time

From each root, cubes of 2.5 x 2.5 x 2.5 cm dimensions (2.5 cm^3) were excised from the middle of each root. The cubes were immersed in a pot of water at 95°C on a gas cooker. The timer was started immediately upon closing the lid. At 10 min, and every 2 to 3 min thereafter, the lid was opened, and the root pieces were probed with a thin wooden stick (toothpick) to assess the extent of cooking. A root was considered cooked when the toothpick was pushed all the way through the center, with minimum resistance. The average time was recorded in min, as the optimal cooking time (OCT).

Heating treatments for texture analysis

To determine the cooking conditions that best discriminate between the textural properties of the sweetpotato varieties, roots from each variety (prepared as above) were subjected to four heat treatments; 85°C for 10 min, 85°C for 15 min, 95°C for 5 min and 95°C for 10 min. The samples were left at room temperature and allowed to cool to a core temperature of 28°C, as determined by using a thermometer probe on replicate samples not used for texture analysis. The choice of temperature/time treatments was based on preliminary findings; boiling for up to 20 min resulted in soft samples with poor discrimination of firmness between varieties, thus the temperatures were reduced slightly, to still maintain conditions closer to home cooking.

Texture analysis

The texture of cooked roots was determined on a TA.XT*Express* texture analyzer (Stable Micro Systems, UK) equipped with a 10-kg load cell. The wedge fracture test makes use of a wedge to cut through a sample at an angle, and force tissue apart while propagating a crack in the cube ahead of the wedge (Ross et al., 2010; Vincent et al., 1991). In these experiments, the wedge fracture test was adapted by cutting the sample once, across the fibres (transversely), with a Perspex blade probe (A/LKB) penetrating the sample with an angle of 34°. The test was conducted at a speed of 2 mm/s to a target distance of 10 mm.

Comparison of wedge fracture and compression tests

To determine the applicability of the wedge fracture method developed in 2.1, it was compared to a compression test, commonly used for sweetpotato (Ellong et al., 2014; He et al., 2014; Sajeev et al., 2012; Sato et al., 2018). A different set of sweetpotato varieties were used, to assess how the test performs over a wide range of samples.

Materials

Sweetpotato roots were obtained from farmers in and around Western Kenya and analyzed 4 days after harvest. Five varieties with varying flesh colours were selected; Kabode (orange-fleshed), Irene (dark orange-fleshed), Bungoma (yellow-fleshed), Namnyekere (cream-fleshed), and Mugande (cream-fleshed). The roots were washed under running tap water to remove surface debris, and air-dried.

OCT and texture analysis

From each variety, five roots were selected, prepared and the OCT determined as outlined earlier. For texture analysis, cubes of 2.5cm^3 size were cut from the middle of each root, heated in a water bath at 85°C for 15 min, and cooled to a core temperature of 28°C. Texture measurements were conducted on five roots from each variety, on a texture analyzer (TA.XT, Stable Micro Systems, UK) equipped with a 50-kg load cell. A shearing/wedge fracture test was performed with an acrylic blade probe (A/LKB) cutting into the sample across the fibers (transversely) to a target distance of 10 mm at a speed of 2 mm/s. A compression test was performed with a 5 cm diameter cylinder probe (P/50); the sample was compressed to a target distance of 6 mm at a test speed of 2 mm/s. A shorter compression distance was used for the compression test to minimize the complete disintegration of the sample during analysis.

Data analysis

For all texture analyses, the data collection and calculations were completed using the Exponent Lite Express software v6.1.16.0 (Stable Micro Systems, UK). Firmness/Hardness was measured as peak positive force while toughness was measured as the total work done, represented by the positive area under the curve. The texture data was analyzed on Minitab 19® Statistical software (www.minitab.com) using ANOVA at the 5% significance level, to determine if the texture method was discriminatory. The Tukey HSD test was conducted to determine which varieties were significantly different.

RESULTS AND DISCUSSION

Effect of various heat treatments on texture

The textural properties were directly affected by the cooking temperature and incubation time. The samples cooked at 95°C for 10 min had the lowest instrumental texture (firmness and toughness) values, that is they were the softest, while those incubated at 85°C for 10 min had the highest texture values (Figure 1). Similarly, in a study by Binner et al. (2000), sweetpotato cooked at a lower temperature of 70°C for 30 min had a firm, non-mealy texture while cooking for only 10 min at 100°C had in a soft, mealy/floury texture.

Firmness decreases as cooking progresses, due to the physical and structural changes that occur as a result of
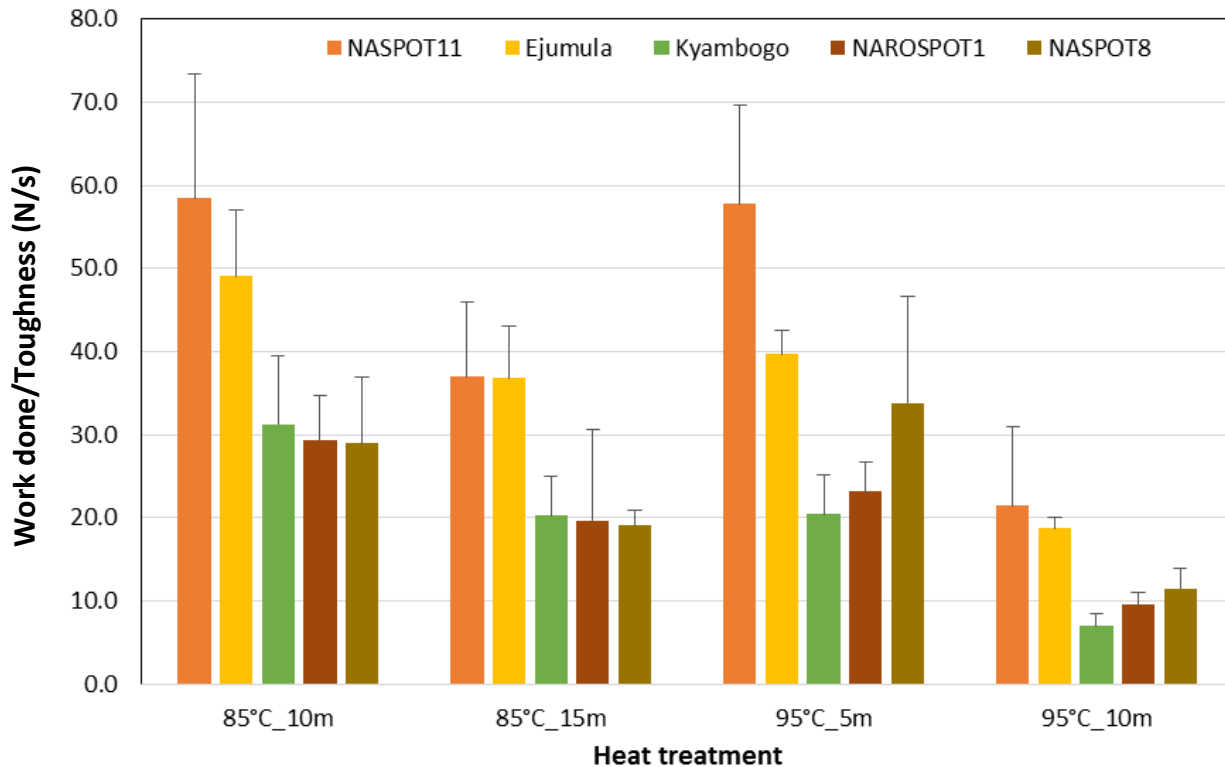
Figure 1. Texture (toughness) of sweetpotato roots prepared by different heat treatments. Graphs represent mean values with standard deviations as error bars.

heat and enzymatic activity. Starch swelling, gelatinization, and hydrolysis associated with changes in cell pressure and cell wall structure are the main contributors to loss of firmness (Gallego-Castillo and Ayala-Aponte, 2018; Sjölin et al., 2018; Valetudie et al., 1999). These biophysical/ biochemical changes are dependent not only on the composition but also on the intensity of cooking.

With regards to individual varieties, the overall ranking (hardest to softest) at 85°C was NASPOT 11 > Ejumula > Kyambogo > NAROSPOT 1 > NASPOT 8, while at 95°C the ranking was NASPOT 11 > Ejumula > NASPOT 8 > NAROSPOT 1 > Kyambogo (Figure 1). At 85°C, NASPOT 8 was the softest, while at 95°C, Kyambogo was the softest. Thus, the extent of softening at the different temperatures appears to be variety-dependent.

At temperatures around 55 to 75°C, cell wall modifying enzymes such as pectin methyl esterases (PMEs) are activated. These modify cell walls by replacing the methyl groups from polyuronic acids with calcium ions, forming stable calcium egg-box structures that strengthen the cell walls (Binner et al., 2000; Liu and Scanlon, 2007; Ross et al., 2010, 2011) and as a result increases firmness. However, cooking at higher temperatures of 80 to 100°C for longer periods results in rapid loss of firmness. In this study, such high temperatures were employed, but with shorter cooking periods to maintain some integrity to the samples, to allow analysis and discrimination amongst

genotypes. Such PME related changes also rely on the initial degree of pectin methylation in the cell walls, which might be variety-dependent. The amount of starch, gelatinization properties, and subsequent hydrolysis is also important to texture development. At temperatures around 60 to 90°C, a thermostable β amylase enzyme hydrolyses gelatinized starch into maltose and maltodextrins which leak out of the cell wall resulting in a reduction of cell swelling pressure. This reduces the degree of cell separation during cooking and leads to a brittle, firm, non-mealy texture (Binner et al., 2000; He et al., 2014). Thus, the rate and extent of hydrolysis have an impact on the cooked texture of sweetpotato storage roots.

Relationship between OCT and texture

The OCT ranged from 12 (NAROSPOT 1) to 54 min (Ejumula), showing a great diversity amongst the varieties (Table 1). Ejumula, an OFSP variety, had the longest cooking time, despite the common perception that orange-fleshed sweetpotatoes cook faster and develop a soft and moist texture due to low dry matter contents (Low et al., 2017; Tumwegamire et al., 2005).

Similarly, Truong et al. (1997) reported that the moist/ soggy orange varieties Hernandez, Beauregard, and

Table 1. Optimal cooking times (OCT) for five sweetpotato varieties.

Sweetpotato variety	Flesh colour	OCT (min)
NAROSPOT1	Pale yellow	12*
Kyambogo	White	18
NASPOT8	Pale orange	30
NASPOT11	Cream	39
Ejumula	Orange	54

*OCT reported as the minimum time required for each variety to cook.

Table 2. Correlation between heat treatment and texture measurements.

Treatment	OCT vs. Firmness (R^2)	OCT vs. Toughness (R^2)
85°C_10 min	0.516	0.566
85°C_15 min	0.715	0.725
95°C_5 min	0.549	0.495
95°C_10 min	0.467	0.699

Table 3. Instrumental texture as determined by wedge fracture and compression tests performed in sweetpotato.

Variety	OCT (min)	Wedge fracture test		Compression test	
		Peak positive force/firmness (N)	Work done/toughness (N. s)	Peak positive force/firmness (N)	Work done/toughness (N. s)
Bungoma	18	22.9 (1.5)[b]*	72.6 (4.4)[b]	229.4 (40.3)[a]	301.3 (42.1)[a]
Irene	24	33.6 (3.9)[ab]	108.0 (13.0)[ab]	227.4 (39.1)[a]	218.8 (40.0)[a]
Kabode	33	39.7 (3.9)[a]	129.8 (16.3)[a]	204.4 (19.5)[a]	247.4 (25.5)[a]
Namnyekere	36	34.0 (2.4)[ab]	113.1 (11.0)[ab]	189.9 (9.7)[a]	210.0 (8.0)[a]
Mugande	40	41.1 (2.8)[a]	128.3 (10.9)[a]	220.8 (22.5)[a]	231.1 (28.6)[a]

*Values reported as mean (standard error of mean). Means that do not share a letter in the same column are significantly different (p<0.05).

Jewel cooked slowly 18, 19, and 20 min, respectively, while some dry/mealy varieties required between 12.5 and 16 min. Ejumula is one of the few high dry matter (>30%), high β carotene landraces released by the sweetpotato programme in Uganda in 2004 (Mwanga et al., 2007). It is liked by consumers in Kenya and Uganda (Tumwegamire et al., 2005).

The OCT is dependent on several factors such as genotype, physiological age, biophysical/biochemical composition, size of roots, cooking method, and the heat-transfer dynamics during cooking. Large roots tend to cook slower than small-sized roots, as they require more time for heat transfer to the interior. There is thus a need to standardize test samples.

When sweetpotato varieties are assessed at a fixed time before they are fully cooked, the firmness values should discriminate between the fast and slow cooking types. Incubation at 85°C for 15 min resulted in the best correlation between OCT and both peak positive force and work done (Table 2). The higher correlations at 85°C_15 min and 95°C_10 min could have been influenced by the lower range of texture values (Figure 1). In all treatments, except 95°C_5 min, the OCT gave slightly higher correlations with the work done values in comparison with peak positive force values. Either of the parameters could be used as reliable indicators for instrumental texture, however, the work done value could be a more reliable indicator of instrumental texture as compared to peak positive force, a one-point measurement.

Comparison of wedge fracture and compression tests

The sweetpotato varieties used for the comparison study showed a variation of OCT (Table 3), with the yellow-fleshed Bungoma cooking the fastest (18 min) and Mugande, a white-fleshed variety, being the slowest (40 min). The peak positive force and work done values were much higher with the compression test (Table 3). This could be due to the larger 5 cm diameter probe, which

Table 4. Correlation between OCT and texture measurements from wedge fracture and compression tests.

Test	OCT vs. Firmness (R^2)	OCT vs. Toughness (R^2)
Wedge fracture	0.742	0.749
Compression	0.372	0.432

measures the resistance of a wider surface area and the underlying tissues.

The wedge fracture test was discriminatory (ANOVA, p ≤ 0.05), thus it was able to distinguish the varieties based on the means of the texture measurements. Bungoma, the fastest cooking variety, had significantly lower texture measurements than Kabode and Mugande as expected. The compression test was not discriminatory; the texture measurements from the five varieties were not significantly different from each other (ANOVA, p ≤ 0.05). The compression test, however, has been reported by other researchers to distinguish varieties; Truong et al. (1997) reported that a 57 mm compression plate resulted in good discrimination of firmness amongst ten sweetpotato varieties, while Laurie et al. (2013) reported that instrumental firmness as determined by a 20 mm diameter probe was more sensitive than sensory firmness in distinguishing twelve sweetpotato varieties. This could be an effect of the varieties used and cooking conditions employed.

The correlation between OCT and texture was higher with the wedge fracture test than with the compression test (Table 4). The OCT, determined by a puncture test, and the wedge fracture measure a more similar property of fracture, whereas the compression test measures deformation properties of the entire sample.

With both tests, there was high intra-variety variation (as shown by SEM values in Table 3). This is typical of root quality traits in most root and tuber crops. Differences in agronomic practices, storage conditions, are all factors that can lead to variability. Many replicates are thus required to account for this. Five replicates were used in this study, other researchers have reported the use of between three up to fifty replicates for each variety (Ali et al., 2012; Laurie et al., 2013; Sato et al., 2018; Truong et al., 1997). Compositional variation has also been observed within the same root, as has been reported in potato tubers (Bandana et al., 2016; Ross et al., 2010). Ross et al. (2010) reported that the stem end of potato tubers of both the Tuberosum and Phureja groups was consistently firmer than the rest of the tuber and could be due to the accumulation of vascular tissue. In sweetpotato, some variations were observed across the root length, although in some varieties it is difficult to distinguish the proximal and distal ends due to the root shape. To avoid such mislabelling, the ends were cut off and all analyses were from the middle part, which represents the bulk of the root. Further studies are required to understand the compositional variation in different varieties.

Conclusion

Wedge fracture is an acceptable method for measuring the firmness of boiled sweetpotato. The wedge fracture correlates well with optimal cooking time when samples are heated at 85°C for 15 min, thus it is ideal for discriminating varieties that vary in cooking times. The work done (positive area under the curve) measurement is a better indicator of firmness, in comparison with peak positive force which is a single point measurement. To be utilized as a substitute for sensory hardness, the performance of the wedge fracture needs to be assessed against sensory data. Also, there is a need to determine its discriminative power on a larger sample size.

CONFLICT OF INTERESTS

The authors have declared any conflict of interests.

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Nutrient and mineral components of wild edible mushrooms from the Kilum-Ijim forest, Cameroon

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Kilum-Ijim forest is a montane forest in the North West Region of Cameroon. Wild edible mushrooms are mostly consumed by the communities of Kilum-Ijim as substitute of meat to obtain protein, hence the need to evaluate the nutrient and mineral components of the species consumed in these communities. The most eight preferred wild mushroom species from ethnomycological studies are: *Polyporus tenuiculus, Termitomyces striatus, Termitomyces macrocarpus, Auricularia polytricha, Laetiporus sulphureus, Termitomyces* sp.1, *Termitomyces* sp.2 and *Polyporus dictyopus* were identified by ITS gene region. These species were analysed for nutrient and mineral contents using standard protocols. Significant differences in nutrient values were demonstrated among these mushroom species. The study results on dry weight basis range from 43.49 to 64.88 for carbohydrates, 6.60 to 30.69 for crude protein, 7.74 to 14.10 for ash, 2.17-3.22 g for fat and 11.60 to 20.69 g per 100 g for crude fibres with significant differences (P< 0.05) between species for each nutrient. The dry matter content ranged from 12.69-17.77 g per 100 g while the total calorie values ranged from 285.16-319.27 Kcal per 100 g. Mineral nutrient analyses also showed that these mushrooms are rich in both macro and micro nutrients. In conclusion, the study revealed that soil inhabiting mushrooms especially the *Termitomyces* species have nutritional values which can greatly supplement diets especially in rural communities.

Key words: Cameroon, Kilum-Ijim Forest, Macrofungi, Mineral content, nutritional analysis.

INTRODUCTION

Edible mushrooms are mostly growing in forests in association with woody parts of trees either as parasite, saprophyte or as symbionts in the soil (Chamberlain et al., 1998). Macrofungi have several ecological functions

in both natural and agroecosystems, and are widely exploited by humans for food and medicinal purposes (Mueller et al., 2007; Osemwegie et al., 2006; Boa, 2004). Mushrooms represent one of the world's greatest untapped resources of nutrition (Wani et al., 2010). More than 2,000 species of mushrooms exist in nature; however, less than 25 species are widely accepted as food and only a few have attained the level of an item of commerce (Lindequist et al., 2005). Mushrooms have probably been a part of the human omnivore diet ever since humans have evolved as a species. Actually, it is quite possible that many fungal species developed the highly nutritious sporocarps concurrently with the evolution of omnivores, as a very small number of animal species has been reported to be strictly mycophagous (Witte and Maschwitz, 2008).

Macrofungi play important roles in the lives of many people around the world. They provide two main benefits; they are a source of food, income and also have medicinal properties. The awareness of wild edible fungi and their importance to people are generally poor. Subsistence uses in developing countries have often been ignored. The importance of wild edible fungi to people in developing countries may also have gone unremarked for the simple reason that many of the collections are for personal use (Yorou and Kesel, 2002).

The most cultivated mushroom worldwide is *Agaricus bisporus*, followed by *Lentinula edodes*, *Pleurotus* spp. and *Flammulina velutipes* (Aida et al., 2009; Chang and Miles, 2004). Newer species or varieties of wild mushrooms like *Tricholoma* spp. (Spain), *Cantharellus* spp., *Hydnum* spp., *Lactarius* spp., *Xerocomus* spp., *Amanita* spp. and *Hygrophorus* spp. (Greece), *Lactarius* spp., *Tricholoma* spp., *Leucopaxillus* spp., *Sarcodon* spp. and *Agaricus* spp. (Portugal), *Ramaria* spp., *Psathyrella* spp. and *Termitomyces* spp. and *Agaricus* spp., *Amanita* spp., *Boletus* spp., *Hydnum* spp., *Hypholoma* spp., *Lactarius* spp., *Pleurotus* spp., *Russula* spp. and *Tricholoma* spp. from various countries have been investigated for their nutritional values and antioxidant activity (Aletor, 1995; Barros et al., 2007; Ouzouni et al., 2007). Despite these advances in mushroom cultivation (Manjunathan and Kaviyarasan, 2011), over 95% of edible mushrooms are still collected from the wild in most African countries.

The people of West African sub-region still rely on wild edible mushrooms for their livelihood especially as a low-cost alternative for animal proteins and flavouring in diets. In addition, they represent a venerable source of subsistent income and incontrovertible raw material in local traditional medicine practice (Osarenkhoe et al., 2014).

In Cameroon, edible and medicinal mushrooms are ubiquitous and constitute a substantial volume of internal trade especially by women in rural areas (Kinge et al., 2014; Teke et al., 2018). Mushrooms have good nutritional value particularly as a source of protein that can enrich human diets, especially in some developing countries where animal protein may not be readily available and are expensive (Heleno et al., 2010). Edible mushrooms have high nutritional values since they are quite rich in protein, vitamins, mineral, fibers and various amino acids (Hyde et al., 2010; Luangharn et al., 2014; Bandara et al., 2015), with an important content of essential amino acids, and low in fat contents. Edible mushrooms also provide a nutritionally significant content of vitamins (B_1, B_2, B_{12}, C, D and E) and have high antioxidant abilities (Manjunathan and Kaviyarasan, 2011; Mattila et al., 2001), although the total nutrient contents vary significantly among species. Hence, due to their high content of nutritional values, edible wild mushrooms are considered in many parts of tropical Africa as "meat" for the poor communities (Kinge et al., 2014). Based on their chemical composition, mushrooms have also been reported as therapeutic foods, useful in preventing diseases such as hypertension, hypercholesterolemia, and cancer (Shashirekha and Rajarathnam, 2011).

Wild edible mushrooms are one of the important natural resources on which the local people of all nationalities rely heavily, and these mushrooms certainly play a role in improving the food nutrition (Yang, 2002). Most people eat mushrooms, mostly because of its flavour, meaty taste and medicinal value (Grangeia, 2011). Hence, this study set out to determine the nutrient and mineral components of some wild edible soil and wood inhabiting mushrooms in order to assess its nutritional value and enhance their cultivation. Thus the objective of this study was to evaluate and compare the nutrients and minerals from soil and wood inhabiting edible mushroom species which would increase our understanding of their nutritional potential and their possibility for cultivation using different substrates and development of new foods in the food industry.

MATERIALS AND METHODS

Study area and sample collection

Fresh fruiting bodies for proximate and nutritional analysis were collected from five community forests in the Kilum-Ijim (Figure 1). Prior to entering into the Kilum-Ijim forest, visitations were made to the various chiefs and administrative authorities within the Kom and Oku districts to sought traditional and administrative permission to use the forest. Five community forests out of 18 were selected based on accessibility after a reconnaissance survey was carried out in the study area.

Nutritional analysis of edible mushrooms

The eight species used for nutritional and mineral analysis were identified using DNA barcoding of the ITS regions using ITS1/ITS 4 primers (Teke et al., 2017). The species were identified as: *Termitomyces microcarpus, Laetiporus sulphureus, Auricularia polytricha, Termitomyces striatus, Polyporus tenuiculus, Polyporus dictyporus, Termitomyces* sp. 1 and *Termitomyces* sp. 2. These
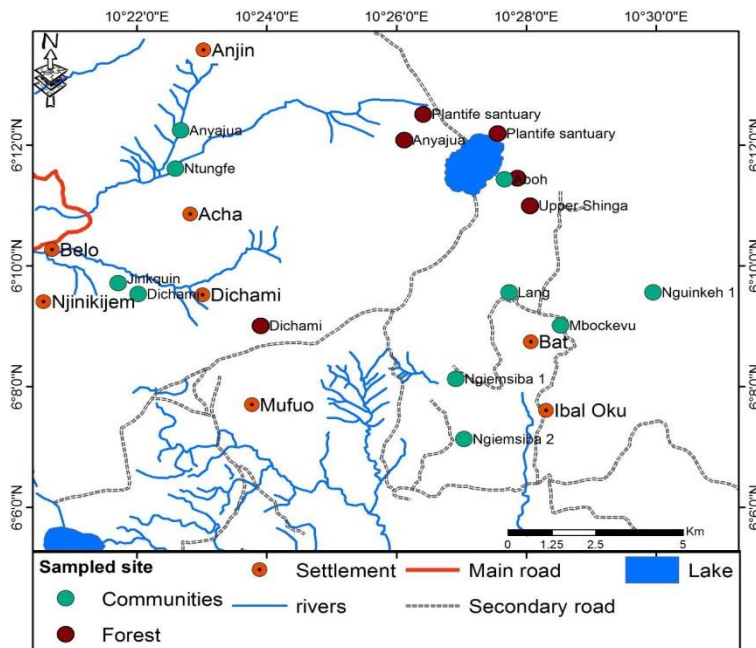
Figure 1. Field sites where samples were collected for Proximate and Mineral Analysis in Kilum-Ijim forest.

eight mushroom species had also been identified as edible from an ethnomycological survey (Teke et al., 2018). One Kg each of dried fruiting bodies of the different samples were separately milled to powder using a blender and stored in air tight bottles at 4°C until use. The samples were then analysed for dry moisture content, crude protein, carbohydrates, energy values, total fat, crude fibre, total ash and mineral contents using standard protocols of Association according to Official and Analytical Chemists (AOAC, 2005).

Dry matter content determination

Dry matter content was determined by oven drying method, in which porcelain crucibles were oven-dried at 110± 5°C until a constant weight was attained. The dishes were cooled in a vacuum desiccator for 30 min and weighed (W_1). This operation was done repeatedly until a constant weight was attained. 1 g of sample was put into the pre-weighed crucibles. The crucibles were then placed in a pre-heated oven and dried for 16 h at 110°C. The crucibles with the samples were removed and immediately transferred into a vacuum desiccator for 30 min and weighed. The heating/cooling weighing procedure was repeated until a constant weight was attained (W_3). The moisture content was calculated using the following equation:

$$Dry\ matter\ content\ (\%) = \frac{W_1 - W_2}{W_1}\ x\ 100$$

(1)

Where:
W_1 = Weight of sample before drying
W_2 = Weight of sample after drying

Determination of crude protein

Crude protein content was determined using modified Folin-Lowry's

method (AOAC, 2005). 100 mg of dried sample was weighed in duplicates into 25 ml falcon tubes. 5 ml of 5% Sodium Dodecyl Sulphate (SDS) was added and allowed to stand for 2hours at room temperature and vortexing every 30 min. After two hours the tubes were placed in the centrifuge and centrifuged at 2000 rpm for 10 min. 50 µl aliquot of the sample was diluted into 950 µl of distilled water. 100 µl aliquot of the diluted sample was then extracted for analysis (according to Folin-Lowry's method). The tubes were allowed to stand for 30 min for colour development. Using a UV-Visible spectrophotometer, the absorbance of the standards and samples versus the blank were measured at 750 nm. A calibration curve was prepared by plotting the absorbance values of the standards against their corresponding protein concentrations. This was used to determine the protein concentrations of the samples. The crude protein content of the samples was calculated using the formulae:

$$Total\ protein\ \left(\frac{g}{100g}\right) = \frac{C\ x\ 100\ x\ DF}{10^6\ x\ W}$$

(2)

Where:
C=Concentration obtained from calibration curve in µg/ml
100=Conversion factor to express protein in g/100 g
DF = Total dilution factor (100)
10^6=Conversion from µg to g
W = Weight of the sample taken

Determination of total fat

The total fat was determined using the Chloroform/Methanol gravimetric method. Two grams of ground mushroom sample was weighed into 50 ml falcon tubes (W_1). To each tube, 32 ml of Clarase solution was added and the tube was gently shaken until the sample was well mixed with the enzyme solution. The sample was incubated in a 50°C water bath for 1 h, with gentle inversion after every 15 min. The digest was quantitatively transferred to a

blender assembly with 80 ml methanol and 40 ml chloroform in a fume hood and blended for 2 min. The solution was centrifuged at 2000 rpm for 15 min to clarify the chloroform. The top aqueous phase was carefully discarded using a tap aspirator pump, leaving a 4mm thick layer of the top phase on the chloroform. A hole was broken into the surface crust using a glass rod and 20 ml of the chloroform extract was pipetted into a pre-weighed dried 50 ml beaker (W_2). The solution was evaporated to dryness by allowing it to stand for three days in a fume hood after which the beaker and fat residue was weighed (W_3). The fat in the residue was calculated using the formulae:

$$Total\ fat\ \left(\frac{g}{100}g\right) = \frac{(W_3 - W_2)}{W_3}\ X\ 100\ x\ 4 \tag{3}$$

Where;
W_3 = Weight of the beaker plus fat residue after drying
W_2 = Weight of the beaker
W_1 = Weight of the sample.
100 = Conversion factor to report results in g/100 g
4 = Factor of volume extract in chloroform taken for evaporation

Determination of total ash

Crucibles were heated for 3 h in a muffle furnace at 500°C removed from muffle furnace cooled in a desiccator and weighed (W_1). One gram of mushroom sample was weighed into the crucible and the weight taken (W_2). The crucible was placed over a hot plate at 90°C until the entire sample was completely charred. The charred samples were incinerated in a muffle furnace at 550°C for 5 h until residue was completely white or nearly white in colour. The crucibles were then cooled in a desiccator and weighed (W_3). The total ash was calculated as follows;

$$Ash\ content\ \left(\frac{g}{100}g\right) = \frac{(W_3 - W_2)}{W_2 - W_1}X\ 100 \tag{4}$$

Where:
W_3 = Weight of crucible + ash sample
W_1 = Weight of crucible
W_2 = Weight of crucible + dried sample
100 = Conversion factor to report results in g/100 g

Determination of crude fibre

Two grams for moisture contents and fat free sample was weighed, treated with 0.255 N sulphuric acid and 0.313 N sodium hydroxide and washed with ethanol and ether, boiled for 30 min, filtered and washed again with boiling 1.25% sulphuric acid, water and alcohol. The residue was then transferred to a preweighed crucible (W_1), dried overnight at 80-100°C and weighed (W_2). The crucible containing the ash was incinerated in a muffle furnace at 600°C for 6 h, cooled and weighed again (W_3) and crude fibre content calculated thus:

$$Crude\ fibre\ \left(\frac{g}{100}g\right) = \frac{(Wt\ of\ crucible\ before\ ashing - Wt\ of\ crucible\ after\ ashing\ )}{Weight\ of\ sample} \tag{5}$$

Determination of available carbohydrate

The content of the available carbohydrate was determined indirectly by difference (FAO, 2003).

$$Available\ Carbohydrate = 100 - (Total\ Lipid + Total\ Protein + Ash + Crude\ Fibre) \tag{6}$$

Determination of energy value

Energy value was determined using the Atwater factor method described by Onyeike et al. (1995).

$$Energy\ Value\ \left(\frac{kcal}{100g\ sample}\right) = 4\ X(Protein) + 9\ X(fat) + 4\ X(carbohydrate) \tag{7}$$

Determination of mineral contents

Sample preparation for determination of mineral nutrients

One gram of oven dried sample was weighed and put into a digestion tube. 5 ml of concentrated HNO_3 and 1 ml of 30% hydrogen peroxide was added into the tube. The tube was allowed to stand overnight in a fume hood. The digestion tube was then placed into a block digester and digested. Complete digestion was attained when the residue was clear or colourless. The tube was then removed from the digester and allowed to cool. The digest was transferred into a 50mL volumetric flask. Distilled water was used to dilute the digest to the 50 ml mark.

Mineral nutrients analyses

The mineral nutrients were determined using Atomic Absorption Spectrometer (AAS). Aliquots of the solution was aspirated to the AAS for determination of; calcium (Ca), zinc (Zn), magnesium (Mg), sodium (Na), Potassium (k), Iron (Fe) and copper (Cu). Calibration of the AAS was done using working standards prepared from commercially available standard solutions. The most appropriate wavelength, hallow cathode lamb current, flow rate and other AAS instrument parameters for minerals were selected as given in the instrument user's manual for each mineral. Each value was the mean of three replicate determinations ± standard deviation.
   Phosphorus was determined by spectrophotometric method in which phosphorus reacts with molybdovanadate reagent (ASEAN, 2011). The yellow colouration formed from this reaction is directly related with the amount of phosphorus in the sample and the absorbance measured at 400 nm. To each flask, 10 ml of $6NHNO_3$ was added followed by 10mL each of 0.25% ammonium monovadate and 2.5% of sodium molybdate and diluted with distilled water to the mark. The flasks were well mixed and allowed to stand for 15 min for colour development. The absorbance of the resulting yellow solution was measured at 400 nm. The content of phosphorus present in the sample was calculated using the formula:

$$P\ \left(\frac{g}{100g}\right) = \frac{C\ x\ V\ x\ 100}{V1\ x\ W} \tag{8}$$

Where:
C= Concentration of phosphorus obtained from standard curve in µg/ml
V = Final volume of the extracted solution in ml
V_1= Volume of solution taken in ml
100 = Conversion factor to report results in g/100 g
W = Weight of sample

Statistical analysis

All nutrient analyses for the mushrooms studied were performed in triplicates. All data were subjected to one-way analysis of variance (ANOVA). Results are expressed as mean values and standard

Table 1. Some properties of analyzed mushroom species.

Name	Family	Substrate	Edibility
Termitomyces sp. 1	Lyophyllacceae	Soil	Edible
Termitomyces microcarpus	Lyophyllacceae	Soil	Edible/Medicinal
Termitomyces sp.2	Lyophyllacceae	Soil	Edible
Laetiporus sulphureus	Polyporaceae	Deadwood	Edible/Medicinal
Auricularia polytricha	Auriculariaceae	Deadwood	Edible/Medicinal
Termitomyces striatus	Lyophyllacceae	Soil	Edible
Polyporus tenuiculus	Polyporaceae	Deadwood	Edible
Polyporus dictyopus	Polyporaceae	Deadwood	Edible
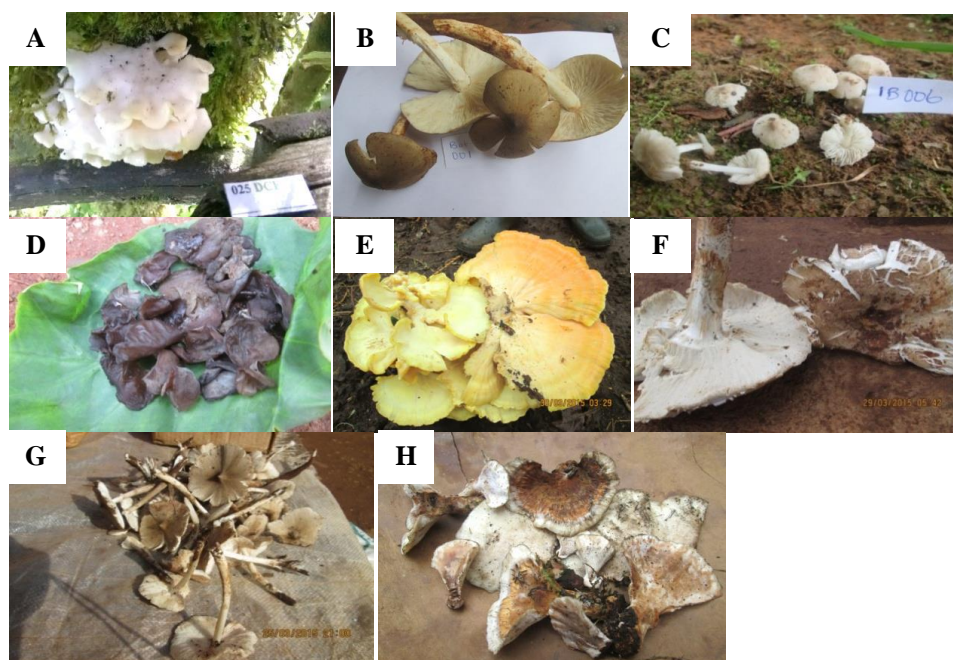
Figure 2. Fruiting bodies of edible mushroom species collected from the Kilum-Ijim forest of the Northwest Region of Cameroon. **(A)** *Polyporus tenuiculus* **(B)** *Termitomyces striatus* **(C)** *Termitomyces microcarpus.* **(D)** *Auricularia polytricha* **(E)** *Laetiporus sulphureus* **(F)** *Termitomyces sp.1* **(G)** *Termitomyces sp.2* **(H)** *Polyporus dictyopus*

deviation (SD) using Minitab software version 16, followed by Tukey method to compare treatment means at p<0.05.

RESULTS

Nutrient contents of edible mushrooms

Table 1 and Figure 2 shows the properties and pictures of the eight mushroom species reported as edible from ethnomycological survey which were used in analysing for the proximate and mineral compositions.

Proximate contents of edible mushrooms

The proximate composition and calculated energy value of edible mushroom species from the Kilum-Ijim forest are shown in Table 2. Dry matter content ranged from 17.77% in *P. dictyopus* to 12.69% in *A. polytricha*. With the exception of *P. dictyopus* which showed significant difference in dry matter content of the species studied, no significant differences were observed in the dry matter contents amongst the other species. Crude protein content of studied mushrooms ranged from 6.6 g/100 g in *P. dictyopus* to 30.69 g/100 g in *T. microcarpus.* Carbohydrate content ranged from 43.49 g/100 g in *Termitomyces sp.* to 64.88 g/100 g in *L. sulphureus.* Crude fat content ranged from 2.17 g/100 g in *T. microcarpus* to 3.22 g/10 0g in *P. tenuiculus.* Ash content varied between 7.74 g/100 g in *A. polytricha* and 14.10 g/100 g in *P. dictyopus* while crude fibre content ranged

Table 2. Proximate composition of wild edible mushroom species from the Kilum-Ijim forest.

Mushroom species	Dry matter content	Dry weight basis(g/100 g)					
		Carbohydrate	Crude Protein	Crude Fat	Ash	Crude Fibre	Energy Kcal/100 g
Termitomyces sp. 1	16.97[a,b]±0.58	43.49[d]±2.70	28.24[a]±0.75	2.38[a]±0.32	12.26[a,b]±1.45	13.63[c,d]±0.76	308.32[a,b]±5.57
Termitomyces microcarpus	15.56[a,b,c]±0.51	44.23[d]±1.83	30.69[a]±0.71	2.17[a]±0.36	11.30[a,b,c]±0.38	11.60[d]±1.60	319.27[a]±8.19
Termitomyces sp. 2	16.09[a,b]±0.88	48.54[c,d]±1.38	21.26[b]±0.56	2.23[a]±0.28	11.03[a,b,c]±1.36	15.94[b,c]±1.13	308.30[a,b]±8.46
Laetiporus sulphureus	16.40[a,b]±1.53	64.88[a]±0.66	8.62[d,e]±0.57	3.07[a]±0.31	8.19[b,c]±0.74	15.24[b,c,d]±1.50	321.67[a]±4.08
Auricularia polytricha	12.69[a]±0.74	51.23[c]±1.12	17.44[c]±1.65	2.91[a]±0.61	7.74[c]±1.20	20.69[a]±1.20	301.51[a,b]±12.90
Termitomyces striatus	14.41[a,b]±1.13	46.82[c,d]±2.84	21.76[b]±1.45	2.40[a]±0.37	12.33[a,b]±1.50	16.70[b,c]±0.55	295.88[a,b]±3.63
Polyporus tenuiculus	17.02[a,b]±0.97	58.84[a,b]±1.72	10.89[d]±0.62	3.22[a]±0.17	11.57[a,b,c]±1.83	15.48[b,c]±0.59	299.49[a,b]±18.02
Polyporus dictyopus	17.77[c]±0.20	58.29[b]±1.62	6.60[e]±0.95	2.84[a]±0.31	14.10[a]±1.28	18.17[a,b]±0.92	285.16[b]±7.38

Data are means (±S.D) of triplicate values; means along a column with the same letters are not significantly different from each other at P<0.05.

Table 3. Macro mineral composition of wild edible mushroom species from the Kilum-Ijim forest.

Mushroom species	Dry weight basis(mg/100 g)				
	Calcium (Ca)	Potassium (K)	Magnesium (Mg)	Phosphorus (P)	Sodium (Na)
Termitomyces sp.1	25.93[e]±0.81	1179.63[b]±6.17	29.11[d]±1.10	776.82[b]±12.51	11.19[a,b]±0.30
Termitomyces microcarpus	37.47[d]±0.46	1112.76[b]±28.41	39.03[c,d]±0.37	898.17[a]±3.44	12.91[a]±0.24
Termitomyces sp. 2	49.31[c]±0.73	1200.28[b]±31.07	50.75[c]±1.36	925.69[a]±11.08	11.21[a,b]±0.82
Laetiporus sulphureus	13.04[f]±0.11	433.62[c]±4.28	13.85[e]±0.79	542.88[e]±4.26	4.20[d]±0.58
Auricularia polytricha	88.62[a]±1.82	294.00[d]±7.25	83.54[a]±4.07	623.96[d]±11.73	10.91[a,b]±0.28
Termitomyces striatus	26.39[e]±0.98	1450.44[a]±36.88	28.47[d]±1.63	739.06[b,c]±10.31	12.31[a]±0.33
Polyporus tenuiculus	90.95[a]±1.62	428.41[c]±8.80	94.48[a]±4.14	592.25[d,e]±10.97	9.70[b,c]±0.54
Polyporus dictyopus	65.31[b]±1.89	239.45[d]±7.03	64.47[b]±1.16	684.21[c]±10.54	7.95[c]±0.19

Data are means (±SD) of triplicate values; means along a column with the same letters are not significantly different from each other at P < 0.05.

from 11.60 g/100 g in *T. microcarpus* to 18.17g/100g in *P. dictyopus*. It was observed that the *Termitomyces* species differed significantly in crude protein content from all the other species. The mean content of crude fat showed no significant difference amongst all the species. However, significant differences were observed amongst species in ash and crude fibre contents. The studied mushroom species proved to be high in energy content ranging from 285.16 Kcal/100 g in *P. dictyopus* to 321.67 Kcal/100 g in *L. sulphureus*.

Some macro mineral nutrient contents of edible mushrooms

Macro mineral compositions of the edible mushrooms are presented in Table 3. Macro mineral contents were predominantly high in

Table 4. Some trace element composition of wild edible mushroom species from the Kilum-Ijim forest.

Mushroom species	Dry weight basis(mg/100 g)		
	Copper (Cu)	Iron (Fe)	Zinc (Zn)
Termitomyces sp. 1	3.53^{a,b}±0.36	19.09^{c}±1.09	7.24^{b}±0.04
Termitomyces microcarpus	3.90^{a}±0.22	20.86^{c}±1.24	8.13^{b}±0.14
Termitomyces sp. 2	3.04^{a,b}±0.35	36.01^{a}±0.15	10.80^{a}±0.36
Laetiporus sulphureus	1.15^{c}±0.06	8.69^{d,e}±0.46	2.66^{d}±0.18
Auricularia polytricha	0.14^{c}±0.02	17.64^{c}±0.31	1.51^{e}±0.21
Termitomyces striatus	2.41^{b}±0.24	27.77^{b}±1.10	4.90^{c}±0.04
Polyporus tenuiculus	0.86^{c}±0.07	6.92^{e}±0.05	4.82^{c}±0.20
Polyporus dictyopus	0.78^{c}±0.01	11.76^{d}±0.37	1.31^{e}±0.02

Data are means (±S.D) of triplicate values; means along a column with the same letters are not significantly different from each other at $P<0.05$.

potassium and phosphorus when compared with Calcium, Magnesium and Sodium.

Phosphorus concentrations ranged from 542.88 mg/100 g in *L. sulphureus* to 898.17mg/100g in *T. microcarpus*. Calcium and Magnesium contents ranged from 13.04 mg/100 g and 13.85 mg/100 g in *L. sulphureus* to 90.95 mg/100 g and 94.48 mg/100 g in *P. tenuiculus* respectively recording significant differences among the species. However, *P. tenuiculus* and *A. polytricha* recorded no significant differences from each other in Calcium and Magnesium contents. Potassium ranged from 239.45 mg/100 g in *P. dictyopus* to 1450 mg/100 g in *T. striatus*. *Termitomyces* species recorded no significant differences from each other in Potassium content, but where significantly different from the other species. Sodium content was very low in all the mushrooms studied ranging from 4.2 mg/100 g in *L. sulphureus* to 12.91 in *T. microcarpus*. However, *Termitomyces* species recorded no significant differences from each other but were significantly different from the other species. Overall, *L. sulphureus* is very low in macromineral concentrations while *T. microcarpus* is very rich in macrominerals. Our results also showed that soil-inhabiting macrofungi species *(Termitomyces* sp.1, *T. microcarpus, Termitomyces* sp.2 and *Termitomyces striatus)* showed higher levels of Potassium and Phosphorus than the wood-inhabiting species (*L. sulphureus, A.polytricha, P. tenuiculus* and *P. dictyopus).*

Some micromineral nutrient contents of edible mushroom species

The mean values of micro mineral contents of Copper, Iron and Zinc of edible mushrooms are presented in Table 4. Micromineral contents for copper ranged from 0.14 mg/100 g in *A.polytricha* to 3.90 mg/100 g in *Termitomyces microcarpus* with significant differences from each other. Iron content ranged from 6.92 mg/100 g in *P. dictyopus* to 36.01 in *Termitomyces* sp. 2.

Termitomyces sp. 2 recorded a very high iron content with significant difference from the other species analysed. Zinc concentrations ranged from 1.31 mg/100 g in *P. dictyopus* to 10.80mg/100g in *Termitomyces* sp 2. It was observed that soil inhabiting fungi were richer in micro minerals than their wood-inhabiting counterparts.

DISCUSSION

Mushrooms contribute enormously to the supply of nutrients in our diet. They are considered to be good sources of carbohydrates, proteins, fats and minerals. Results from our study revealed that the soil inhabiting mushrooms were higher in nutrient content than their wood inhabiting counterparts. The chemical composition of mushrooms varies depending on the substrate, species of mushroom, harvest time and storage conditions after harvest (Adejumo and Awosanya, 2005; Guillamón et al., 2010). The nutrient contents of the wild mushrooms studied were generally high. This may be due to the fact that the Kilum-Ijim forest is a humid zone. This is similar to the findings of (Colak et al., 2009), who reported that mushrooms from humid zones had high concentration of nutrients due to the high organic matter content of the soil. Different species of wild mushrooms had varied nutrient composition probably due to species or strain differences (Mattila et al., 2001; Mshandete and Cuff, 2007).

Dry matter content ranged from 17.77% in *P. dictyopus* to 12.69% in *A. polytricha.* This difference may have probably been caused by fluctuations in environmental factors during growth and storage therefore affecting metabolism (Mattila et al., 2001). Our study revealed that the dry matter contents of the wild mushroom studied were relatively high. Similar results in wild mushrooms have been reported by previous authors in other parts of the world (Sanmee et al., 2003; Saiqa et al., 2008). The protein content of wild mushrooms in this study ranged from 6.6 g/100 g in *P. dictyopus* to 30.69 g/100 g in *T.*

microcarpus. Protein content of mushrooms may vary according to the genetic structure of species, the physical and chemical differences in the growing medium (Sanmee et al., 2003; Ragunathan and Swaminathan, 2003). Variations in protein contents in mushrooms may also be due to species/strain, stage of development, size of the pileus and the method of analysis (Bernas et al., 2006).

Results obtained from this study revealed that the wild mushrooms studied were found to be rich in proteins but with very low fat contents. This finding is similar to those of Barros et al. (2008) who reported that wild mushrooms were richer sources of protein and had a lower amount of fat than commercial mushrooms. The protein content of *P. tenuiculus* recorded in this study was 10.89±0.62 g/100 g. This results however differed from that obtained by Nakalembe et al. (2015) who had protein content values for *P. tenuiculus* species from Uganda ranging from of 11.56% for subhumid species to 16.86% for humid species. Mushroom protein is generally higher than those of green vegetables and oranges (Jonathan, 2002).

Proximate analysis of *T. microcarpus* revealed carbohydrate content of 44.23±1.83 g/100 g, crude protein content of 30.69±0.71 g/100 g, crude lipid content of 2.17±0.36, ash content of 11.30±0.38 g/100 g and crude fibre content of 11.60±1.60 g/100 g. All these results are closely similar with that of Nabubuya et al. (2010) who studied the nutritional properties of *T. microcarpus* in Uganda. The values of the polypore mushroom *A. polytricha* analyzed were compared with those carried out by Usha and Saguna (2014). Our study revealed slight variations for dry matter content, ash and crude fibre contents while high variations were noticed for carbohydrates, protein and fat. Nevertheless, our findings on protein and fat content were similar to those of Asaduzzaman et al. (2009) on their study on nutrient composition of *A. polytricha* mushroom. Based on ash content, (Varo et al., 1980) reported ash content of edible fungi ranging from 5 g/100 g to 13 g/100 g. Our findings revealed that the ash contents were within this range with the exception of *P. dictyopus* which had an ash content of 14.10 g/100 g.

Mushrooms are generally considered as low calorie diets. Calculated energy values of edible wild mushrooms studied varied from 285.16 kcal/100 g to 321.67 kcal/100 g on dry matter basis confirming them as low calorie source. These values fall slightly below that of cereals (millet; 341 kcal and maize 349 kcal) (FAO, 1972). Similar studies from different parts of the world have also revealed high energy values in mushrooms ranging from 367.9-450.2 kcal/100 g (32-33). Though *P. dictyopus* has relatively low crude protein content of 6.6 g/100 g, it is relatively rich in carbohydrate; 58.29 g/100 g; ash 14.1 g/100 g and crude fibre 18.17 g/100 g. It is also a very low source of fat 2.84 g/100 g and energy 285.16 Kcal/100 g. *P. dictyopus* was highly cherished as meat by

the Kilum-Ijim inhabitants due to its taste and tender nature.

The wild mushrooms reported in this study were predominantly rich in potassium and phosphorus compared to the other macro minerals. This is in agreement with studies reported by different authors on mushrooms (Mattila et al., 2001; Colak et al., 2009; Barros et al., 2008; Palazzolo et al., 2012). Potassium is an important electrolyte in the body and is the major cation within cells. It functions in reducing the effect of salt on blood pressure. All the *Termitomyces* species studied showed high concentrations of mineral nutrients. This is in agreement with (Mattila et al., 2001) who reported that *Termitomyces* species were generally rich in minerals such as potassium, calcium magnesium and iron. Manzi et al. (1999) reported that calcium levels are not so high in mushrooms. Calcium level in this study, varied from 13.04 mg/100 g to 90.95 mg/100 mg. However, reported literature range for calcium in mushrooms varies from 1.8 mg/100 g to 59.0 mg/100 g (Falandysz et al., 2001). Magnesium levels in this study ranged from 13.85 mg/100 g to 94.48 mg/100 g. These results differ with those of Nakalembe et al. (2015) who reported magnesium values ranging from 7.14-31.9 mg/100 g in some wild mushroom species from Uganga. However, reported literature ranges magnesium contents in mushrooms from 60 mg/100 g to 250 mg/100 g (Bakken and Oslen, 1990). Sodium concentrations were relatively low in this study ranging from 4.2 mg/100 g to 12.91 mg/100 g. This supports previous findings that sodium is relatively less in mushroom species and therefore of great benefit to patients with hypertension (Feldman et al., 1986).

Among the trace elements studied, Fe content was higher (6.92 mg/100 g -36.01 mg/100 g) than other trace elements. Nevertheless, range of reported literature values vary between 1.46 mg/100 g-83.5 mg/100 g (Tuzen, 2003). Copper is the third most abundant trace element in the body and plays a role in protecting the cardiovascular, skeletal and nervous systems. The copper range in our study varied from 0.14 mg/100 g to 3.9 mg/100 g. The recommended daily intake of copper for all age groups is 2 mg/day. However, pregnant and lactating mothers need 1 mg/100 g of copper daily (Food and Nutrition Board, 2001). Copper contents in mushrooms might vary due to the habitat and substrate of the mushrooms. Very low copper contents were reported (Nakalembe et al., 2015). On the contrary, various studies from different parts of the world have also reported high copper contents in mushrooms (Colak et al., 2009; Nabubuya et al., 2010). Zinc content in this study varied from 1.3 mg/100 g to 10.8 mg/100 g. Zinc is an important element in cellular metabolism involving cell division, wound healing and protein synthesis (Heyneman, 1996). The recommended daily intake of zinc is 15 mg/day (Food and Nutrition Board, 2001). Reported literature range of Zinc contents in mushrooms

is between 2.98 and 15.8 mg (Islolu et al., 2001). Nevertheless, (Nakalembe et al., 2015) reported zinc content values of studied mushrooms in Uganda as low as 0.56 to 1.1 mg/100 g.

Conclusion

From the results obtained, it can be seen that all the mushroom species can be used as nutrient sources to upgrade the diet of the communities. These high nutritional qualities and unique flavors of the studied mushrooms are likely to be poorly known and to be lost if they are not documented, so it is imperative that a nutritional database of these mushrooms is set up to collect and improve the characteristics of these unique species and for their eventual domestication.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Marketing potential of improved dried sardine (*Sardinella gibossa*) and capelin (*Mallotus villosus*) in the Southern Kenyan coast

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Traditional dried small fish are an important source of protein for low income people in many developing countries. The aim of this study was to determine marketing potential of improved dried sardine and capelin as new products in markets accustomed to traditional dried small fish. One hundred and twenty participants were recruited among shoppers at supermarkets and open-air markets in Kenya. Each participant received 500 g of each product to be prepared and consumed at home, before evaluating acceptability and willingness to buy. The products obtained high acceptability ratings. Middle income classes were willing to pay up to USD 6 for 500 g of capelin but USD 4 for sardine, while low income classes were willing to pay up to USD 4 the reference price for both products. There is market potential for new dried small fish products that are of improved quality among consumers accustomed to traditionally dried fish.

Key words: Marketing, capelin, sardine, acceptability, willingness to buy.

INTRODUCTION

In Eastern Africa, particularly Kenya, Uganda and Tanzania, there is a high demand for dried fish, mainly small pelagic species (IOC, 2012). Originally, the main market for small pelagic fish was the animal feeds industry. However, due to an increase in human population, reduced availability of high value fish species in local markets and improved fish drying methods, over 80% of small pelagic fish now goes to human consumption (IOC, 2012). Consumer preference for dried small pelagic fish is not only because of the flavor, but also the reasonable price, availability and stability during storage (Oduor-Odote et al., 2010). Dried small pelagic fish are traditionally sold in open-air markets in small portions to meet the needs of the low income class (FAO, 2007; Oduor-Odote et al., 2010).

The growth of the middle class in East Africa

(African Development Bank, 2014) and reduced availability of high value species (IOC, 2012) has resulted in a demand for premium dried small pelagic fish. Small pelagic fish dried on improved traditional racks raised on ventilated platforms in open-air, are widely available in open-air markets (Oduor-Odote et al., 2010). But their quality is still uncertain owing to dependence on weather conditions and mostly it does not meet the local food regulation standards (Kenya Bureau of Standards, 2015; Langat and Rey, 1999). Quality uncertainty notwithstanding, small quantities of packed fresh water dagaa (*Rastrineobola argentea*) dried on racks have gained access to national retail stores, largely supermarkets, although a much higher proportion is still sold unpackaged in open-air markets.

There is a growing awareness of the nutritional and health benefits associated with fish consumption, especially the omega-3 polyunsaturated fatty acids (Bilgin et al., 2008; Stołyhwo et al., 2006). Dried small fish are highly nutritious (Jain and Pathare, 2007) and improving the quality, and marketing in national retail stores is likely to increase consumption among the middle class. This will raise the value of the fishery thereby creating more employment and higher income along the value chain, especially among women who play an important role in the processing and marketing of this fishery (Schuurhuizen et al., 2006).

Fresh water dagaa (*R. argentea*) landed from the Kenyan part of Lake Victoria was about 92,000 MT comprising about 54% of the total catch of fish in Kenya (Lake Victoria Basin Commission, 2015; Munguti et al., 2014) and sardine landings estimated at 535 tons being 6% of 8,947 tons of artisanal marine fish landed (Warui, 2014) cannot meet the existing demand. Most developing countries import low value fish while they export more valuable species landed from their waters. In 2008, 75% of fishery exports (in value terms) from developing countries were exported to developed countries, while 40% of fish they imported (in value terms) for local consumption (mainly low-priced small pelagic and also high-value species for their processing industries) originated from the developed countries (FAO, 2010). Capelin landing in Iceland has exceeded half a million tons in recent years (Statistics Iceland, 2015). Capelin is not used in Iceland for human consumption and most of it is reduced to fish meal and oil (Statistics Iceland, 2015; Shahidi et al., 1995). Therefore, there is a potential to introduce dried capelin as a new product into the East African markets.

The choice and acceptability of a food product is mainly based on sensory properties. If a product has low sensory acceptability, no brand or nutritional and/or health benefit promise will manage to get it accepted by consumers (Sosa et al., 2008; Hough et al., 2006). But if a product has high sensory acceptability, there are additional issues that have to be resolved to ensure overall acceptability, for instance packaging, price,

convenience and cultural habits. In the East African markets, fish price is a major determinant of consumer purchasing decisions (IOC, 2012). Before deciding on the introduction of a new product into the market, it is necessary to obtain information about sensory acceptability and possible pricing of the product (Grunert et al., 2009; Sosa et al., 2008). Such information can also aid in deciding on the launching strategy.

Home use tests and standardized situation tests are universally used in consumer research (Boutrolle et al., 2007; Sosa et al., 2008). Home use tests are more reliable as they are conducted in a setting where the product being tested is normally consumed (Boutrolle et al., 2007; Boutrolle et al., 2005). Larger amounts of products tend to be consumed in home use test and consumers are free to choose when to prepare and consume the product (Boutrolle et al., 2007, 2005). Since dried small fish are mainly cooked and consumed in the homes as part of the main course of a meal, home use test was found to be ideal for the current study. In Kenya, the majority of low income consumers shop for food in open-air markets whereas middle income groups especially in towns do most of their shopping in supermarkets. Therefore, Mombasa city and Kwale County in Kenya were selected for the study. Mombasa is cosmopolitan in nature and hosts the main supermarkets along the Kenyan coast, with the majority of its population belonging to middle income class (Ipsos-Synovate, 2013; Kenya National Bureau of Statistics, 2015). The main sardine landing beaches along the Kenyan coast are in Kwale County where consumption of dried sardine is widespread. Majority of the population in Kwale belong to the low income class (Ipsos-Synovate, 2013; Kenya National Bureau of Statistics, 2015).

The objective of this study was to determine the marketing potential of dried sardine of improved quality and indoor dried capelin among low and middle income consumers presumed to be represented by respondents shopping in open-air markets and supermarkets, respectively. The information is necessary to evaluate the feasibility of improving drying methods and packaging of sardine, and the introduction of new dried fish products such as capelin to the markets accustomed to traditionally dried small fish.

MATERIALS AND METHODS

Samples

Sardine were dried on raised rack drier in Mombasa, Kenya and packed in sealed polyethylene bags weighing 500 g each before the study (water content 24%, fat 9%). Capelin were dried under controlled drying conditions (Cyprian et al., 2015) in Iceland and transported by air freight to Mombasa Kenya. Capelin (water content 19.5%, fat 27%) was packaged in the same way as sardine in polyethylene bags weighing 500 g. Processing and packaging complied with local food regulations (Kenya Bureau of Standards, 2015; Langat and Rey, 1999).

Subjects/Respondents

The study was carried out in Mombasa city and Kwale County that are located in southern part of the Kenyan coast. Participants were recruited among shoppers in three supermarkets in Mombasa and three open-air markets in Kwale County over a four week period. They were adults willing to take part in the study. Their contact details for instance phone number and place of residence were obtained. In the open-air markets, a local person from each area was hired during the period of study to collect completed questionnaires. Participants shopping in supermarkets returned completed questionnaire at the supermarkets and those who returned completed questionnaires could win a prize which were announced in the radio. A total of 120 consumers participated; 60 supermarket shoppers and 60 open-air market shoppers.

Evaluation protocol

The participants among shoppers in the open-air markets were visited in their homes twice, while those from supermarkets returned completed questionnaires at the supermarkets. Home use test was used in this survey. Participants were given a pack of the first product (500 g) with the instructions that they were free to prepare the product as they habitually do when it suited them best together with family and/or friends and complete the questionnaire within one week. Completed questionnaires were returned by participants from supermarkets on a specified date at the supermarket, and were collected during the first visit a week later for participants from open-air markets. Once the completed questionnaires were collected, the respondents received the second product (500 g) to be consumed within one week's time. Product presentation order was balanced while issuing out products with a half the number of participants receiving the sardine first and the other half got the capelin first.

Questionnaire

Standardized structured questionnaires were administered to respondents to rate their liking of the product appearance, flavour and texture using a 9-point hedonic scale ranging from 1 (dislike extremely) to 9 (like extremely). Respondents were also asked about their general willingness to buy 500 g of the products at US dollars (USD) 2, 4, 6 and 8 on a 9-point scale from 1 (very unlikely) and 9 (very likely). The participants were informed that the price of dried sardine in the market was around USD 4 (reference price). Socio-economic demographic questions (gender, religion, education level, occupation, household size and who consumes dried fish in the household) was also included in the questionnaire since they have been found to relate to the preferred type of food and reason for purchase (Green et al., 2003; Obiero et al., 2014). The questionnaires were translated into local dilate ('Swahili') and briefly explained to participants when they received the first product. On returning completed questionnaires (supermarkets shoppers) or during the first visit, seven days after giving out the first product (open-air markets shoppers), completed questionnaires were collected and the respondents received the second product (500 g) with the same instructions. Within seven days, participants were contacted and the supermarket shoppers were asked to return completed questionnaires, whereas open air market shoppers were informed of a planned second visit to collect completed questionnaires about the second product. The whole process, across the study areas lasted four weeks.

Data analysis

Data was analyzed using the Statistical Package for the Social

Sciences (IBM - SPSS Inc. version 20.0). Descriptive analyses were done by use of means, standard error, percentages and frequency distribution of responses. The influence of product presentation order, product liking rating and willingness to buy based on the product type and shopping location were tested with ANOVA (score = product × subject/consumers) followed by Duncan's means separation test (Post-hoc) for differences between groups. P values of < 0.05 were considered significant.

RESULTS AND DISCUSSION

Socio-economic profile of fish consumers

A hundred and twenty completed questionnaires were collected (60 supermarket shoppers and 60 open-air market shoppers). This number of respondents is considered according to Hough et al. (2006) to be adequate for a consumer test. The socio-demographic characteristics of the two groups differed (supermarkets and open-air markets) except for gender that was relatively similar in both groups (Table 1). Although more than half of the participants (58%) were women, the proportion was less than expected as females are the primary shoppers of households in most parts of Africa (Obiero et al., 2014; Schuurhuizen et al., 2006). Women were less willing than men to participate in the study, possibly because of a high rate of illiteracy among the women. Majority of respondents shopping in open-air markets were Muslims (80%) unlike the supermarkets which were dominated by Christians (67%). This was expected given that the population of Kwale County is largely Muslims while a higher proportion of the population in Mombasa is Christians.

Seventy-two percent of the respondents shopping in open-air markets had only elementary education, followed by high school level (28%) with none of the respondents having obtained a university degree (Table 1). Sixty-three percent of respondents shopping in supermarkets had completed high school, followed by those with a university degree (30%) and elementary education (7%). Most of the respondents shopping in open-air markets were working as fishermen (27%), businessmen (27%) and farmers (25%) with the most common household size of 7 to 9 people. The respondents shopping in supermarkets were mainly working for private companies (48%) and government (30%) with a common household size of 4 to 6 people.

Respondents shopping in open-air markets consumed dried fish more frequently (33%, more often or equal to four times a week) than those shopping in supermarkets (5%, more often or four times a week) (Table 2). This indicates that shoppers in open-air market consume dried fish on a regular basis. Consumption of dried fish was negatively influenced by education, with high consumption frequency among less educated consumers (Table 2). Educated consumers are generally more aware of the health and other benefits associated with fish consumption. In a study on preferences for fish and

Table 1. Socio-economic profile of respondents shopping in supermarkets (Mombasa) and open-air markets (Kwale) in Kenya.

Variable	Response	Village markets, % (n=60)	Supermarkets, % (n=60)	Average, % (n=120)
Gender	Male	43.3	41.7	42.5
	Female	56.7	58.3	57.5
Religion	Islam	80.0	33.3	56.7
	Christian	20.0	66.7	43.3
Education level	Elementary	71.7	6.7	39.2
	High school level	28.3	63.3	45.8
	University level	0.0	30.0	15.0
Occupation/Working with	Government	5.0	30.0	17.5
	Private company	19.0	48.3	29.2
	Farmer	25.0	0.0	12.5
	Fisherman	26.7	3.3	15.0
	Businessman	26.7	6.7	16.7
	Unemployed	6.7	11.7	9.2
Household size	1 - 3	3.3	8.3	5.8
	4 - 6	28.3	58.3	43.3
	7 - 9	46.7	30.0	38.3
	> 10	21.7	3.3	12.5
Purchase location	Open market	95.0	58.3	76.7
	Supermarket	5.0	41.7	23.3
Consumer in family	Child/children	5.0	18.3	11.7
	Adults	1.7	13.3	7.5
	All members	93.3	68.3	80.8

Table 2. Dried fish consumption pattern among respondents at the coast of Kenya divided by shopping location and education level.

Education level/shopping location	% respondents consumption frequency					
	Less than once a month	Once a month	2-3 times a month	Once a week	2-3 times a week	More often
Elementary education	4.3	6.4	14.9	10.6	29.8	34
Secondary education	22.2	5.6	38.4	11.1	11.6	11.1
University degree	25.6	20.9	18	18.2	8.2	9.1
Village markets	1.7	8.3	10	16.7	30	33.3
Supermarkets	30	8.3	33	11.7	11.7	5

seafood using an 'evoked set' analysis education was found to positively influence peoples preference for fish (Kinnucan et al., 1993). Health benefits are however questionable when it comes to low quality products that are contaminated. Kenyan consumers consider dried small pelagic fish to be an inferior quality product sold mainly in rural areas (Oduor-Odote et al., 2010), where a majority of the population are poor with limited education.

A majority of the respondents shopping in the supermarkets are most likely middle class as they were mainly working for private companies or government and had relatively small households. Therefore, they are able to purchase more expensive protein sources than dried fish whose quality is uncertain and not often available in the supermarkets.

Dried fish is largely sold in open-air markets, with 95

Table 3. Overall acceptability of improved dried sardine and indoor dried capelin. Average (Std. Error) values based on a 9-point hedonic scale ranging from 1 (dislike extremely) to 9 (like extremely) (n=120).

Sensory attribute	Capelin		Sardine	
	Open market	Supermarket	Open market	Supermarket
Overall acceptability*	8.0 (0.2)[a]	7.1 (0.3)[b]	7.7 (0.2)[a]	7.0 (0.2)[b]
Appearance***	8.4 (0.2)[a]	7.8 (0.2)[b]	6.8 (0.2)[c]	6.8 (0.2)[c]
Flavour***	6.7 (0.2)[a]	6.3 (0.2)[a]	7.6 (0.2)[b]	7.4 (0.1)[b]
Texture	7.2 (0.2)	7.4 (0.2)	7.0 (0.2)	7.1 (0.2)

[a]Different letters (superscript) indicate significantly different values between samples within a row. *p < 0.05, ***p < 0.001.

and 58% of respondents shopping in the open-air markets and supermarkets, respectively purchasing dried fish in open-air markets (Table 1). Forty two percent of supermarket shoppers and 5% open-air markets shoppers purchased dried fish from supermarkets. The low proportion of consumers purchasing dried fish from supermarkets is mainly attributed to restricted sales of dried fish to low price open-air markets and people with low income in Kenya (Oduor-Odote et al., 2010) with only small quantities reaching national retail stores/ supermarkets.

Product acceptability

The products were generally well received with acceptability rating scores ranging between seven and eight (Table 3). Although the overall acceptability values were relative for both products, respondents shopping in open-air markets rated both products higher than those shopping in supermarkets. Open-air shoppers rated the products higher as familiar and regular consumers of dried fish. The result is in agreement with a study by Boutrolle et al. (2005) who reported that greater familiarization with a product which resulted in higher acceptability ratings. Dried capelin had significantly (p<0.05) higher appearance rating irrespective of the respondents' shopping location. On the other hand, sardine obtained the highest flavor rating. Texture was not significantly different (p>0.05) between the two locations, with a higher rating for capelin than sardine. Capelin appears to be attractive to consumers but the flavor was moderately ranked and needs to be improved. Both dried capelin and improved processed sardine were acceptable in the Kenyan markets and could in general be accepted in East African markets accustomed to dried small fish.

The socio-demographic did not appear to influence product acceptability except for level of education (Table 4). Earlier studies (Obiero et al., 2014; Green et al., 2003; Kinnucan et al., 1993) reported similar results where education was reported to primarily determine the consumers occupation and in this case the income. Most

respondents shopping in the supermarkets commented that poor quality dried products (contaminated with soil) and unavailability in national retail stores limited dried fish consumption among the group. Even though the majority of respondents shopping in supermarkets were irregular dried fish consumers, they rated products highly implying that they might accept new dried fish products such as capelin if quality could be improved. Gender, religion and household size had no significant influence on product acceptability.

Respondents' willingness to buy

The results shows consumers were willing to buy the products irrespective of the shopping location (Table 5). The average values of willingness to buy capelin and sardine were relatively high and very close, with a significant difference (p<0.05) only obtained based on respondents shopping location. Those shopping in open-air markets were more willing (p<0.05) to purchase the products than those shopping in supermarkets. This may be because consumers shopping in open-air markets were more familiar with dried fish.

On the specific amount of money, the respondents were willing to pay for 500 g of the product, open-air markets and supermarkets shoppers had high rating for both products at USD 2, but significantly higher rating was obtained for capelin than sardine (Table 5). Consumers were not willing to pay more than the reference price of USD 4 for improved dried sardine, but supermarket shoppers were willing to pay up to USD 6 for dried capelin (Table 5). The unwillingness of consumers to pay more than the reference price for sardine could be that they were not able to see the difference of improved dried sardine from traditionally dried. Sosa et al. (2008) reported food product choice and acceptability to be based on the sensory properties. Sardine was dried in raised drier that depended on weather conditions and may have only reduced contaminations from the environment (such as soil) but not lipid oxidation that affects color development during drying resulting in unattractive products. Also, the

Table 4. Overall acceptability (1 = "dislike extremely" to 9 = "like extremely") and willingness to buy (1 = "very unlikely" to 9 = "very likely" of dried capelin and improved dried sardine by demographic variables. Responses from open market and supermarket compiled.

Variable	Character/Response	Overall Acceptability		Purchase intent	
		Capelin	Sardine	Capelin	Sardine
Gender	Male	7.4 (0.2)	7.3 (0.2)	7.8 (0.3)	7.5 (0.2)
	Female	7.6 (0.2)	7.4 (0.2)	7.9 (0.2)	7.6 (0.2)
	P-value	0.517	0.623	0.769	0.645
Religion	Islam	7.8 (0.2)	7.5 (0.2)	8.0 (0.2)	7.7 (0.2)
	Christian	7.2 (0.3)	7.2 (0.2)	7.6 (0.2)	7.5 (0.1)
	P-value	0.83	0.223	0.207	0.45
Education level	Elementary	7.9 (0.3)[a]	7.6 (0.2)[a]	8.2 (0.3)[a]	7.9 (0.2)[a]
	High school	7.5 (0.2)[a]	7.7 (0.3)[a]	7.8 (0.2)[ab]	7.6 (0.3)[a]
	University	6.6 (0.5)[b]	6.4 (0.2)[b]	7.1 (0.4)[b]	6.9 (0.2)[b]
	P-value	0.028	0.045	0.046	0.039
Household size	1 to 3	8.3 (0.5)	7.4 (0.7)	8.1 (0.5)	8.3 (0.3)
	4 to 6	7.4 (0.3)	7.3 (0.2)	7.6 (0.2)	7.3 (0.2)
	7 to 9	7.4 (0.3)	7.4 (0.2)	7.8 (0.3)	7.8 (0.2)
	Equal to/More than 10	8.3 (0.4)	7.5 (0.3)	8.4 (0.3)	7.5 (0.3)
	P-value	0.203	0.929	0.402	0.091

[a]Different letters (superscript) indicate significantly different values between samples within a column for a specific variable (p < 0.05).

Table 5. Willingness to buy (1 = "very unlikely" to 9 = "very likely") capelin and sardine at specified amount (I USD =100 KES).

Willingness to buy	Capelin		Sardine	
	Open market	Supermarket	Open market	Supermarket
Unlikely/Likely to buy***	8.33 (0.191)[a]	7.30 (0.212)[b]	7.97 (0.130)[a]	7.18 (0.192)[b]
At USD 2***	8.57 (0.209)[a]	8.83 (0.135)[a]	7.90 (0.134)[b]	7.78 (0.209)[b]
At USD 4***	6.73 (0.271)[a]	7.48 (0.212)[b]	6.12 (0.167)[a]	5.20 0.261)[c]
At USD 6***	4.03 (0.223)[a]	6.40 (0.234)[b]	3.15 (0.187)[c]	2.13 (0.211)[d]
At USD 8***	1.43 (0.133)	3.80 (0.260)[a]	1.18 (0.087)	1.15 (0.085)

[a]Different letters (superscript) indicate significantly different values between samples within a row, ***p < 0.001.

reference price used in the study was based on the supermarket price of a product similar to the improved sardine used in this study and therefore more expensive than traditional dried sardine sold at about USD 3 in open-air markets.

Conclusions

Dried capelin and improved dried sardine received relatively high acceptability ratings. However, the products differed in definite attributes with capelin obtaining significantly higher ratings for appearance, while sardine obtained significantly higher flavor ratings. These resulted in high acceptability rating for capelin especially among the consumers shopping in supermarkets. Consumers

shopping in supermarkets considered to represent middle income groups were willing to pay up to USD 6 for 500 g of capelin. Consumers shopping in open-air markets who consume dried fish on regular basis were willing to buy 500 g of dried capelin and sardine at up to KSH 400. The consumers of traditional dried small fish as well as new consumers especially in the middle income class might accept new dried fish products if overall quality could be guaranteed. A follow-up study covering a large geographical area is recommended to assess business feasibility.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Effect of harvest age of cassava roots and sweet potato tubers on alcohol yield

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Several studies have been conducted in the past using cassava and sweet potato as feedstock to optimise the yield of alcohol. Harvest age of cassava and sweet potato may have some effects on the fermentable carbohydrates quantity. This study aims to establish the best harvest age of cassava and sweet potato for alcohol production. Two varieties of cassava (*Sika bankye* and *Ampong*) cultivated and harvested at 8, 10 and 12 months and two sweet potato varieties (*Apomuden* and *Tuskiki*) harvested at 3, 4 and 5 months were used for the study. Starch hydrolysis was performed with two sets of enzymes followed by fermentation with Bio-Ferm XR (Lallemand) yeast. The nutrients in *Sika bankye* were generally higher than in *Ampong*, except for ash. *Sika bankye* had the highest alcohol yield (14.8% v/v) between the two cassava varieties, with the best harvest age of cassava for ethanol production being 10 months. *Apomuden* had relatively higher nutrients than *Tuskiki* at all levels of growth except for fat. *Apomuden* had the highest alcohol yield (15.7% v/v) between the two sweet potato varieties with 3 months being the economical harvest age of sweet potato for ethanol production.

Key words: Cassava, sweet potato, harvest age, saccharification, fermentation, alcohol yield.

INTRODUCTION

Cassava and sweet potato contain high concentrations of starch which could be converted into ethanol (Ozoegwua et al., 2017; Lareo et al., 2013). Several investigations in the recent past confirmed the potential of cassava and sweet potato as feedstock for ethanol production (Costa et al., 2018; Martinez et al., 2018; Pereira et al., 2017; Schweinberger et al., 2016; Archibong et al., 2016; Swain et al., 2013; Oyeleke et al., 2012). The major crops that are usually used globally for ethanol production are corn, sugar cane and wheat (Zabed et al., 2016; Li et al., 2016; Gupta and Verma, 2015; McMurry, 2015; Vollhardt and Schore, 2014; Boundy et al., 2011).

Fresh cassava roots contain about 30% starch (Amarachi et al., 2015) and 1l of ethanol could be produced from 5-6 kg of fresh roots (containing 30% starch) and 3 kg of cassava chips (14% moisture content).

It is also reported that cassava and sweet potato have higher starch yield per unit area than grains (Duvernay et al., 2013; Lee et al., 2012; Srichuwong et al., 2009; Ziska et al., 2009). Cassava can be grown under relatively poor agronomic conditions; therefore, cassava is a "food security crop" (Parmar et al., 2017; Amarachi et al., 2015). Sweet potato is an excellent feedstock for ethanol production (Lareo et al., 2013). Industrial sweet potato could produce 4500–6500 l/ha of ethanol compared to 2800–3800 l/ha for corn (Duvernay et al., 2013; Ziska et al., 2009).

Importation and use of ethanol in developing countries such as Ghana in recent times has been on the rise. In 2016 for instance, a total of over seventy million litres of ethanol was imported into Ghana for various industrial uses (Ghana Business News, 2017), this quantity could have been produced using cassava as raw material. The Ministry of Food and Agriculture, Ghana (MoFA Statistics Ghana, 2016), reported 17,213,000 tonnes of fresh cassava production by Ghana in 2015. A surplus of 30 to 40% production figure was reported from the above production figure in 2016, which could be utilised in industries as raw materials for other products, without adverse effects on food security (Grow Africa, 2015).

The amount of fermentable carbohydrates available in cassava root and sweet potato tuber depend on the variety and growth conditions of the crops (Teerawanichpan et al., 2008). The harvest age of the crops could therefore have some effects on the fermentable carbohydrates, which could have direct relation with the amount of alcohol produced. The study was to establish the best harvest age of cassava and sweet potato for alcohol production.

MATERIALS

Flour processed from two varieties of cassava (*Sika bankye* and *Ampong*) cultivated at Caltech Ventures Ltd farms, Ho, in the Volta region, Ghana and sweet potato flour processed from two varieties of sweet potato (*Apomuden* and *Tuskiki*) cultivated at Mantsi, in Greater Accra region, were used for the study. The cassava roots were harvested at 8, 10 and 12 months and the sweet potato was harvested at 3, 4 and 5 months and processed into flour for the study. *Liquozyme SC DS, Viscozyme L and Spirizyme Fuel* enzymes were provided by Novozymes, Denmark. Bio-Ferm XR yeast (unique yeast strain of *Saccharomyces cerevisiae)* produced by Lallemand, Georgia, USA was used for fermentation.

METHODS

Processing of cassava (Sika bankye and Ampong) and sweet potato (Apomuden and Tuskiki) flours

The 8, 10 and 12 month old lots of *Sika bankye* and *Ampong* (freshly harvested) and the 3, 4 and 5 month old lots of freshly harvested *Apomuden* and *Tuskiki* were weighed, washed, sliced thinly (average of 2 mm thick) with peels on, steam blanched for 10 m, dried at 62°C in an oven for 6 h, after which it was cooled and milled through a sieve with 350μ mesh size. The flour samples were subsequently used for ethanol production. Amount of starch in the flour was determined using Litner's method, proximate analysis carried out, visco-amylograph analysis and other physicochemical properties determined.

Ethanol production from cassava and sweet potato flour

The alcohol content of 50 g each of the cassava (8, 10 and 12 months) and sweet potato (3, 4 and 5 months) flour samples processed was determined using the method described by Komlaga et al. (2021), followed by alcohol yield by weight calculation using the Cutaia et al. (2009) formula: $A_{w/w} = 0.38726^*$ $(OE - AE) + 0.00307^* (OE - AE)^2$. Where, $A_{w/w}$ is Alcohol content by weight, OE is original extract and AE is the apparent extract. The alcohol by volume conversion was done using the Probrewer conversion table (Probrewer, 2018).

Determination of Starch content A (Litner's method)

Five grams of cassava and sweet potato flour samples were triturated with 10 ml of water, and 20 ml hydrochloric acid (sp.gr.1.15) added in small portions. The mixture was washed into a 100 ml flask with hydrochloric acid (12% w/w HCl) and 5 ml of 5% phosphotungstic acid added to precipitate proteins and the volume made up to 100 ml with 12% hydrochloric acid. The mixture was shaken, filtered and the optical rotation of the filtrate was measured in a 200 mm tube. The mean specific rotation of starch was taken as +200.

$$\text{Starch (\%)} = \frac{2000 \text{ x optical rotation}}{\text{Specific rotation}}$$

The experiment was performed in triplicates.

Crude fibre determination

Three grams of cassava and sweet potato flour samples was weighed and transferred into Erlenmeyer flask. Petroleum ether (15 ml) was added, the solution stirred, allowed to settle for 15 min and decanted. The washing procedure was repeated three times. The extracted sample was air dried and transferred into a 1000 ml conical flask. 200 ml H_2SO_4 (0.1275M) was added and the solution brought to boiling for 30 min by heating. The boiling sample was poured into a prepared Buckner funnel after allowing it to stand for 1 min. Insoluble matter was washed with hot water until the washing was free from acid. The insoluble matter was washed back into the 1000 ml conical flask with 200 ml of 0.313M NaOH solution by means of a wash bottle. The solution was boiled for 30 min, allowed to stand for 1 min and filtered through a No. 1 filter paper. The insoluble material was transferred to the filter paper with boiling water. The material was washed with 1% HCl and finally with boiling water until free from acid. The sample was washed twice with 20 ml ethanol and 3 times with 20 ml of petroleum ether. The insoluble material was then transferred to a dry pre-weighed filter paper, dried at 100°C to constant weight. The filter paper and contents was incinerated in the Thermconcept furnace, (Thermconcept GmbH, Bremen, Germany), at 550°C for 8 h to ash. The weight of the ash was subtracted from the increase of weight on the filter paper due to insoluble material and the difference reported as crude fibre.

$$\text{Crude fibre (\%)} = \frac{\text{Weight of insoluble material} - \text{Weight of ash}}{\text{Weight of sample}} \text{ x 100}$$
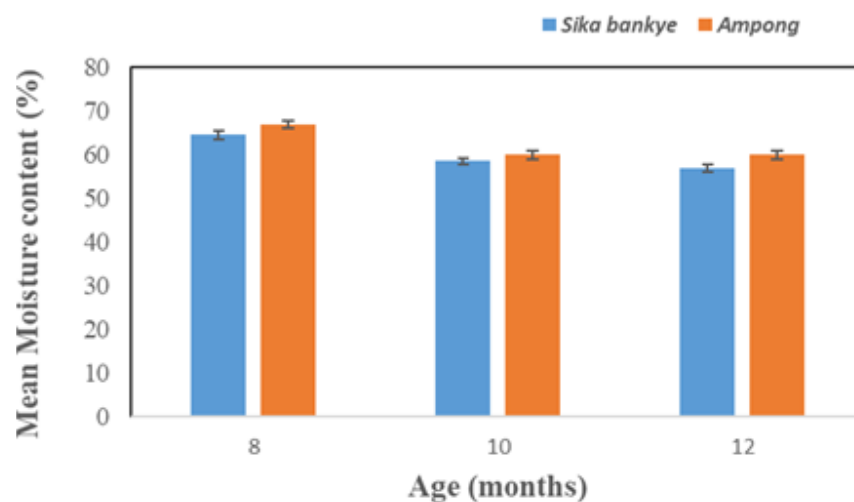
Figure 1. Mean moisture contents of *Sika bankye* and *Ampong* varieties.

Water absorption capacity determination

Water absorption capacity of the cassava and sweet potato flour samples was determined based on a modification of the centrifugation method of American Association for Clinical Chemistry methods (AACC, 1989). 2g of the flour sample was mixed with 20 ml distilled water. Samples were then allowed to stand at 30°C for 30 min, then centrifuged at 3500 rpm for 30 min. The reduction in the volume of the supernatant in a graduated cylinder was noted and recorded as water absorption capacity. Means of triplicate determinations were recorded. Water absorption capacity (%) = $V_1 - V_2$, where V_1 is the initial level (volume) of supernatant and V_2 is the final level (volume) of supernatant.

Swelling power determination

Swelling power was determined using the method described by Afoakwa et al. (2012). 1 g of flour was transferred into a weighed graduated centrifuge tube (50 ml). Deionized water was added to give a total volume of 40 ml. The sample in the centrifuge tube was heated at 85°C in a thermostatically controlled temperature water bath (Grant OLS 200, Keison products, Chelmsford, UK) for 30 min with constant shaking (80 strokes/min). The tube was then taken out, wiped dry on the outside and cooled to room temperature. It was centrifuged (Hermle Z 206 A, Hermle Labortechnik GmbH, Germany) for 15 min at 2200 rpm. The swelling power was determined by evaporating the supernatant in a hot-air oven (Gallenkamp Oven, England, UK) and weighing the sediment paste and supernatant residue. The swelling power was then calculated using the formula:

$$\text{Swelling power} = \left(\frac{\text{Weight of precipitated paste}}{\text{Weight of sample}}\right) - \text{Weight of residue in supernatant}$$

Proximate analysis

Moisture and protein contents were determined according to Helrich (1990), while ash and fat contents were determined according to Horwitz (2000) methods.

pH determination

The pH of the samples was determined by homogenizing 10g of flour samples in 50 ml of distilled water, after which the pH of the resulting mixture was measured with a Mettler Toledo (Seven Compact pH meter, Mettler Toledo group, Switzerland) pH meter. The experiment was performed in triplicates.

Pasting characteristics determination

Visco-Amylograph (Viscograph-E) manufactured by Brabender GmbH & Co, KG, Illinois, USA, was used to determine the gelatinisation temperature of the flour samples. The moisture content of the flour sample was determined using Sartorius MA 45 (Sartorius AG, Goettingen, Germany) moisture analyzer after which and the moisture value was fed into the software of the Viscograph-E. The quantities of flour sample and distilled water to mix for the test was then determined by the software. The flour sample was then weighed and poured in the measured distilled water, mixed well to form consistent slurry with no lumps. The sample was transferred into the reaction chamber of the Viscograph-E and run to analyse the sample. The data generated at the end of the analysis were copied and saved from which the gelatinisation temperature was recorded.

Data analysis

Analysis of variance (ANOVA) was carried out on the ethanol yields from the samples using Minitab version 17.1 (Kutner et al., 2005).

RESULTS AND DISCUSSION

Moisture content

The moisture contents of the fresh cassava and sweet potato varieties studied are represented in Figures 1 and 3, respectively. The moisture content ranged from 57 to
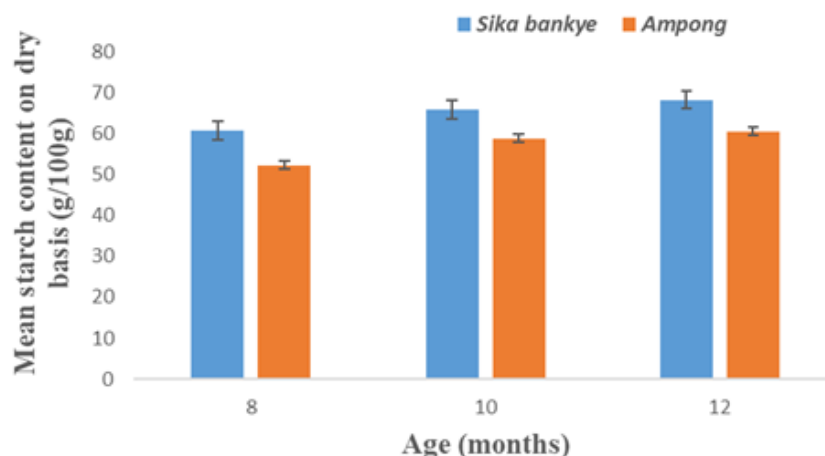
Figure 2. Mean starch contents of *Sika bankye* and *Ampong* varieties.
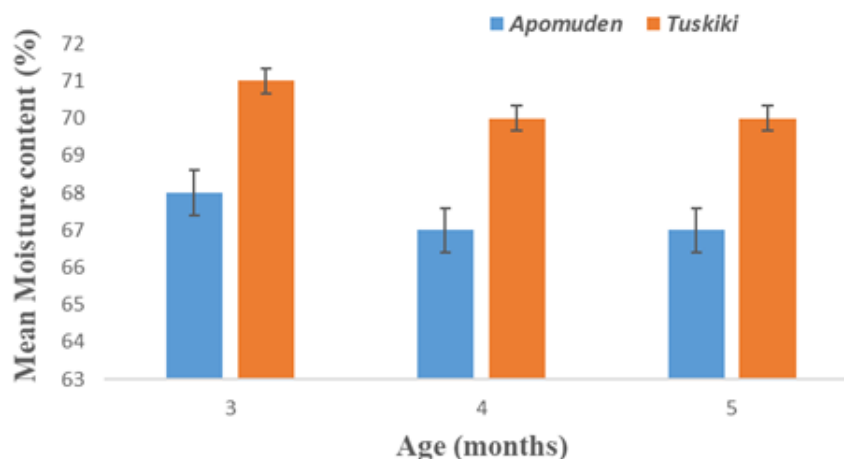

Figure 3. Mean moisture contents of *Apomuden* and *Tuskiki* varieties.

67% for cassava varieties and 67 to 71% for sweet potato varieties for the three growth stages. The moisture content of the cassava roots was comparable with the 68.1% value reported by Amarachi et al. (2015). The moisture content of *Ampong* roots were significantly higher (p < 0.05) compared to *Sika bankye* variety for all three growth levels. The amount of moisture is related to dry matter content of root crops. The higher the moisture content, the lower the dry matter content. It therefore implied that, *Sika bankye* variety has relatively higher dry matter content than *Ampong* variety at the same harvest age. It was also observed from the two varieties that, the more matured the cassava roots, the less moisture it has. The cassava roots were harvested in June, August and October with highest root moisture content recorded in June and the least moisture documented in October. There was much rain in June at the time of the 8 month harvest than in August and October in the location of the

cultivation. The moisture levels in the soil at the time of harvest could make the roots absorb more water which could lead to higher moisture content in the 8 months matured roots than the 10 and 12 months matured roots. The moisture content of the fresh *Tuskiki* variety was significantly higher compared to *Apomuden* variety for all three harvesting stages. It implied that, *Apomuden* variety has relatively higher dry matter content than *Tuskiki* variety at same maturity levels.

Starch content

Figures 2 and 4 represent the starch contents of the cassava and sweet potato varieties studied. The starch content of the cassava varieties ranged between 52% and 69% and that for sweet potato ranged between 78 and 90% on dry basis. It was observed that the starch
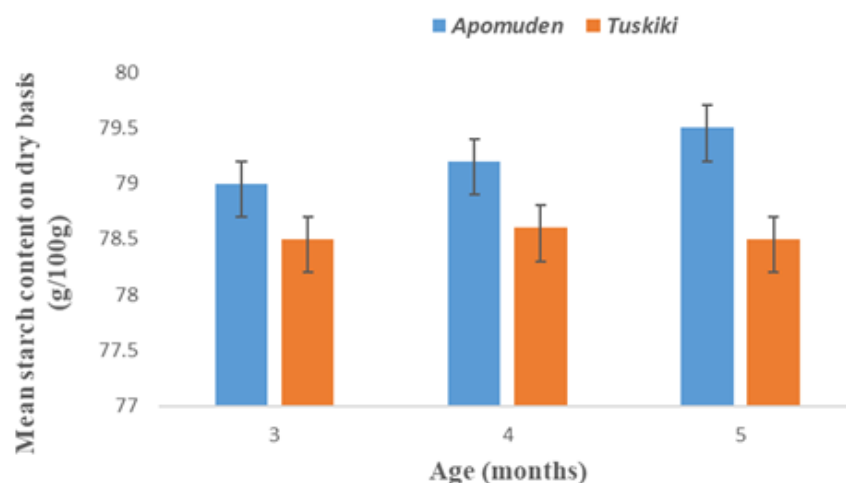
Figure 4. Mean starch contents of *Apomuden* and *Tuskiki* varieties.

Table 1. Mean proximate composition of 8, 10 and 12 months old *Sika bankye* and *Ampong* varieties (N=3).

Nutrient (g/100 g)	*Sika bankye* variety			*Ampong* variety		
	8 months	10 months	12 months	8 months	10 months	12 months
Ash	2.37 ± .01	2.39 ± .01	2.42 ± .08	2.99 ± .02	2.99 ± .02	3.05 ± .06
Protein	1.67 ± .08	1.69 ± .10	1.70 ± .90	1.62 ± .06	1.63 ± .09	1.64 ± .08
Fat	0.70 ± .00	0.73 ± .02	0.73 ± .00	0.54 ± .00	0.55 ± .01	0.55 ± .00
Crude fiber	4.22 ± .08	4.54 ± .03	4.67 ± .04	2.32 ± .06	2.36 ± .05	2.57 ± .05
Total carbohydrates	91.01±.17	90.66± .16	90.47± .17	92.53± .26	92.48 ± .32	92.20± .34

content of *Sika bankye* variety was significantly higher at all levels of growth than in the *Ampong* variety. The starch content of *Apomuden* variety was significantly higher at all levels of maturity than in the *Tuskiki* variety. Ethanol yield from a starchy raw material is largely dependent on the starch content and dry matter of the raw material (Li et al., 2015; Ademiluyi and Mepba, 2013). Teerawanichpan et al. (2008) reported that the amount of hydrolysable carbohydrates available in cassava root and sweet potato tuber depended on the variety and growth conditions of the crops. *Sika bankye* variety is a better variety for ethanol production compared to *Ampong* variety based on the fact that it has higher dry matter and higher starch contents. Likewise, for the sweet potato varieties, *Apomuden* is a better variety for ethanol production compared to *Tuskiki* variety.

Proximate composition

The proximate composition of the cassava and sweet potato varieties studied are presented in Tables 1 and 2, respectively. The nutrients (ash, fat, protein, carbohydrates and crude fibre) are generally higher in *Sika bankye* than

in *Ampong* variety except for ash. The nutrients determined (ash, fat, protein, carbohydrates, crude fibre) in the sweet potato varieties were generally higher in *Apomuden* than in *Tuskiki* variety, except for fat content. The fat content of *Tuskiki* variety was relatively higher for all levels of growth than that of *Apomuden* variety (Table 2). Nutrients in Wort during brewing (fermentation) are essential to how well the sugar is fermented into ethanol (Kunze, 2004). The yeast cells need amino acids to build proteins and new cells, they need vitamins and minerals to make enzymes work-well and they need phosphorous to create new DNA.

Nitrogen is a key factor in determining the ethanol yield in brewing (Agu et al., 2009). Nitrogen is approximately 10% of the dry weight of yeast cells. Since the nutrients are relatively higher in *Sika bankye* than in *Ampong* variety and higher in *Apomuden* than in *Tuskiki* variety, especially that of protein, it suggested that *Sika bankye* and *Apomuden* could supply, to a large extent, the needed nutrients to yeast cells during fermentation than *Ampong* and *Tuskiki*. *Sika bankye* and *Apomuden* varieties could therefore be the best varieties in terms of nutrients supply for ethanol production than *Ampong* and *Tuskiki* varieties.

Table 2. Mean proximate composition of 3, 4 and 5 months old *Apomuden* and *Tuskiki* varieties (N=3).

Nutrient (g/100 g)	*Apomuden* variety			*Tuskiki* variety		
	8 months	10 months	12 months	8 months	10 months	12 months
Ash	0.60 ± .00	0.61 ± .01	0.62 ± .01	0.56 ± .01	0.56 ± .01	0.56 ± .01
Protein	1.11 ± .02	1.12 ± .02	1.16 ± .03	1.07 ± .03	1.13 ± .02	1.14 ± .04
Fat	0.45 ± .01	0.47 ± .00	0.46 ± .00	0.70 ± .01	0.81 ± .00	0.80 ± .00
Crude fiber	0.10 ± .01	0.14 ± .00	0.14 ± .02	0.11 ± .01	0.11 ± .01	0.12 ± .00
Total carbohydrates	97.60± .30	97.66± .06	97.61± .03	97.56± .08	97.40± .02	97.39± .06

Table 3. Mean physico-chemical properties of cassava and sweet potato varieties.

Sample	Gelatinisation temperature (°C)	pH	Swelling power	Water absorption capacity
Sika bankye	68.8± 0.3[a]*	5.8 ± 0.2[c]	9.4 ± 0.3[d]	0.5 ± 0.1[f]
Ampong	69.1 ± 0.3[a]	6.0 ± 0.0[c]	10.0 ± 0.3[d]	0.4 ± 0.1[f]
Apomuden	72.2 ± 0.6[b]	5.8 ± 0.0[c]	5.8 ± 0.0[e]	3.1 ± 0.1[g]
Tuskiki	72.3 ± 0.6[b]	5.8 ± 0.2[c]	5.6 ± 0.1[e]	2.9 ± 0.2[g]

*Means in the same column with different letters are significantly different (p<0.05)

Physico-chemical properties

The physico-chemical properties of the cassava and sweet potato varieties studied are presented in Table 3. The gelatinisation temperatures of the cassava varieties ranged between 68 and 70°C and that of the sweet potato varieties ranged between 72 and 73°C. Gelatinisation irreversibly dissolves starch granules in water in presence of heat, by breaking the intermolecular bonds of the starch molecules. The process improved the availability of starch molecules for hydrolysis by amylases. The gelatinisation temperatures observed for the cassava and sweet potato varieties were far below the optimum temperature (85°C) of the Liquozyme SC DS enzyme used for dextrinization in this study. The starch molecules in the cassava and sweet potato varieties would therefore gelatinise before the optimum temperature of the liquozyme SC DC enzyme is attained. This would ensure that all the starch molecules present in solution would be broken down into short chain carbohydrates for subsequent hydrolysis by saccharifying enzymes. The pH values recorded during the study for cassava and sweet potato varieties were between 5.5 and 6.1. The pH values obtained in the study are conducive for the hydrolysis and fermentation of the samples, since all the enzymes and the yeast used have their optimum pH values between 5 and 6. The adjustment of pH of the reaction medium, with economic implications for the ethanol production, is therefore not necessary.

The swelling capacities of the cassava varieties studied ranged from 9.4 to 10.0, with *Sika bankye* generally having relatively low swelling capacity compared to *Ampong* variety. The swelling capacity of the sweet potato varieties were 5.8 and 5.6 for *Apomuden* and *Tuskiki*, respectively. Swelling capacity is a measure of the ability of starch to imbibe water and expand in volume at a particular temperature (Amarachi et al., 2015). Low swelling capacity of flour suggested that the starch granules have strong binding force and low amylose content. Low-amylose starch has an excellent functionality of easy digestibility when compared with high-amylose starch (Amarachi et al., 2015). In addition, low swelling power in cassava flour is a clear indication of restricted starch which shows a high resistance to breaking during cooking. Since the cassava and sweet potato varieties studied have relatively low swelling capacities, they could all be digested easily, hence ideal for ethanol production. The water absorption capacity of the cassava and sweet potato varieties ranged between 0.3 and 3.2. *Sika bankye* variety had relatively higher water absorption capacity than *Ampong*, and *Apomuden* had relatively higher water absorption capacity than *Tuskiki* variety.

Water absorption capacity is the ability to take up and retain water either by adsorption or absorption. It is influenced by the extent of starch disintegration. Low water absorption capacity could be attributed to the protein content in a product because protein has been reported to limit the ability of water uptake in food (Amarachi et al., 2015). There were no significant differences between the water absorption capacities of *Sika bankye* and *Ampong* and between *Apomuden* and *Tuskiki* varieties.

Ethanol yield

Results of limit attenuation and corresponding mean

Table 4. Mean alcohol yields of cassava and sweet potato varieties.

Cassava/sweet potato variety	Limit attenuation (%)	Alcohol yield (%/$_{v/v}$)	Limit attenuation (%)	Alcohol yield (%/$_{v/v}$)	Limit attenuation (%)	Alcohol yield (%/$_{v/v}$)
	8 months old		10 months old		12 months old	
Sika	81.3 ± 0.5	13.3[a*] ± 0.2	81.9 ± 0.2	14.8[b] ± 0.4	81.3 ± 0.3	14.7[b] ± 0.1
Ampong	80.3 ± 0.5	11.5[c] ± 0.2	80.5 ± 0.6	12.8[d] ± 0.2	81.3 ± 0.3	12.7[d] ± 0.1
	3 months old		4 months old		5 months old	
Apomuden	85.5 ± 0.3	15.2[e] ± 0.2	82.7 ± 0.4	15.1[e] ± 0.1	83.7 ± 0.2	15.1[e] ± 0.1
Tuskiki	82.4 ± 1.0	14.8[e] ± 0.3	81.9 ± 0.2	14.9[e] ± 0.2	81.9 ± 0.2	14.8[e] ± 0.1

*Means in the same column with different letters are significantly different (p<0.05)

alcohol yields from the cassava and sweet potato varieties studied are presented in Table 4. The attenuation of the samples ranged between 80 and 86%, which are comparable to other previous studies (Kunze, 2004). Attenuation refers to the conversion of fermentable sugars in a Wort into alcohol and carbon dioxide by yeast during fermentation. The greater the attenuation, the more sugar that has been converted into alcohol (Krstanovic et al., 2019). The alcohol values observed in the study ranged from 11.5 to 15.2% v/v. The results obtained are comparable with that of other studies (Cutzu and Bardi, 2017; Ocloo and Ayernor, 2010; Begea et al., 2010). Flour processed from 10 months old Sika bankye produced the highest alcohol (14.8% v/v) among the two varieties of cassava studied, while 3 months old *Apomuden* flour produced the highest alcohol (15.2% v/v) among the two varieties of sweet potato studied. The ethanol content of *Sika bankye* is higher and significantly different (p < 0.05) compared to those of *Ampong* variety of same level of growth (Table 4). This is attributed to the higher dry matter, starch content and other nutrients like protein and fat which are relatively higher in *Sika bankye* than *Ampong* variety (Table 1 and Figure 2). There was no significant difference between the ethanol yield of cassava samples of 10 and 12 months old. There is therefore no economic value, according to the findings, to keep cassava roots on the field after 10 months if they are meant for processing alcohol.

The economic harvest age of cassava meant for ethanol production is therefore 10 months. The starch contents of the sweet potato varieties studied are significantly higher than the cassava varieties studied. This reflected in higher ethanol yields in the sweet potato than cassava varieties. Apart from the higher starch content and other nutrients, the higher ethanol yields from the sweet potato varieties could also be attributed to significant β-amylase activity in sweet potato, which could aid the degradation of starch during mashing to produce simple sugars (Dziedzoave et al., 2010). There was no significant difference between the ethanol yield of sweet potato samples of 3, 4 and 5 months old. There is no

economic value, according to the findings, to keep sweet potato on the field after 3 months if they are meant for ethanol production. The economic harvest age of sweet potato meant for ethanol production is therefore 3 months. The ethanol yields from the 10 months old *Sika bankye* and 3 months old *Apomuden* flours could be exploited to process the 30 to 40% surplus cassava (documented in Ghana in 2016) into ethanol to cut down the importation of ethanol, which indirectly saves foreign exchange for developing countries (Grow Africa, 2015).

Conclusion

The results from the study indicate that nutrients in *Sika bankye* variety at the same harvest age are generally higher than in *Ampong* variety, except for ash. *Sika bankye* variety has more dry matter and higher starch content at the same harvest age which resulted in higher ethanol yield than *Ampong* variety. *Sika bankye* variety had highest ethanol yield (14.8% v/v) between the two cassava varieties at 10 months. The best harvest age of cassava for ethanol production is 10 months. *Apomuden* variety has relatively higher nutrients than *Tuskiki* variety at all levels of maturity except for fat. *Apomuden* variety has more starch and produced much ethanol than *Tuskiki* variety at the same harvest age. *Apomuden* variety had the highest ethanol yield (15.7% v/v) between the two sweet potato varieties at age of 3 months. The best economical harvest age for ethanol production from sweet potato is 3 months.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest.

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