CHARACTERISTICS OF YAM COMPOSITE FLOUR: PROPERTIES AND FUNCTION OF BREAD AND TORTILLA MAKING

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Title

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

DOCTOR OF PHILOSOPHY

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ABSTRACT

Consumer interest in dietary fiber is on the rise as more information about its potential impact on health has become available. Flour from yam (*Dioscorea rotundata*) could have useful applications in the baking industry, in composite flour blends, because of its high level of dietary fiber and other essential nutrients. Study of the chemical composition, physicochemical characteristics, and pasting properties of unfermented-white yam flour (UYF) and fermented-brown yam flour (FYF) were investigated. Studies show that composite flour from yam has high ash, total starch, and fiber content than refined wheat flour. Thermal studies showed the energy required for composite flour gelatinization is greater than that of refined wheat flour. The firmness of FYF gel significantly increased with increasing number of days unlike UYF where slight hardness in texture was observed. This study revealed that each flour type exhibited different characteristics when compared to refined wheat flour. This necessitates further studies to substitute the yam flour samples with refined wheat flour to create composite flours that could be employed in bakery products.

Inclusion of UYF and FYF flour at 5, 10, 15 and 20% levels of substitution with wheat flour affect the dough physicochemical, rheological pasting properties, and the nutritional quality. Proximate analysis of the flours carried out shows composite flours were of lower protein value but had higher fiber content than refined wheat flour. Impact on the gluten quality, gassing power, farinograph parameters was observed. The farinograph water absorption increased significantly ($p<0.05$) for blends prepared with UYF. Investigation revealed that the end-product quality (oven spring, loaf volume, bread crumb, tortilla weight, flexibility, thickness and color) of bread loaves and tortilla was significantly affected. This study demonstrated that incorporation of up to 10% FYF flour appears to give acceptable dough with good viscoelastic

properties and bread with quality traits similar to refined wheat bread. This might be because bread itself is a fermented bakery product. For the tortilla; an unfermented product, 20% UYF inclusion seems to be more suitable to produce tortillas with good extensibility, acceptable thickness and whiteness with no dark spots that will appeal to the consumers.

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DEDICATION

This research work is dedicated to

Almighty Allah

The sustainer and cherisher of the whole universe, in whose hands lies my affairs, who grants me the intellect and sound health to successfully sail through this path of knowledge acquisition

My better half and comforter, Dr Ademola Monsur

For his encouragement, to believe in myself during my educational career as well as his care, spiritual and moral support. I couldn't have made it this far without you

The apples of my eyes: Hikmah, Ikhlas, Hudhayfah and Humaid Abdul-Hammed

For their perseverance and understanding throughout my sojourn. Your presence in my life kept me going

Wishing you success here and afterlife. I love you all.

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LIST OF ABBREVIATIONS

A/X	Arabinose to xylose ratio
AM	Amylose
ANOVA	Analysis of variance
AP	Amylopectin
BKD	Breakdown
BU	Brabender units
CPV	Cold paste viscosity
CRD	Completely random design
ΔH	Enthalpy of gelatinization
DWB	Dry weight basis
eGI	Estimated glycemic index
EP	Extractable phenolics
FAE	Ferulic acid equivalents
FQN	Farinograph quality number
FV	Final viscosity
FWA	Farinograph water absorption
FYF	Fermented yam flour
HI	Hydrolysis index
HP	Hydrolysable phenolics
HPSEC-MALS	High performance size exclusion chromatography Multi-angle light scattering
HPV	Hot paste viscosity
IDF	Insoluble dietary fiber
LSD	Least significant difference

MTI	Mixing tolerance index
PPO	Polyphenol oxidase
PV	Peak viscosity
RDS	Rapidly digestible starch
RS	Resistant starch
RVA	Rapid visco analyzer
RWF	Refined wheat flour
SDF	Soluble dietary fiber
SDS	Slowly digestible starch
SEM	Scanning electron microscopy
STB	Setback
T_c	End temperature
T_c-T_o	Range of temperatures
TDF	Total dietary fiber
T_o	Onset temperature
T_p	Peak temperature
TPA	Texture profile analysis
TS	Total starch
UYF	Unfermented yam flour

GENERAL INTRODUCTION

The understanding of food-health relationship has awakened people's consciousness about the importance of adopting healthy diet life style. Consumers' demand for high quality product has prompted food researchers to develop wholesome quality food. Products from wheat-based composite flour have shown to possess high nutritional advantages. This is because of increased protein and most especially increased fiber content (Koh-Banerjee et al., 2004).

Root and tuber crops are important source of dietary fiber. Dietary fiber has been associated with beneficial attributes such as improving bulk motility, decreasing blood cholesterol and glucose, reduced risks of obesity, type 2 diabetes and cardiovascular disease, eliminating constipation , acting as prebiotic, and preventing some types of cancer (Căpriţă et al., 2010; Slavin et al., 1997). Yam (*Dioscorea* spp), is a tuber crop, one of the main staples of sub-Saharan Africa, and among the thiocyanate-yielding foods. It is a native crop of importance with great nutritional and medicinal value to human diet (Agbai, 1986; Pius and Odjuvwuederhie, 2006).

In Africa, most often yam is consumed as a fresh vegetable through boiling. Yam is highly perishable because of its high moisture content (52.3–55.1%). Thus, yam is processed into dry flour as a product with longer shelf life. Yam flour is later reconstituted to make gelatinous dumpling prior to consumption (Ukpabi et al., 2008). The processing of yam to "composite yam flour" is a necessary preservative measure to prevent economic loss to farmer and allow efficient utilization of this locally grown crop (Schultheis and Wilson, 1998).

Bread made from composite flours has been reported to be rich in carbohydrates, fiber, protein and minerals (Mondal and Datta, 2008). For example, composite flour from legumes such as peas or soy flour for bread making has been reported to complement each other.

However, the beany and grassy unpleasant flavor is regarded as some of the shortcomings affecting the end-product quality from wheat-legumes composite flours. Bread from wheat-yam composite flour will possibly overcome this known quality challenges as such product will have a nice aroma and free of unpleasant off-flavor odor. Likewise, wheat-yam composite flour can be a potential material for making of tortilla with a good rollability and smooth crumb texture. The possible benefits of wheat-yam composite flours include nutritional advantage, the improvement of food-handling and better end-product qualities (Noorfarahzilah et al., 2014). The concept of wheat-yam composite flour is technically feasible and economically desirable. The substitution of yam flour to complement wheat for bread and tortilla production represents an interesting option for producers and consumers. This study involves investigation of physicochemical changes, baking quality, rheological and pasting properties of wheat-yam composite flours and their end-products (bread and tortilla).

At present, there is very limited documented work reported on yam-wheat composite flour for bread making process and no work done on yam-wheat tortilla. In view of this, we have conceptualized the supplementation of yam composite flour with refined wheat flour for bread and tortilla baking process to enhance the textural and nutritional quality, specifically, the fiber, vitamins and phytochemicals level of the bread and tortilla. Concisely, the health benefits and other properties of wheat-yam composite flour and their tortilla and bread are expected to be comparable, if not improved, to that of refined wheat flour.

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LITERATURE REVIEW

Introduction to yam (*Dioscorea* spp)

Yam is a common name for some plant species belonging to the family Dioscoreceae, the genus *Dioscorea* and class of roots and tubers. It is a climbing annual plant, with cordate leaves and tuberous root. It is mostly grown in tropical and subtropical Africa, the Caribbean, South Pacific and Asia (Adegunwa et al., 2011). It is cylindrical in shape, with rounded end, mostly blackish or brown bark-like skin, and white, purple, or light yellowish flesh. The typical weight of yam tuber range from as small as 7 lb to over 22 lb (Pius and Odjuvwuederhie, 2006). Yam is a tropical regional plant mainly (native to Africa and Asia) cultivated for the purpose of its starchy tubers (Hou et al., 2002). About 400 million people depend on yam as their main food source (Ovono et al., 2010). In West Africa, yams are valuable source of carbohydrate, which provides about 200 calories of energy per capita daily consumption. Likewise, yam is a major source of income and has high cultural value (Okoro and Ajieh, 2014). The farmers and the villagers at large are always looking forward to successful cultivation and harvest of yam. In Nigeria for instance, a festival “Odun Isu” is held annually to celebrate the arrival of yam during the first phase of harvest. This happiness and celebration is simply due to the nutritional and economic value of yam that the people will derive from yam. Figure 1 shows the images of activities in a typical yam festival.

a: Women parade with yam on their head (welcome2nigeria.com)

b: Men dancing with yams on their shoulders (www.nnewi.info)

c: Some dignitaries making the first cut of yam for the season

(enugustatetourismboard.com)

Figure 1. Images of typical yam festival activities.

Although, some varieties of sweet potato (*Ipomoea batatas*) are also called yam in parts of the United States and Canada, yam is not the same as sweet potatoes. Sweet potato is a dicot with two embryonic seed leaves and from the Convolvulacea family, while yam is a monocot with one embryonic seed leaf from the Dioscoreaceae family. Also, yam is starchier and drier than sweet potato. Table 1 highlights the distinct differences between sweet potato and yam.

Table 1. Differences between sweet potato and yam (Schultheis and Wilson, 1998).

	Sweet potato	**Yam**
Scientific Name	*Ipomoea batatas*	*Dioscorea* species
Plant family	Morning glory	Yam
Chromosome number	2n=90 (hexaploid)	2n=20
Edible part	Storage root	Tuber
Appearance	Smooth, with thin skin	Rough, scaly
Shape	Short, blocky, tapered ends	Long cylindrical, some with toes
Plant sex	Monoecious	Dioecious
Taste	Sweet	Starchy
Propagation	Transplants/vine cuttings	Tuber pieces
Mouth feel	Moist	Dry

Yam production

Yam is grown between February and April by planting pieces of tuber, or small whole tubers known as seed yam saved from the previous season. Depending on the weather condition in humid forest or on the savanna, yam is harvested after 180 to 270 days of planting. Harvesting of yam requires skill and should be done gently to minimize bruises and damage to tubers.

Damaged yam usually results in decay, loss of aesthetic value and a decrease in market value (Mestres et al., 2004). Yam tubers like other root and tuber crops are subject to physiological deterioration after harvest leading to up to 70% rotted tubers after 5 months, fresh weight losses up to 60% after 9 months' storage and up to 60–70% losses of consumable dry matter after 10 months. Generally, harvested tubers stay dormant without sprouting for about 120 days depending on environmental conditions, the time of harvest, and the species (Huang et al., 2006). Although, the peel offers some protections, deterioration becomes very rapid if yam is bruised. Worldwide yam production in 2008 was 52 million tons with Africa producing 96% of the world's total production. Figure 2 shows the distribution pattern of the top 10 yam producing countries. Out of the 94% of yam production from West Africa, Nigeria alone produces 71%, corresponding to more than 37 million metric tons with value equivalent of US $5.654 billion annually (Alinnor and Akalezi, 2010).

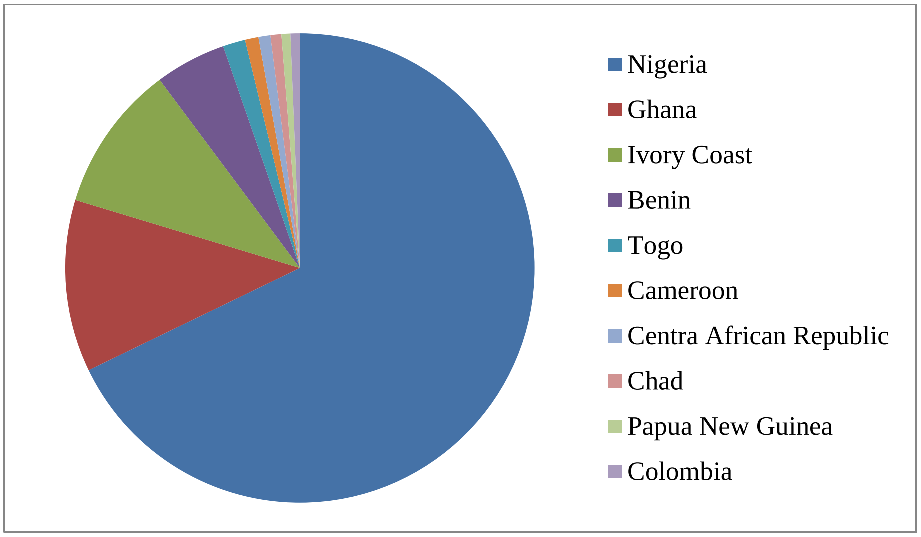


Figure 2. The top 10 yam producing countries (UN food and agricultural organization)

Common cultivars of yam and their composition

Out of about 600 identified yam species, only twelve are edible and six are economically important staple species. These economic important yam species are: *D. rotundata*, *D. cayenensis*, *D. alata*, *D. bulbifera*, *D. esculenta*, and *D. dumetorum*. Figure 3 shows the pictures of the common yam cultivars.

Dioscorea alata

Dioscorea alata is known as the water yam or winged yam (Figure 3a and b). *Dioscorea alata*, is of two types the white species and the purple species. The white species is prevalent in the African region including Nigeria, and Ghana while the purple species is popular in the Asian region such as Philippine, Vietnam, and Indonesia. The purple color of the purple species is due to the presence of anthocyanins which is used as a natural food colorant (Yoshida et al., 1991). Extracts of the purple specie have been employed in China traditional medicine and recent scientific evidences have shown numerous bioactivities including antioxidant, antidiabetic, antiosteoporotic, anti-ulcer, anti-inflammatory and hepatoprotective activities (Dey and Chaudhuri, 2014).

Dioscorea rotundata

Dioscorea rotundata is known as the white yam (Figure 3c). It is among the most widely cultivated yams species and usually cultivated for food purpose. The white yam is of high economic importance and social-cultural value. It is associated with longer dormancy period.

Dioscorea cayenensis

The yellow yam is also widely cultivated (Figure 3d). This yam specie is closely related to the white yam. Except that yellow yam has a longer vegetation period and shorter dormancy than that of white yam. The yellow color of *Dioscorea cayenensis* is as a result of the presence of β-carotene (Achi and Akubor, 2000; Dumont and Vernier, 2000).

Dioscorea bulbifera

Dioscorea bulbifera is known as aerial yam or air potato although it is a species of true yam (Figure 3e). The plant forms bulbils in the leaf axils of the twining stems, and tubers similar to small, oblong potatoes beneath the ground. It is commonly found in both Africa and Asia. Some varieties of this tubers can be eaten raw while detoxification of the bitter taste of some are done through boiling (Schultz, 1993).

Dioscorea esculenta

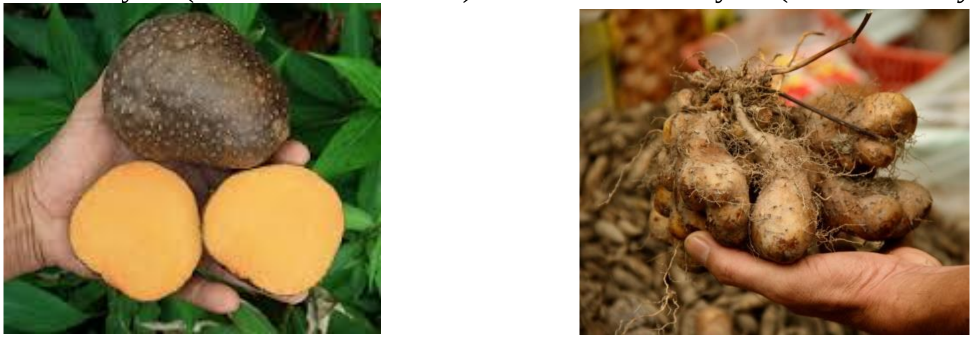
Dioscorea esculenta is called the lesser yam possibly because of its small sized tuber (Figure 3f). It is native to Southeast Asia. Although it is cultivated very little in other parts of the world, it is the third most commonly cultivated species in Southeast Asia including Philippine, Vietnam, and eastern India (Wanasundera and Ravindran, 1992).

Dioscorea dumetorum

The bitter yam is popular as a vegetable in some parts of West Africa possibly because its cultivation requires less labor than other yams (figure 3g). However, the wild forms of this yam are very toxic. In the south-western Nigeria, bitter yam serves as food of choice for the diabetic patients and as herb for the treatment of various ailments (Egbuonu et al., 2014). Likewise, the potential use of bitter yam extract as an effective hypoglycaemic agent with hypolipidaemic and hypocholesterolaemic properties for the treatment of diabetes mellitus (Nimenibo–Uadia, 2003) as well as malaria treatment have been reported (Dike et al., 2012).

a: Water yam; purple (*Dioscorea alata*) b: Water yam; white (*Dioscorea alata*)

c: White yam (*Dioscorea rotundata*) d: Yellow yam (*Dioscorea cayenensis***)**



e: Aerial yam (*Dioscorea bulbifera*) f: Lesser yam (*Dioscorea esculenta*)

g: Bitter yam (*Dioscorea dumetorum*)

Figure 3. Some common yam species
(images were obtained from, www.healingmoringatree.com; www.healthbenefitstimes.com; www.stlucianewsonline.com; www.reggaetreats.com; www.flickr.com; tropical.theferns.info; digitalkobo09.blogspot.com)

Composition of yam

Yam is composed mainly of starch, with small amounts of proteins, lipids, vitamins, high amount fiber and all the essential amino acids. In addition, it has manganese, vitamin B, vitamin E, vitamin K, and beta-carotene together with potassium and sodium, which are of higher values. Yam is especially rich in vitamins C which is lacking in wheat (Okoro and Ajieh, 2014). The proximate composition of yam varies depending on species, but generally harvested fresh yam are high in moisture which are within the range 50–65%, ash (0.5–1.2%), protein (3.4–6.0%), fat (0.1 – 0.3%), starch (75–84%) and fiber (1.5–6.2%). Table 2 shows some nutritional composition of some common yam species.

Table 2. Phytochemical (mg/100g), vitamins (mg/100g) and mineral (mg/100g) contents of *Dioscorea* species on dry weight basis (Okwu and Ndu, 2006).

	D. rotundata	*D. cayenensis*	*D. alata*	*D. bulbifera,*	*D. dumetorum*
Alkaloids	0.38±0.12	0.68±0.02	0.29±0.02	0.88±0.11	1.68±0.01
Flavonoids	3.10±0.11	5.78±0.11	1.78±0.20	8.04±0.20	9.94±0.10
Phenols	0.005±0.22	0.0024±0.11	0.005±0.11	0.004±0.10	0.003±0.10
Saponins	2.90±0.01	16.48±0.10	7.78±0.20	14.88±0.10	14.78±0.11
Tannins	0.05±0.10	0.01±0.20	0.06±0.20	0.08±0.10	0.09±0.20
Ascorbic acid	0.97±0.11	1.23±0.11	0.70±0.11	1.67±0.22	1.93±0.20
Niacin	0.03±0.21	0.13±0.21	0.04±0.12	0.01±.0.20	0.01±0.10
Riboflavin	0.006±0.11	0.004±0.11	0.006±0.10	0.009±0.12	0.011±0.20
Thiamin	0.008±0.10	0.007±0.10	0.009±0.11	0.009±0.20	0.009±0.11
Magnesium	0.85±0.20	0.73±0.20	1.10±0.11	0.85±0.21	0.85±0.10
Calcium	1.20±0.11	1.60±0.11	2.00±0.10	1.80±0.20	2.41±0.10
Potassium	0.39±0.10	0.75±0.10	0.66±0.20	1.00±0.11	0.85±0.20
Sodium	0.14±0.11	0.19±0.11	0.18±0.10	0.22±0.11	0.14±0.10
Phosphorus	0.20±0.10	0.29±0.20	0.16±0.11	0.36±0.10	0.26±0.20

*Values are presented in mean ± standard deviation

Bioactive compounds in yam (*Dioscorea* spp)

The chemistry of *Dioscorea* spp shows that they are very rich with numerous natural products classes and functional characteristics. Yam is widely cultivated in the tropics as an important source of thiocyanate and some polyphenols including; catechins, epicatechins, chlorogenic acids, leucoanthocyanidins, steroid, and anthocyanins have also been identified. The potential biological activities of natural products of yam origin are presented in the next paragraphs.

Anti-sickling potential of yam

The harmless heterozygous sickle cell trait (SCT) occurs more frequently in Africans than in African-Americans in the United States, the active form of sickle cell anemia (SCA) is quite rare. This rarity SCA in Africans was in the past attributed to an unknown environmental protective factor. The protective factor against SCA was identified to be thiocyanate (SCN-), (Houston, 1973) which are found in African yam (*Dioscorea* spp). Yam is the second richest known food source of thiocyanate with range of about 50- 60 mg/10 g. This value is higher when compared with other vegetables which ranges between 0.4 - 10.1 mg/10 g. Thiocyanate a precursor of cyanate physiologically present in mammalian fluids is obtained from the beta-cyanogenetic glucosides in food plants, and from nitrilosides also known as vitamin B_{17} (Krebs, 1970). Nitrilosides form thiocyanate upon their hydrolysis in the body in the presence of sulfur donor cysteine or methionine through the action of rhodanese; an enzyme found in all normal body tissues (Aminlari et al., 2002). Its hematopoietic effect to ameliorate sickle cell anemia has been clinically observed. Nitriloside and thiocyanate were found to elevate plasma thiocyanate many fold in rats and in humans (Agbai, 1986). Cyanate, the end-product of thiocyanate, has irreversibly inhibited the sickling of red blood cells in vitro and extends the life span of treated sickle cells to near normal range in vivo, consequently, prevent the general manifestation of sickle cell anemia.

Immune booster and anti-ageing capability of yam

Diosgenin (Figure 4), one of the steroid sapogenins was reportedly isolated from *Dioscorea* species of Mexican origin. Diosgenin has been commercially used to produce steroid hormones such as cortisone, estrogen, and progesterone through in-vitro chemical modification (Araghiniknam et al., 1996). This steroid significantly reduced serum lipid peroxidation, lowered serum triglycerides and increased HDL levels in the selected older people. Its extract has been a dietary precursor of Dehydroepiandrosterone (DHEA). This is because DHEA declines with age and low DHEA level correlated with high mortality rate, since ageing involves reduced protein synthesis, increased risk of chronic disease, and risk of cancer, increased level of DHEA is essential to reverses immunosenescence and restore cancer immunity (Araneo et al., 1993). Likewise, Diosgenin extract of *D. villosa* has been used as a steroid precursor of progesterone, to minimize post-menopausal symptoms and for treatment of low progesterone levels (Benghuzzi et al., 2002) and its anti-collagenase activity and the possibility of skin disorders prevention through *Sapogenins* incorporation in cosmetics has been investigated (Sautour et al., 2006).

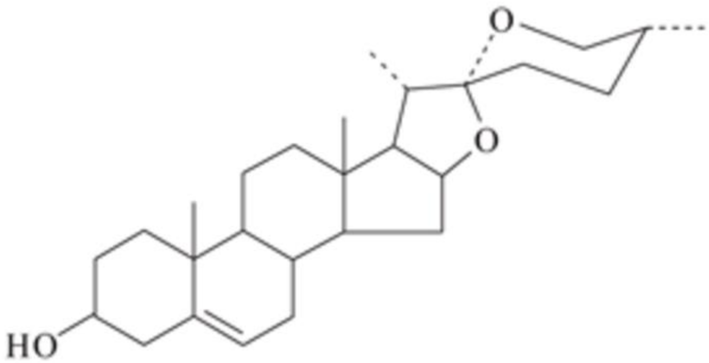


Figure 4. Structure of Diosgenin (Harvey and Boulter, 1983)

Anti-cancers and anti-fungal properties of yam

During the ethanol extract of *D. panthaica*, two novel Furostanol compounds; *Dioscoresides* 1 and 2 (Figure 5) were isolated which when tested in vitro on A375-S2, L929 and HeLa cell lines exhibited cytotoxic activity (Ozo et al., 1984). In addition, the fractionated saponin extract of *D. villosa* was reported to displayed antifungal activity using the broth dilution method against *Candida albicans*, *Candida tropicalis* and *Candida glabrata* (Sautour et al., 2006). The result corroborate with the author previous findings on the antifungal activity of spirostanetype saponins isolated from *D. cayenensis* (Sautour et al., 2004).

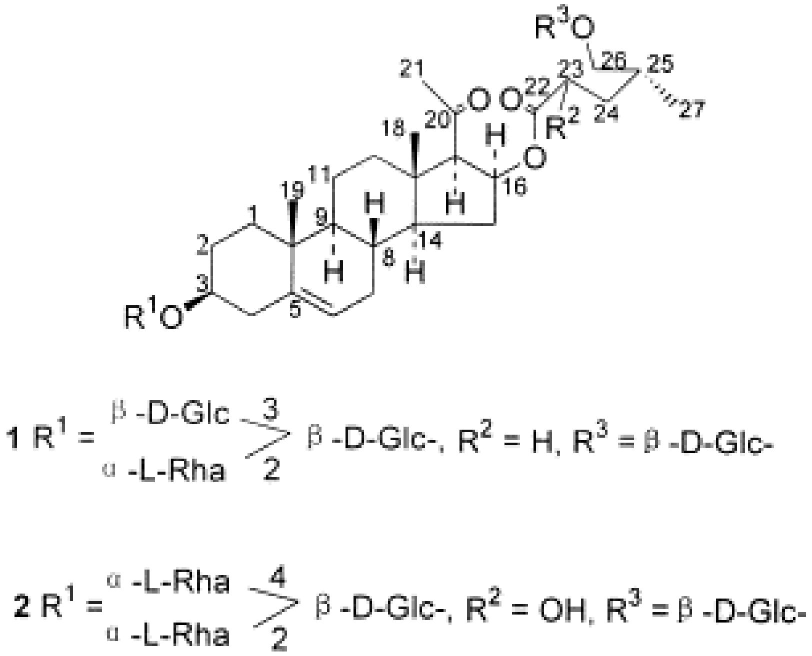


Figure 5. Two novel furostanol; Sapon*ins* 1 and 2 (Ozo et al., 1984).

Antioxidants potential of yam

The oxidative damage and human diseases caused by environmental chemicals involves the free radicals resulting in cellular damages, such as cancer and cardiovascular diseases. Natural antioxidants are very important, play major role in the oxidative prevention by safely interacting with the free radicals, and terminate the chain reaction before vital molecules are damaged. The phenolic compounds flavan-3-ol, such as catechin or epicatechin, procyanidin, dimers B-1 and B-3 have been reported in D. *alata*, D. *cayenensis*, D. *cirrhosa*, D. *dumetorum*, D *rotundata* and D *bulbifera* (Gao et al., 2002; Sautour et al., 2006). Likewise, presence of phenolic acid compound has been reported in Nigerian brown yam. The browning of the yam flour was as a result of the polyphenolic compounds in yam which undergo poly-phenolic oxidase-catalysed reactions to form o-quinones, their primary oxidation products, which then react with other components to form brown polymeric compounds (Farombi et al., 2000). Also, amino acids and proteins in the yam, when heated, can react non-enzymatically with sugars forming brown-colored compounds commonly called Maillard reaction products (Maillard, 1912). Browning reaction products such as pyrazines and acetylfurans have been reported to exhibit antioxidants activity to ameliorate peroxidative damage, induced by free radicals and xeno-biotics, to membranes and tissues. Additionally, *Dioscorea* sp of yam tuber from Nepal was reported to be a natural antioxidant source. The phenol content ranges from 13 -166 mg/100 g was observed, the organic acids; succinic acid, citric acid, malic acid and oxalic acids were 1316 mg/100 g, 274 mg/100 g, 147and 110 mg/100 g, fresh weigh respectively (Bhandari and Kawabata, 2004b).

Anti-diabetic potential of yam

Nimenibo–Uadia (2003)**,** reported the presence of saponins, flavonoids and cardiac glycosides from *D. dumetorum* during the phytochemical screening of the aqueous extract of the tuber. The author demonstrated significant hypoglycaemic activities which at ($p<0.05$) considerably reduced elevated blood levels of triacylglycerol, cholesterol and β–hydroxybutyrate associated with alloxan-induced diabetes mellitus.

Natural food colorant of yam

Anthocyanins (Figure 6) are mostly from vascular plants and are amongst the most utilized vegetable colorants in the food industry. They are an important, healthy, harmless colorant pigments. Due to their water-soluble ability, their incorporation in aqueous media is much easy. They have been extracted from grapes, berries, red cabbage, apples, radishes, tulips, roses and orchids (Shoyama et al., 1990). From the purple type of water yam species, some new types of Anthocyanins have been isolated. Three new anthocyanins; Alatanin A, B, and C were isolated from *D alata* of Philippine origin and were reportedly very stable in neutral aqueous solution (Yoshida et al., 1991). Likewise two new anthocyanins, cyanidin and peonidin were reportedly isolated from *D alata* originated from Sri Lanka (Shoyama et al., 1990). The purple colorant from yam has found to be very useful in several food applications as shown in figure 7.

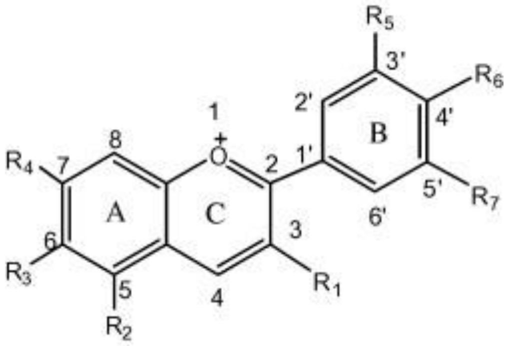


Figure 6. General structure of anthocyanin (Bhandari and Kawabata, 2004a)

Figure 7. Food colorant from yam and their food applications

Processing of yam products

Yam undergoes several processing steps for it to be converted into edible forms. This is shown in Figure 8. Depending on the intended final products, yam processing involves combination of techniques starting from washing, size reduction, peeling, fermentation, pounding, roasting, boiling, frying, steeping, dehydration, grinding and packaging. The first step is the washing, which is carried out to remove adhered soils and stones and make handling in subsequent processing steps easier. Peeling is required to remove a layer of about 2mm thickness of the yam peels of using knife and then followed by cutting. Peeled yams are cut into the smaller sizes to be able to fit into pot and plates and, then boiled for approximately 30 min. At this stage, yam could be consumed as boiled yam and, usually served with fried egg or soup. Furthermore, partially boiled yam could be subjected to frying to produce fried yam. In addition, peeled yam can be roasted or grilled prior to consumption. Another usual practice it to make fried yam ball is by grating peeled yam, then make into ball and then fried. Some spices might be added prior to frying.

Yam is very high in moisture; therefore, it is processed to dried flours with longer shelf life. Yam flour can either be fermented-brown or non-fermented-white yam flour. The changes in color was attributed to browning reactions during fermentation as a result of the presence of water-soluble phenolic substances (Achi and Akubor, 2000). In Nigeria, until recently, brown yam flour is popular and is used to make brown dumpling-structured paste (called 'Amala'). 'Amala' is produced by reconstitution of the brown flour in boiling water under continuous stirring prior. Though white dumpling structured balls are also been made, its processing method involves pounding of freshly boiled yam using mortar and pestle to give the final product called pounded yam (Ukpabi et al., 2008). However, this method is highly strenuous and labor, intensive. So, to overcome the problem associated with pounded yam production, white yam flour was recently developed. White yam flour is then reconstitution in boiling water accompanied with stirring to give the dumpling structure similar to that of pounded yam (Mestres et al., 2004).

Although, consumer perception revealed high acceptability for white yam flour and of high aesthetic value, brown yam flour is much popular though because of convenience in production. More so, most of the white yam flour produced are exported outside of the country. Figure 8 below shows the method of yam flour processing. The major difference in the two processes is the presence or absence of browning reaction that occur during the steeping stage. Natural enzymatic browning would be allowed to occur during the production of fermented-brown yam flour, unlike that of white flour. Sodium benzoate (0.1%) is added during the washing and conditioning stages to prevent browning (Omonigho and kenebomeh, 2000).

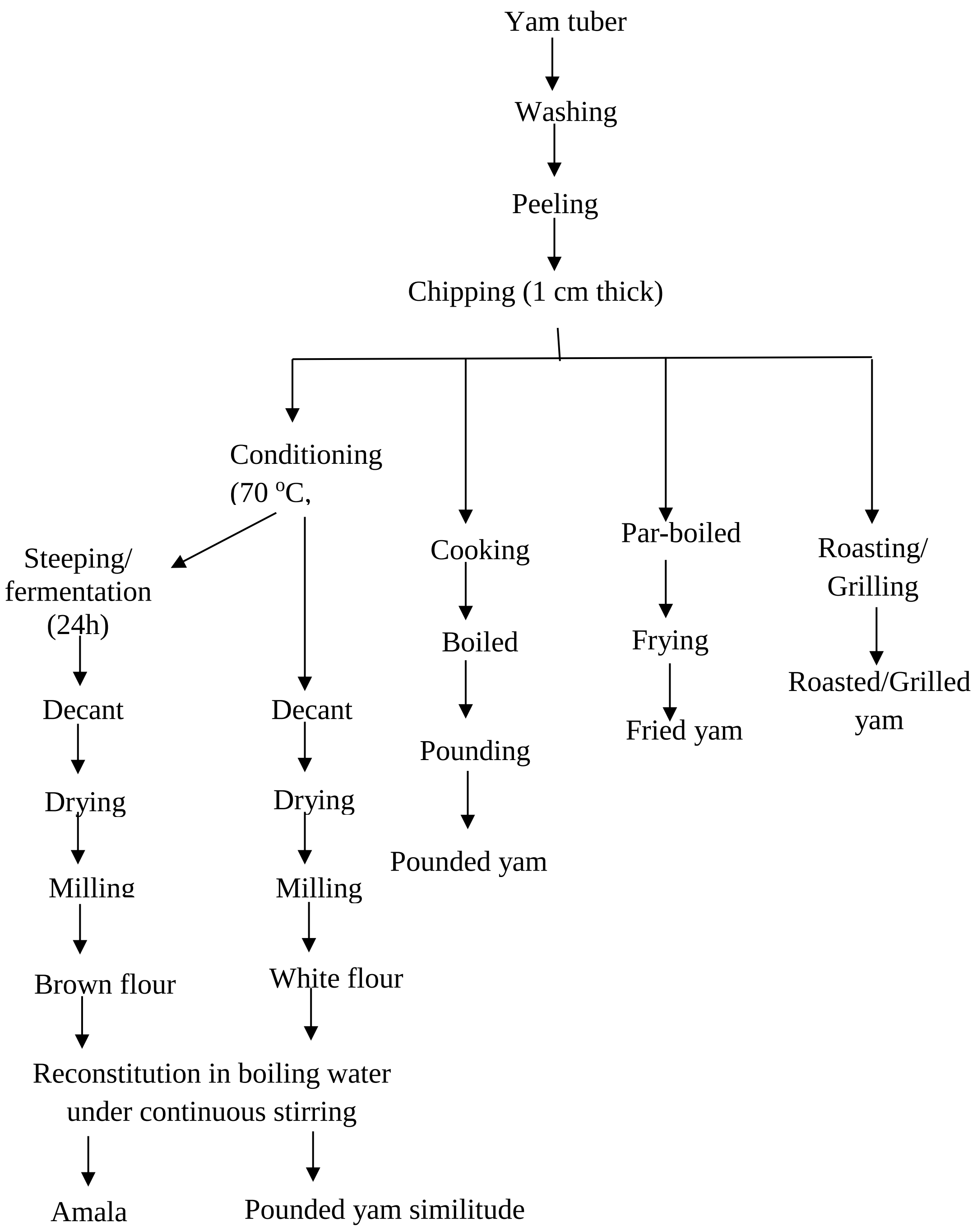


Figure 8. Flow chart to product different products from yam (Modified from Ukpabi et al., 2008)

Composite flours

Wheat (Triticum aestivum L.) and their classes

Cereal grains have been the principal component and a great source of nutrients in human diet for decades. They are recognized as staple foods and a major player in shaping human civilization around the world. Cereals include rice, wheat, maize, oat, barley and to a lesser extent, sorghum and millets (Jayakody et al., 2007).

Wheat belongs to the Poaceae family of the monocotyledous flowering plant known as grass and genus *Triticum*. It is considered as cereal since it is primarily cultivated for the edible component of its grain for human consumption as food and for livestock feed. Wheat is the third most consumed important staples and accounts for one-third of total grain production. It is one of the most important sources of dietary protein for humans, critical to daily survival of billions of people worldwide (Gooding et al., 2009). The world's largest producers of wheat are the EU-27 countries followed by China, India, Russia and the United States. Wheat grain is the third largest field crop produced in the U.S besides corn and soybeans (Awika et al., 2011).

In 2015, U.S. wheat production represented 9% of the world total, with production of about 2.14 billion bushels. Although the term wheat describes a number of species and subspecies in the genus *Triticum*, the most important are the hexaploid common wheat (*T. aestivum* subsp. *aestivum*), also known as the bread wheat, which account for more than 90% of the world wheat production (Mekonnen and Hoekstra, 2010). In North America, *Triticum aestivum* wheats are divided into soft and hard wheat cultivars, based on the force required to crush the kernels (Delcour et al., 2012). At present, North Dakota is the largest wheat producing state by volume with 340 million bushels, Kansas ranking second, with 245.5 million bushels while Montana is the third in ranking with 205 million bushel (US wheat statistic, 2016).

Wheat production in the US can be categorized into six major classes, with each of the class suited for different end-uses. hard red spring for bread flour that can also be utilized for high-protein blending flour; hard red winter for bread flour; soft red winter for cakes, cookies, and pastries; hard white for whole wheat products; soft white for Asian noodles, crackers, cakes, and cookies; and durum for pasta production. Hard red spring and hard red winter account for 60% of production total, soft red winter accounts for 22% production total, white wheat accounts for 14% of production total, with Durum having the least production total of 4% (Bushuk and Rasper, 1994; Shewry, 2009).

Wheat based composite flours

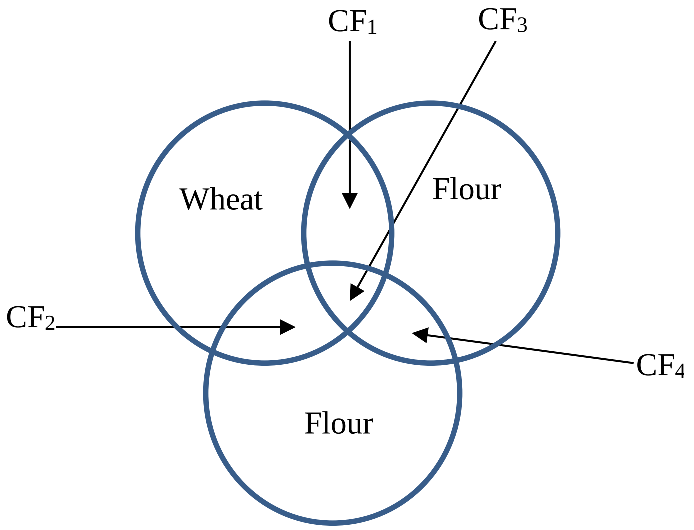
Composite flour is defined as a blend of wheat flour and flour from other sources. For wheat-based composite flour, portion of wheat flour is replaced by flours from locally grown food crops, starch, or hydrocolloid. Likewise, composite flour could consist of binary or ternary flour mixtures wholly from non-wheat sources. Leavened bread, pastry product, unleavened baked product, pasta, or snack food have been reportedly made from the flour mixture (Bojnanská et al., 2012; Shittu et al., 2007). The development of composite flours is aimed to achieve the improvement nutrition and functional qualities of wheat flour. Composite flour is of utmost benefit to developing countries as it promotes the exploration of some important native plant species, enhances the nutritional supply of protein, and promotes domestically grown products (Bugusu et al., 2001).

Development of suitable wheat-based composite flours has attracted great attention in developing country most especially for economic reasons. Numerous initiatives have been underway including compulsory inclusion of 10% cassava flour into wheat flour for bread making in Nigeria. The Food and Health Organization (FAO) in 1964 has equally proposed including of cassava, yam, maize and others to partially substitute wheat flour for temperate countries. It was further stated that inclusion of domestic grown products into wheat for production of confectionaries and bread would be of great economic and nutritional advantages. The rising call for development of composite flours is tantamount to call for scientific research required for new product development. Researches in composite flour and their products have investigated the following factors:

i. The type of non-wheat flours

ii. The percentage of inclusion of non-wheat flour in composite flour and

iii. The effects of different treatments of non-wheat flour on composite flour.



CF_1 and CF_2 : Binary Composite flours

CF_3 : Tertnary Composite flour

CF_4 : Non-Wheat based composite flour

Figure 9. Venn-diagram of composite flour

Literature search shows that numerous binary composite flours have been investigated; but only few studies have been done on ternary wheat based composite flours (Menon et al., 2015; Noorfarahzilah et al., 2014). This concept is presented in figure 9 as a Venn-diagram. The acceptable levels of different flours in wheat-based composite flour for bread making are shown in Figure 10. To arrive at this value, researchers have investigated the effects of different percentages of wheat flour substitution on the properties wheat flour and products. It is envisaged that composite flours should exhibit similar properties, if not better, compared to that of refined wheat flour. The acceptability level in wheat-based composite flours varies for different flours with buckwheat, a pseudo cereal, has the highest acceptability level of 30% (Noorfarahzilah et al., 2014). This might be due to different in physicochemical properties of the other flours that were added to wheat flour.

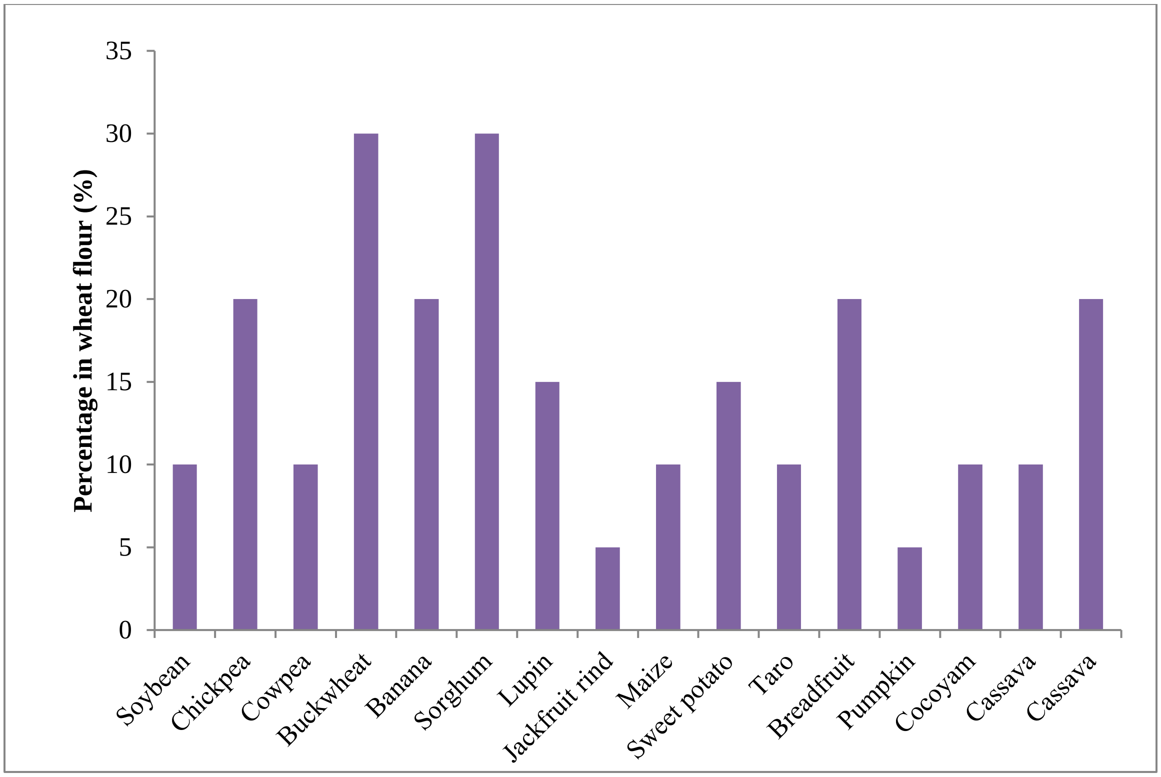


Figure 10. Acceptable level of different flours in wheat-based composite flours (Adapted from Noorfarahzilah et al., 2014)

Many studies have investigated the chemical, physicochemical, functional, nutritional, and rheological properties of composite flour from food crops, legumes, roots and tubers such as corn, millet, potato, banana, sorghum, beans, sweet potato and cassava. The findings from previous works related to this area of research are presented in the following paragraphs.

Properties of wheat based composite flours and products

In this section, effort has been made to concisely review the properties of wheat-based composite flours including properties of their bread and tortillas. Although, numerous numbers of wheat-based composite flours have been investigated, little work has been reported on wheat-yam composite flour and their products.

Nutritional properties of wheat based composite flour

Enrichment of protein

The impacts of inclusion of other flours into wheat flour on the sensory qualities, rheology characteristics, and nutritional values of different baked products have been reported. Flours from corn, barley, cassava, soy, and chickpea are the most widely utilized to produce composite flour for bread making. Legume proteins from various sources, including lupin flour (Pollard et al., 2002), soy flour (Ribotta et al., 2005), germinated chickpea flour (Luz and Berry, 1989), chickpea flour (Gómez et al., 2008), and germinated pea flour (Sadowska et al., 2003) have been successfully used in baked products. This main reason is that legume proteins have high lysine, an essential amino acid that is lacking in wheat. Although wheat is lacking in lysine, it is a good source of sulphur-containing amino acid. Substituting part of wheat flour with legume flour makes them a great complement for each other. Wheat-legume composite flour will therefore be rich in lysine and sulphur-containing amino acids. This promotes a protein-enriched product with improved amino acid balance (Mohammed et al., 2012).

Micronutrient enrichment

Maize flour could supplement wheat flour since it is a rich source of many important vitamins and minerals, including potassium, phosphorus, zinc, calcium, iron, thiamine, niacin, vitamin B6, and folate (Watson, 1997). Likewise, germinated rice flour was stated to be advantageous and is preferably used over raw rice flour for bread making since the increasing germination time improves the physical and nutritional quality of bread (Noorfarahzilah et al., 2014). Fruit flour has also been used in development of composite flour for bread making. Banana flour was used to enhance bread phytochemical compound. The phenolic content was reported to be significantly higher in the banana flour complemented bread as compared to those made from refined flour (Zuwariah and Aziah, 2009). Likewise, the viability of using agricultural by-products such as mango seed kernel in the development and enrichment of leavened bread was investigated. The composite flour made from mango seed kernel flour, sprouted mung bean flour, soy flour, and refined wheat flour in the ratio 5:5:5:85, respectively. This ratio was stated to be the best formulation with similar organoleptic and physical properties as refined wheat flour breads (Menon et al., 2015).

Increase in fiber content

Increasing the fiber content of foods including wheat-based products has become one of the goals for food developers and researchers. The increase in demand of high food fiber has been associated with its health implications. Among the focus of recent researches is to introduce dietary fiber in food products. Dietary fibers - a group of compounds contains a mixture of oligosaccharides and polysaccharides - include indigestible cellulose, inulin, hemicellulose, lignin, resistant gums and mucilage. Soluble fiber possess hypocholesterolemic effect and insoluble fiber is capable of reducing the risk of colon cancer (Freitas et al., 2004).

The dietary fiber of wheat flour could be increased through addition of flour from high fiber plants such as yam. Malted rice flour supplementation significantly reduces the glycemic index of bread, and hence, a better choice for management of diabetes (Veluppillai et al., 2010). In another study, crude fiber contents were recorded in bread supplemented with toasted African bread fruit seed flour (Akubor and Obiegbuna, 2014). Numerous studies have been reported that the inclusion of α, β-glucan-rich barley fraction into wheat flour increase the fiber content of the bread products (Alves et al., 2002; Noorfarahzilah et al., 2014). Table 3 shows the different sources of dietary fiber for production of functional bread.

Table 3. Different sources of dietary fiber for production of functional breads with useful technological applications (Alves et al., 2002)

Dietary fiber sources	Technological and functional properties
Buckwheat	Improvement of antioxidant properties and functional composition Enrichment of antioxidant and antiradical activities
Maize and oat flour	Enhancement of loaf volume, crumb softness and overall acceptability
Rice bran (B-type hemicellulose)	Higher ability to bond water and fat
Rice bran fiber	Acceptable level of dietary fibers and development of favorable rice taste
Rye flour	Improvement of digestion and digestive issues Increase of antioxidative properties
Barley flour	Increase of antioxidant properties
Soybean flour and barley flour	Improvement of protein, total lysine, dietary fiber, β-glucan, phytic acid, polyphenol contents, Increase of trypsin inhibitor activity
Soy flour	Increase of moisture, protein, fat, crude fiber contents, decrease in carbohydrate and energy contents, decrease in bread volume, best overall quality acceptability Decrease of bread volume, increase of moisture and protein contents, Improving of crumb and crust color, having good flavor Increase of organoleptic characteristics score such as bendability, appearance, flavor, taste, crust texture and overall acceptability properties of bread
Hydrocolloids and prebiotic Oligosaccharides	Higher resistant starch, lower digestible starch and glycemic index, Higher sensory scores, longer shelf life

Sensory properties

Generally, the supplementation of wheat flour with no more than 20% legumes composite flour, from soy, lentil, and peas have been reported to greatly improve the quantity of nutritional protein in bread (Bojnanská et al., 2012). Nonetheless, the acceptance of legumes/wheat bread is low due to the undesirable odor imparted by the legume composite flours associated with the beany and grassy flavors (Noorfarahzilah et al., 2014). Effort to reduce the beany flavor of wheat-soy composite flours using oxidizing improvers and surfactant was not successful.

The incorporation of maize flour at a level of up to 40% and defatted maize germ flour at a level of up to 15% is reported to produce bread without any negative effects in quality attributes. The product was with reasonable acceptance and has the potential of offering a promising, nutritious and healthy alternative to consumers (Păucean and Man, 2013). The inclusion of malted rice flour at 35% level has been reported to produce bread with better consumer acceptability and nutritional value than those from refined wheat bread. Possible reason for the enhancement of sensory attributed of malted rice include the increased gas production in the dough, improved crust color formation, a better crumb moisture retention and enhanced flavor development (Veluppillai et al., 2010).

Rheological properties of composite flour and end products

Change in protein and fiber compositions of wheat flour through the substitution with other flour sources has been reported to cause inevitably effect on the flour rheological properties. Increase in the amount of substation of wheat flour with sorghum flours resulted in decreased in farinograph properties (dough water absorption, development time, stability time and farinograph quality number while the mixing time index increased. The extensogram results showed that resistance to extension and dough extensibility decreased with increase in sorghum substation in the composite flour (Abdelghafor, 2015). Increase in substitution of wheat flour with taro flour caused increase in farinograph water absorption, dough weakening and resistance to extension but the dough stability, mixing time and dough extensibility were decreased (Ammar et al., 2009). Increased mixograph absorption was with increase in percentage of legumes (chickpeas, peas and soybeans) flours in wheat-based composite flours. Fermentation of legumes prior to inclusion of into wheat flours resulted in higher stickiness unlike roasted and cooked legumes (Baik and Han, 2012). Increase in addition of fiber such as β-glucan cause increase in farinograph water absorption. The farinograph water absorption of dough also increase as the molecular weight of added fibers increases (Skendi et al., 2009).

In the dough rheological properties of wheat tortilla studies by Torres et al. (1994), where partial substitution of 30% wheat with sorghum flour tortilla production was done. The reports stated that there were no significant differences in the consistency of wheat dough and composite dough. However, higher viscosity and maximum stress during the relaxation was observed in the wheat/sorghum dough. The appearance of the composite dough was negatively imparted due to the presence of undesirable black specks. Inclusion of flax seed flour into wheat flour reported led to increase in Farinograph water absorption, mixing tolerance, and dough development time however, the dough stability and extensibility decrease with increase in percentage of flax seed flour (Jayakody et al., 2007).

Generally, a progressive increase in the substitution of wheat flour with flour from other source causes a decrease in dough quality, which has been attributed to reduced flour strength, weakened dough and reduced gas retention capacity. Another reason is the dilution of flour gluten content leading to the disruption of the wheat protein-starch interface by non-wheat proteins (El-Adawy, 1997; Khalil et al., 2000).

End-products qualities of wheat-based composite flours

Bread making process (yeast leavened pan bread)

Bread, a leavened product, is one of the most popular staple foods around the world. It is a simple, convenient, and nourishing item and its production and consumption dates to the Neolithic era. Bread is mostly made from wheat flour, the fermentation of sugars provided by wheat starch, added sugar and by baking in the oven with dry heat (Mondal and Datta, 2008). Two types of formulation are involved in the bread baking process: the true percent which expresses the total mass of all ingredients as 100%, and the baker percent which represents the ratio between ingredients needed when baking (Miñarro et al., 2012). Due to its simplicity and easier concept of formulation changes, the baker percent is mostly employed where the mass of the flour is expressed as 100%, and so, the total percentage of all ingredients will be greater than 100%. The other essential ingredients needed in bread baking are water, yeast and salt (Kenny et al., 2000). Additional ingredients may include sugar, shortening, alpha amylase, ammonium phosphate, eggs, milk, and oxidizing agent may be added to improve the functional property, nutritional property, rheological property of the dough, as well as the overall quality of the final loaves (Giannou et al., 2003). Straight dough making process, one of the bread baking systems, is relatively fast to make, and involves mixing of all ingredients to form a dough. Its fermentation time varies between 2-3 hours, and is followed by dividing and rounding, intermediate proofing, bread molding and panning, final proofing and lastly baking. The process does not require specialized equipment, requires little or no trained skill workers and is not labor intensive (Xiao et al., 2006).

Properties of bread from wheat-composite flour

The effects of substitution of wheat flour with different flours on the bread baking qualities have attracted researchers' attentions due to the volume of scientific works in this aspect. The characteristics of breads vary depending on the composition of the composite flours. Inclusion α, β-glucan-rich barley fraction in wheat flour is accompanied by a decrease in loaf specific volume, the extent of decrease depending on β-glucan level. The circumference of balady bread and specific volume of pan bread was reportedly decreased as the percentage of sorghum flour increased in wheat-based composite flour. The texture properties in terms of cohesiveness and resilience of pan bread were decreased as sorghum content increased in the composite flour. Also, the sensory properties equally decrease as level of sorghum was increased (Abdelghafor, 2015). The bread made from wheat-based composite flours containing roasted legumes flours exhibited high loaf volume and more appealing aroma than the cooked legumes (Baik and Han, 2012). Addition of maize flour into wheat flour caused adverse effect on the resulting bread samples such that the sensory properties – hardness and springiness – deteriorate rapidly during storage (Begum et al., 2014).

In another research, raw, germinated and fermented cowpea flours were incorporated into wheat flour and the bread qualities were investigated. The bread volume was reportedly decreased with increase percentage of cowpea in composite flour. The sensory and acceptability properties of bread were equally reduced because the bread became compact as the percentage of cowpea increased (Butt et al., 2011).

Tortilla processing and production

Tortilla is a soft thin flat bread made from either ground corn or wheat. Historically, tortilla is a staple food native to Spanish and Mexican people. It is originally made from corn made by cooking maize in alkali, steeping and washing the cooked maize, otherwise referred to as nixtamal, grounding the nixtamal into masa, then forming it into a flat dough pieces and cooked on a hot surface to form tortilla (Arámbula et al., 1999; Torres et al., 1994). However, with Europeans integration and migration, the use of wheat for tortilla production was introduced. Wheat tortilla is a flat, unleavened, yeast-free, water based, pressed dough made of wheat flour. The flattened dough is placed in an oven until it puffed. In USA, commercial wheat tortilla flour is generally milled from hard red winter wheat (Guo et al., 2003). Ingredients for making tortilla include: flour, salt, shortening, water, some chemical leavening agents, and dough conditioner (Whitney et al., 2011). The difference in wheat tortilla and pan bread is the difference in baking duration, moisture content, fat and rheological properties of the dough (Anglani, 1998).

Tortilla market in the U.S is among the fastest growing wheat based products and gaining increased popularity in the baking industry with consumption of about seven billion pounds tortillas or an equivalent of one tortilla per person each day (Pascut et al., 2004). Tortillas are consumed as bread to complement a food dish and are also used as a wrap or a carrier for different fillings. As such, tortillas must resist folding and tearing without cracking or breaking (Ramírez-Wong et al., 2007). Flexibility has been recognized as one of the most significant textural characteristics of the tortilla as this will allow the tortilla to be folded and rolled without cracking. A good quality tortilla is described as one that resists tearing, with a soft crust, and a layered and puffy crumb (Bello et al., 1991; Waniska, 1999). Generally, the rollability, pliability, flexibility, and stretching of tortillas reportedly decrease with increase time during storage (Platt-Lucero et al., 2012). This has been attributed to starch reorganization after its preparation, where the adjacent linear chain of amylose or amylopectin form double helices via hydrogen bonding, and consequently aggregate to produce crystalline structures, otherwise known as retrogradation which alters the texture and nutritional characteristics of tortillas (Aguirre-Cruz et al., 2005).

Properties of tortilla from wheat-composite flour

The continuous search for healthier alternatives to conventional foods has invigorated composite flour development. Substitution of wheat flour with flours from cowpeas, beans, sorghum and maize for making of tortillas has been conducted. The previous reports (Arámbula et al., 1999; Román-Brito et al., 2007; Tovar et al., 2003; Yau et al., 1994) have shown that tortilla from composite flour exhibit different characteristics compared to that of refined wheat flour.

The incorporation of hydrocolloid such as xanthan gum, carboxymethyl cellulose (CMC), alginates, guar gum and carrageenan have been reported to improve and preserve the texture of tortilla (Platt-Lucero et al., 2012). The pliability of tortillas made from wheat-sorghum composite flour decreased faster than that of control (refined wheat flour tortillas) (Torres et al., 1993). However, xanthan gum incorporation at 0.25%, 0.50%, and 0.75% was reported to improve tortilla texture by increasing tortillas flexibility and decrease in hardness during storage at 4°C (Román-Brito et al., 2007). Likewise Yau et al. (1994) reported extended stability of tortillas with xanthan gum at 1% along with other additives during their storage at 25°C. In another finding, tortilla prepared with extruded corn flour with CMC, gum arabic, guar gum and xanthan gum at 0.5% addition was stated to give a good textural characteristics with regards to their rollability, extensibility and shear force (Arámbula et al., 1999).

Tortilla prepared with beans flour (Taco), was reported to retain most of the well-known beneficial slow digestion features of starch with predicted glycemic index value of 48%. Hence, a noteworthy study, considering the high postprandial metabolic response that may be anticipated for the cereal-derived counterpart with to 56% glycemic index value (Tovar et al., 2003).

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OBJECTIVES AND NEEDS STATEMENT

Research objectives

The present study was conducted to:

1) Determine physical and chemical properties of fermented and unfermented yam flours and compare them to the properties of refined wheat flour.
2) Evaluate the physical, rheological and bread quality characteristics of composite flours prepared using fermented and unfermented yam flours blended with wheat flour.
3) Evaluate the physical, rheological and tortilla quality characteristics of composite flours prepared using fermented and unfermented yam flours blended with wheat flour.

Need statement

The continual rise in the population growth has inevitably resulted in high food demand and the worldwide consumption of wheat flour based products has increased. Currently, there is rise in nutritional awareness, so the consumers are not only demanding food to meet their needs but also be high quality food. This development has fueled the need to explore, develop and make alternative composite flours from local staple crop sources to complement the nutrition of wheat flour. Composite flours from staple crops such as rice, sorghum, cassava, yam, and sweet potatoes have been used to complement wheat flour for bakery foods. Incorporation of yam flour with wheat flour would enhance nutritional value by increasing dietary fiber, and supply vitamins A and C that are lacking in wheat flour.

The review of studies on yam and wheat-based composite flours has shown some potential contribution to nutritional and functional properties of wheat flours and products. The type and percentage of non-wheat flour caused some desirable and undesirable changes to the qualities of wheat flour and products (most especially bread and tortillas). Proper investigation is therefore required prior to development of composite flours containing wheat and yam flours for bread and tortilla production.

EXPERIMENT 1: COMPARATIVE STUDY ON CHARACTERISTICS OF WHEAT FLOUR AND FERMENTED AND UNFERMENTED YAM FLOURS

Abstract

In this study, properties of refined wheat flour (RWF), fermented (brown) yam flour (FYF) and unfermented (white) yam flour (UYF) were compared in terms of their chemical composition, physicochemical characteristics, and pasting and rheological properties. In comparison to RWF, FYF and UYF have lower protein, arabinoxylans, phytic acid, phenolic acid and fat but have higher ash, total starch and fiber contents. The amylose content of UYF (17.3 %) and FYF (22.6%) were lower than that of RWF (25.1%). Mineral analysis revealed that the potassium content of FYF and UYF were significantly ($P<0.05$) higher than that of RWF, but, the flours were not significantly ($P<0.05$) different in terms of their calcium content. Results of the Englyst assay showed that all samples exhibited high estimated glycemic index (eGI) as their eGI values were above 90. Thermal studies showed that FYF and UYF required more energy for gelatinization than RWF. The pasting properties revealed that the FYF swelled more rapidly than RWF due to its higher peak viscosity and shorter peak time. Likewise, the FYF is expected to retrograded faster due to its high set back compared to that of RWF. The firmness of gels increased with increasing number of days. Difference in the properties of FYF and UYF is due to difference in their processing conditions and the role of polyphenol oxidase during fermentation. In conclusion, FYF and UYF exhibited different characteristics compared to that of RWF and may be blended with RFW to create composite flours for novel applications.

Introduction

Yam a monocot, root and tuber climbing plant – is the major staple and main calorie source in some tropical regions. During the harvest season, yam is very cheap and affordable source of food for low income families (Zaidul et al., 2008). Yam is unpopular in some other parts of the world where it is considered as inferior to cereal due to its low protein content. In spite of its low protein, yam consists of a good proportion of all the essential amino acids and a fairly good source of minerals and dietary fiber (Ukpabi et al., 2008). Since the moisture content of yam is high, thus prone to perishability, the processing of yam to flour as a preservative measure is necessary for extended shelf life and minimized economic loss. In the South-Western region of Nigeria, yam is usually processed into two types of flours – fermented-brown yam flour (FYF) and unfermented-white yam flour (UYF). The fermentation process during the production of FYF involves enzymatic browning; a reaction that is prevented during the production of UYF.

The factors affecting the processing of yam to FYF has been carried out and sensory properties of hot-water reconstituted product (Amala) were stated to be acceptable to consumers (Ukpabi et al., 2008). Achi and Akubor (2000), studied the microbiological characterization of FYF and reported that there was increase in microbial population with a fall in the pH from 6.2 to 5.4 during the 24 h fermentation period. Also, in the work of Adegunwa et al. (2011), who evaluated the processing effect on the yam nutrient reported that processing method significantly impact the nutrient content, and established the traditional sun-drying methods as the preferred drying method. Mestres et al. (2004) evaluated the sensory and biochemical properties of reconstituted FYF (Amala), and reported that the slight bitterness and darkness was associated with the phenolic content and the level of acidity. The fermentation attributes of the 'Amala' were linked to the presence of organic and lactic acid. The possibility of root and tuber starches in noodles, and other wheat-based foods has been investigated (Abdelghafor et al., 2011; Ahmed et al., 2012; Eddy et al., 2007). Despite being an important source of calories, root and tuber crops research and their products are still at basic stage (Hahn et al., 1989).

Adequate understanding of the properties of flour is important for product formulation and development. The compositions of flour samples have great impact on the flour functionalities. Flours are made up of mostly starch along with other compositions including lipid, protein, minerals, phenolic compounds and fibers. Starch is one of most important natural heterogeneous macromolecules found in food materials. The proper understanding of the gelatinization of the starch granule is very crucial (Marques et al., 2006). Also, protein and phenolic compounds have been stated to influence food functionality. In this study, the chemical composition, physicochemical characteristics and rheological properties of composite yam flour (fermented and unfermented) were investigated and compared to that of refined wheat flour to ascertain if there exist difference among the flour.

Materials and methods

Materials

All the chemicals and reagents were of analytical grade. White (unfermented) and brown (fermented) yam flour used in this study were purchased at Oja Oba market Ibadan, Oyo state in Nigeria. The wheat flour used was hard spring wheat patent flour obtained from North Dakota Mill (Grand Forks, ND).

Flour composition and quality

Proximate analysis of the fermented and unfermented yam flours and refined wheat flour was done to determine the flour quality. An air oven method according to the AACCI Approved method was used to determine the moisture content of the flours by drying the flour and weighing the residue (AACCI Approved Method 44-15.02). Protein content (14% moisture basis, mb) of each of the flours was determined in duplicate by the combustion method following the AACCI Approved method using a LECO FP428 nitrogen analyzer (LECO Corporation, St. Joseph Michigan) (AACCI Approved Method 46-30.01). Ash determination was done using the AACCI Approved method by accurately weighing 3 g of sample to a pre-weight porcelain crucible. This crucible was then placed into a muffle furnace set at an initial temperature of 350°C for one hour and then raised to 590°C overnight. After 24 hours of ashing, the crucible was placed in a desiccator to cool and the weight of the crucible recorded for the final weight of the dried sample to be determined (AACCI Approved Method 08-01.01). Crude fat content of the flour samples was determined by ether extraction (AOAC Official Method 920.39), total starch and starch damage of the flour samples were respectively measured using (AACCI approved methods 76-13.01 and AACCI Approved Method 76-30.02). The soluble, insoluble and total dietary fiber were analyzed according to AACCI Approved Method 32-07.01 with procedures modified for the ANKOM TDF Dietary Fiber Analyzer (Ankom Technology Corp., NY, USA). The flour color was determined using a Minolta colorimeter to determine L*, a*, and b* values on the CIE Lab color scale.

Amino acid profile and mineral contents determination of flour samples

The amino acid profile was determined according to AOAC Official Method 982.30 E(a,b,c). Acid hydrolysis of the samples was done using HCl (6 mol/L) under nitrogen at 110ºC. Prior to analysis, alkaline hydrolysis was conducted on the samples to result in a complete amino acid profile. For methionine and cysteine determination, performic acid oxidation of the samples was done, followed by acid hydrolysis. The three hydrolysates were then analyzed by an anion exchange chromatography amino acid analyzer with post-column derivatization (Simsek et al., 2016). Mineral content of the flour samples was determined according to AOAC Official Method 985.01 (a, b, d).

Extractable polyphenols

Extractable polyphenol was determined using aqueous-organic solvents with some modifications (Yu, 2008). Samples (0.5 g) were placed in 50 mL screw cap centrifuge tube, mixed with 10 mL of acetone/methanol/water acidified with HCl (3.5:3.5:3.0, v/v/v) and vigorously stirred by shaking for 16 h at room temperature. The solution was then centrifuged at 3,000 Relative Centrifugal Force (RCF) at 25° C for 10 min and supernatant was recovered and transferred to 50 mL beaker. Next, 10mL acetone/methanol/water (3.5:3.5:3.0) was then added to the residue, vigorously stirred for 1 h at room temperature, the solution was centrifuge (3,000 RCF for 10 min) and the supernatant recovered. The recovered supernatant were combined and the sample was then acidified to pH 2-4 with 2N HCl, thereafter, the solution was brought to a volume of 25mLwith acetone:methanol:water. This was used to determine extractable polyphenols. Ferulic acid was used to prepare a standard curve. Extractable polyphenols were determined by the Folin-Ciocalteau procedure (Saura-Calixto and Goñi, 2006). The results were expressed as ferulic acid equivalents. Residue of these extractions (EP-residue) was used for further analysis.

Hydrolysable polyphenols

Hydrolysable polyphenols was determined using alkaline hydrolysis (Yu, 2008). The residues of methanol/acetone/water extraction that was done for determination of soluble polyphenols residue was mixed with 10 mL 2N NaOH and incubated by placing in a water bath (Type: 89032, VWR International, PA, USA) with constant shaking at 30°C for 4 h. The solution

(3,000 RCF for 10 min) was centrifuge, and supernatants recovered and transferred to beaker. Next, 2 washings of residue/pellets with 5 mL 2N NaOH each was done, followed by centrifuging (15 min, 25 °C, 3000 RCF) and recovered supernatants were combined. The solution was then acidified to pH 2-4 with HCl and brought to a volume of 25 mL with water. This was used to determine the hydrolysable polyphenols by the Folin Ciocalteu method with a ferulic acid standard curve (Saura-Calixto and Goñi, 2006). The results were expressed as ferulic acid equivalents.

Polyphenol oxidase measurement

Measurement of polyphenol oxidase was determined following the method of Fuerst et al. (2006). Crude polyphenol oxidase of the samples was obtained by extracting 200 mg of flour with 1.5 mL of 10 mM L-DOPA, 50 mM MOPS (3-[N-morpholino] propane sulfonic acid), together with 0.02% Tween-20 at pH 6.5. Samples were incubated for 1 h with constant shaking and centrifuged at 10,000 x *g* for 3 min. The polyphenol oxidase activity was measured at absorbance of 475 nm. Control flour samples were assayed as described above but without L-DOPA substrate. The absorbance of control flour samples was subtracted from the absorbance of L-DOPA flour samples.

Phytic acid content determination

Phytic acid content of flour samples was determined using a modification of the method described by Guttieri et al. (2006) . Phytic acid was extracted with 0.2M hydrochloric acid overnight. The extract was diluted and the sample extracts and standard solutions were boiled before the addition of ferric ammonium chloride. After cooling on ice, the samples were added to microplates along with 2, 2-bipyridine-thioglcolic acid and the absorbance as read at 530nm using UV-Visible spectrophotometer. The phytic acid content was determined by plotting the absorbance of the standard curve against concentration.

Sugar (monosaccharide) composition determination

The monosaccharide compositions of wheat flour, white yam flour and brown yam flour, was determined following acid hydrolysis and alditol acetates preparation using the Gas Chromatography-Mass spectrometry. During the hydrolysis of the polysaccharide to its monomeric constituents, the flour samples (7 mg) were hydrolyzed with trifluoroacetic acid (TFA) (2 M, 250 µL) for 1 h at 121 °C. Myo-Inositol (75 µL of 10 mg/mL solution) was added to the hydrolyzed samples as an internal standard and dried under nitrogen (Gys et al., 2003). The excess acid was neutralized by adding NH_4OH (1 M, 100 µL). The resulting mixture contains the hydrolyzed products. The hydrolyzed samples was reduced by adding sodium borohydride ($NaBH_4$) in a dimethylsulfoxide (DMSO) solution (20 mg/mL, 500 µL) (Blakeney et al., 1983). In this step, aldose form of the sugars was reduced to an alditol by $NaBH_4$. If the reduction is not carried out acetylation of ring form of aldose complicates the chromatogram (in aqueous solution aldoses exist in equilibrium between ring form and open chain but alditols only occur as open chain). After reduction to alditols, excess $NaBH_4$ was decomposed by the addition of glacial acetic acid (ca. 300 µL) to the tubes and the samples was then acetylated.

Acetylation and Monosaccharide content using Gas Chromatography (GC)

Alditol acetates was prepared according to the method described by Blakeney et al. (1983) for the preparation of alditol acetates for monosaccharide analysis. 1-methylimidazol (100 µL) was added as a catalyst for the acetylation reaction. Acetic anhydride (500 µL) was added to the reduced monosaccharaides and the contents were mixed. The reaction was stopped with the addition of 4 mL of water. Methylene chloride was added to the tubes twice to extract the acetylated monosaccharides. Next, methylene chloride was evaporated with a stream of nitrogen and the samples was re-dissolved in acetone and transferred to vials for analysis in GC.

The derivatized alditol acetate samples were analyzed on a Hewlet Packard 5890 series II GC system with a Flame Ionization Detector (FID) (Agilent Technologies, Inc. Santa Clara, CA). Supelco SP-2380 fused silica capillary column (30 m × 0.25 mm × 0.2 µm) (Supelco Bellefonte, PA) was used in the GC system. The system parameters were: flow rate of 0.8 mL/min, 82.7 kPa flow pressure, oven temperature of 100 °C, detector temperature of 250 °C, and injector temperature of 230 °C. Mannose, galactose, glucose, arabinose and xylose content of the samples were obtained.

Total Arabinoxylans (TOT-AX) and Arabinose to Xylose Ratio (A/X) determination

Arabinoxylans was calculated as the sum of xylose and arabinose monosaccharides. The arabinose to xylose ratio was calculated by dividing the total arabinose by total xylose as determined by GC analysis.

Starch hydrolysis determination

The *in vitro* assay was conducted for starch digestibility determination following the method described by (Englyst et al., 1992).The flour samples (0.3 g) with 0.1 mol/L sodium acetate buffer (20 mL, pH 5.2) were incubated at 37°C, 5mL of enzyme mix solution at 1 min intervals was added to each tube (amyloglucosidase, invertase and pancreatin). The enzyme solution prepared is as follows: amyloglucosidase solution (70 U/mg, 24 mg in 12 mL of deionized water), invertase solution (300 U/mg, 60 mg in 8 mL of deionized water, pancreatin solution (3 g in 20 mL of deionized water, stirred for 10 min at 4^{o}C and centrifuged). Aliquots of the digest (0.5 mL) were taken every 20 min for 180 min, mixed with 5 mL of absolute ethanol and centrifuged to determine the amount of glucose released by reaction with glucose oxidase/peroxidase (GOPOD). A commercial white bread purchased from a local grocery store was analyzed and used as the reference material. The rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) were determined as expressed in %. The hydrolysis index (HI) was obtained by dividing the area under the hydrolysis curve of the sample by the area obtained for commercial white bread (hydrolysis curve, 0 min to 180 min). The estimated glycemic index (eGI) of the samples was calculated using the equation: eGI=8.198+0.862*HI (Ovando-Martínez et al., 2011a).

Starch characterization by High Performance Size Exclusion Chromatography with Multi Angle Light Scattering (HPSEC-MALS)

Changes in physicochemical properties, such as starch molecular mass was investigated in from flour sample. For determination of starch molecular mass and apparent amylose content, the starch was extracted from flour samples following the method of Simsek et al. (2013). The extracted starch was dissolved in potassium hydroxide: urea solution and heated for 90 min at 100°C. This was followed by neutralizing the samples using hydrochloric acid. The samples were then filtered prior to analysis by high performance size exclusion chromatography (HPSEC) with multi angle light scattering (MALS). The dn/dc value for calculation of the starch molecular mass was 0.146 (Simsek et al., 2013; You and Lim, 2000). The Debye model with a fit degree of one was used for calculation of the molar mass. The results were fitted to a first order polynomial model.

Thermal properties of flour samples

The thermal properties of the flour samples were measured using a differential scanning calorimeter (DSC-7 PerkinElmer Life and Analytical Sciences Inc., Waltham, MA). Flour sample (3.5 mg) and 8.0 µL distilled water were weighed into an aluminum pan. The pans were hermetically sealed and kept at room temperature overnight to attain an even distribution of water before heating the calorimeter. An empty aluminum pan was used as a reference. Each sample was heated under nitrogen gas from 10 to 100 °C at 10 °C per min. All analyses were carried out in triplicate. The enthalpy of gelatinization (ΔH), onset (T_o), peak (T_p), and conclusion (T_c) temperatures was computed automatically. The gelatinization temperature range was be computed as ($T_c - T_o$) (Zhang and Simsek, 2009).

Scanning Electron Microscopy (SEM) analysis of flour

The Scanning Electron Microscopy of refined wheat flour and yam flour was performed for starch granule morphology determination. Each flour sample was sprinkled onto carbon tape attached to aluminum mounts. Loose particles were removed using short bursts of compressed nitrogen gas. The sample was then coated with gold using a Hummer II sputter coater (Technics/Anatech Ltd., Alexandria, VA, USA). Images was obtained using a JEOL JSM-6490LV Scanning Electron Microscope (SEM) (JEOL, Peabody, MA, USA) (Zhang and Simsek, 2009).

Pasting profile of wheat and yam flours

Pasting properties of the flour samples were evaluated following the AACCI Approved method by using a Rapid Visco analyzer (RVA, Perten instruments, Springfield, IL) interfaced with a computer equipped with Thermocline software (Newport Scientific). Flour (3.5 g, 14% moisture basis) was added to 25 mL deionized distilled water in an RVA canister. The rate of heating and cooling in the Std1 profile was 12 °C per min, idle temperature was 50 °C, with the total run time of 13 min (AACCI Approved Method 76-21.01). Parameters recorded were peak viscosity (PV), hot paste viscosity (HPV), breakdown (BKD), cold paste (CPV) and setback (STB) viscosity. Measurements were reported in centipoise.

Gel texture analysis of wheat flour and composite yam flour gel

The flour paste from the RVA was used to measure gel texture using texture profile analysis (TPA) with a texture analyzer (TA-XT2i, Texture Technologies). The paste was stored at 4 ºC for 24 h. Samples were penetrated with a TA-53 cylinder probe (3 mm, stainless steel) to a distance of 15 mm, following the conditions used by Chávez-Murillo et al. (2008). The peak force of the penetration was reported as firmness (g-force) and the negative peak during retraction of the probe was reported as stickiness (g-force). The same analysis was done in samples stored at 4 ºC for 7 days.

Statistical analysis

The experimental design was a completely random design (CRD). Each treatment and measurement was carried out in duplicate. Data results were analyzed using statistical analysis software package, SAS System for Windows version 9.3, (SAS Institute, Cary, NC, USA). Treatment means were separated by Least Significant Difference test and the significance was defined at $P < 0.05$.

Results and discussion

Proximate composition of yam flours

Proximate composition of refined wheat flour and fermented and unfermented yam flour (Table 4) indicate that moisture, protein, fat, total starch, starch damage and fiber content of the flour samples were significantly ($P<0.05$) different. The moisture content is the percentage water by weight of the sample and is an indication of flour storability. The moisture content of UYF (5.7%) was significantly ($P<0.05$) lower than that of FYF (11.2%) and RWF (13.6%). Sun drying technique is usually being used for dehydration of fermented yam during the production of FYF compared to drum drying or oven drying used for UYF. The efficiency of sun drying to reduce the moisture may be lower to drum or oven drying because sun drying is affected by fluctuation in environmental conditions like temperature and wind speed. Likewise, production of FYF includes overnight soaking process that could also lead to increase in moisture content. The reduced in moisture content observed in UYF compared to other flour samples suggests that UYF will be more stable during storage.

The protein contents of the FYF (3.3%) and UYF (5.9%) are lower than that of RWF (13.8%). This is expected because cereals are known to have higher protein content than tuber crops. The protein content of FYF is very close to the previously reported result of 2.9% reported in the work of Ayodele et al. (2013). Although, FYF and UYF are from same species *Dioscorea rotundata*, the soaking during the fermentation process in FYF production might have caused protein loss.

The ash content of the flour samples ranged between 0.61–2.21%. The ash content of the UYF and FYF is an indication of their higher mineral content than refined wheat flour samples. The result of ash content of FYF is low compared to the value (2.34%) reported for fermented yam flour (Ayodele et al., 2013) while that of UYF is comparable with the value (1.6±0.04% ash) reported for yam flour (Alves et al., 2002). This disparity might be due to possible difference in their fermentation conditions. The difference in ash content of UYF and FYF can be attributed to the additional soaking process for production of FYF that might lead to leaching of minerals. The amount of fat ranged from 0.2–2.2%. There is no significant ($P<0.05$) difference between FYF and WFY in terms of their fat content. The small amount of fat content in the yam flours agrees with previous study. The range of fat content in tuber flour such as sweet potato flour was reported to range from 0.59–1.29% (Ahmed et al., 2010), while that of cocoyam contain 0.24–0.75% (Adegunwa et al., 2011).

The value of total starch of the yam flour samples are 73.8–74.2% DWB. The value is lower compared to previous works on yam flours. The starch content of an oven dried trifoliate yam flour was reported to contain 75.1% (Abiodun and Akinoso, 2015), 88.7% was reported for *D. alata* from Brazil (Alves et al., 2002) and a range of 80.0–85.3% was reported for water yam (Huang et al., 2006). This difference is likely to be due to variation in yam species and cultivar as explained previously (Abiodun and Akinoso, 2015). In addition, the total starch content of the RWF (71.1) was lower compared to previous reported work (Simsek et al., 2011).

The starch damage is a measure of physical damage to flour starch granule. The starch damage values ranged from 3.0–18.1%. The high value of starch damage in UYF, compared to that of FYF, might be due to physical damage during milling. The UYF was milled on a hammer milled while a less sophisticated locally fabricated roller milled was employed for milling the FYF. Dietary fiber in food is beneficial to human health and other health related functions that includes reduction in risk of cardiovascular disease and transit time, some certain cancers and diabetes-mellitus (Muralikrishna and Subba Rao, 2007). In addition, it has been known to attenuate blood glucose and insulin levels. They are known as biological response modifiers (BMS) as they are believed to modulate the immune response and its ability to reduce low-density lipoprotein cholesterols (LDL) in serum has also been demonstrated (Dawkins and Nnanna, 1995). The fiber content of the flour samples ranged between 2.3–3.7%, 2.1–3.5% and 4.4–7.0%, respectively, for insoluble dietary fiber (IDF), soluble dietary fiber (SDF) and total dietary fiber (TDF). The UYF sample was highest in IDF, while FYF was highest in SDF and TDF, however, there was not significant ($P<0.05$) different between the fiber composition of FYF and UYF. The RWF sample contained least amount of all the fiber categories. Although, the composite flour was made from yam of the same species: *Dioscorea rotundata*, variation and difference in their chemical composition might be attributed to environmental difference, genotype and processing method. The impact of processing on the yam flour dietary fiber reveals that fermentation process possibly enhanced solubility of dietary fiber. Also, high protein content of UYF might be responsible for keeping some of the polysaccharide intact; thus, the sample exhibited high starch damage and IDF. This can be explained by interaction of protein-polysaccharide in food matrix. Complexation occurs when there are favorable interactions between protein and polysaccharide and can either result in soluble and/or insoluble complexes (Patino and Pilosof, 2011). It is possible that the protein-polysaccharide interactions resulted into formation of insoluble complexes; thus, increase in IDF in the UYF.

Table 4. The proximate composition of FYF, UYF and RWF

		RWF	UYF	FYF
Moisture %		13.6b	5.7a	11.2b
Protein % DWB		13.8c	5.9b	3.3a
Ash % DWB		0.61a	2.21c	1.70b
Fat % DWB		2.2b	0.4a	0.2a
Total Starch	% DWB	71.1a	73.8b	74.2b
Starch Damage	% As Is	7.4b	18.1c	3.0a
Dietary Fiber	IDF	2.3b	3.7a	3.4a
	SDF	2.1a	3.1b	3.6b
	TDF	4.4a	6.8b	7.0b
Color	L*	89.28c	88.25b	79.24a
	a*	-0.71b	-2.38a	2.45c
	b*	10.30b	13.13c	9.93a

*Values with the same letter in the same row are not significantly different ($P<0.05$). DWB= dry weight basis; RWF= refined wheat flour, UYF= unfermented-white yam flour; FYF= fermented-brown yam flour; IDF= insoluble dietary fiber, SDF= soluble dietary fiber; TDF= total dietary fiber; L= brightness; a= redness; b= yellowness; LSD= least significant difference.

Color is essential for assessment of flour quality and is a strong determinant factor which plays a significant role in consumer’s acceptability. The L* value describes black to white (0-100), a* values describe red (positive) and green (negative), and b* values describe yellowness (positive) and blueness (negative). From Table 4, the L*, a*, and b* values of the flour varied from 79.24–89.82, -0.71–2.45 and 9.93–3.13, respectively. In terms of color analysis, the L* value was significantly different among the flour samples. RWF has the brightest color, while there was significant reduction in the brightness of FYF with lowest L* value. Likewise, the FYF appears to have more redness with a dark touch to the flour which is indicated by its highest a* value compared to other samples with negative values. Additionally, there was a significant ($P<0.05$) difference in the b* value of the samples with UYF having the highest value while the lowest value occurred in the FYF. It appears that RWY and UYF are more yellowish than the FYF.

Amino acid profile of wheat and yam flour samples

Table 5 shows the amino acid profile of RWF, FYF and UYF. The total amino acid content among the flour samples varied widely. Yam tuber (*D. rotundata*) was reported to contain intracellular storage proteins that are in aggregates located within the cellular protein vacuoles and the cytoplasm (Harvey and Boulter, 1983). The protein consists of subunits of one size with apparent molecular weight of 31,000 Da and N-terminal amino acid was glutamine/glutamic acid (Conlan et al., 1998). Glutamic acid was predominant in RWF and FYF, while aspartic acid was predominant in UYF. All the flour samples contain trace amount of hydroxyproline and ornithine. The total amino acid content (14.99 g/100g) was recorded for the RWF, followed by that of UYF (6.03 g/100g) while the lowest value was in FYF (3.06 g/100g).

The results of amino acid content of the yam flours were different from previous work. Alozie et al. (2009) reported 4.60 g/100g for edible *Dioscorea dumetorum*, 13.09 g/100g for unprocessed dried yam and a range of 6.06–9.09 g/100g for yam that have been processed through boiling, frying or roasting. The values obtained in the thermally treated yam samples are close to that of UYF. The reduction in the total amino acid in FYF compared to that UYF might be due to some protein loss during the processing, most especially, during steeping stage.

Table 5. Amino acid profile of wheat and yam flour samples

Amino acid (g/100 g)	RWF	UYF	FYF
Taurine	0.21a	0.15a	0.07a
Hydroxyproline	0.00b	0.02a	0.01ab
Aspartic Acid	0.59b	1.32a	0.36c
Threonine	0.39a	0.22b	0.12c
Serine	0.58a	0.21b	0.15c
Glutamic Acid	5.17a	1.04b	0.51c
Proline	1.76a	0.20b	0.14c
Glycine	0.54a	0.19b	0.13c
Alanine	0.43a	0.21b	0.18c
Cysteine	0.29a	0.08b	0.03c
Valine	0.63a	0.33b	0.16c
Methionine	0.24a	0.11b	0.07c
Isoleucine	0.57a	0.23b	0.14c
Leucine	1.04a	0.34b	0.24c
Tyrosine	0.41a	0.13b	0.06c
Phenylalanine	0.76a	0.26b	0.19c
Hydroxylysine	0.01c	0.22a	0.04b
Ornithine	0.00b	0.01a	0.00b
Lysine	0.33a	0.34a	0.18b
Histidine	0.33a	0.11b	0.07c
Arginine	0.56a	0.28g	0.21c
Tryptophan	0.18a	0.08b	0.05c
Total	14.99a	6.03b	3.06c

*Values with the same letter in the same row are not significantly different ($P<0.05$). RWF= refined wheat flour, UYF= unfermented-white yam flour; FYF= fermented-brown yam flour

Mineral content of wheat and yam flour samples

Table 6 shows that there was significant ($P<0.05$) differences in the mineral content for all flour samples analyzed except for calcium. The UYF has the highest phosphorus and magnesium content while the lowest was observed in FYF. The highest potassium value of 845 mg/100g was found in FYF with UYF having the lowest amount of 119 mg/100g. The traditional processing of yam to brown yam flour is a natural lactic acid fermentation process during which increase in microbial population accompany with changes in pH and acidity development occur (Mestres et al., 2004). The microflora of the fermenting medium consisted of lactic acid bacteria, Bacillus spp. coliforms and yeasts, with *Lactobacillus plantarum*, *Lactobacillus brevis*, *Lactobacillus delbrueckii* and *Bacillus subtilis* as the dominant aerobic mesophilic bacteria (Achi and Akubor, 2000). Fall in the pH from pH 6.2 to 5.4 resulting to steady increase in the acidity of the medium during the fermentation process also take place. The differences in the composite flour mineral content might be due to the major biochemical changes during the fermentation process thus impacting the mineral content of the yam flour.

The zinc and sulfur amount of RWF were significantly ($P<0.05$) higher than the composite flour. The amount of calcium, phosphorous, and potassium of RWF are lower compared to the average values reported for 54 wheat flour cultivars reported by Araujo et al. (2008). The average reported values were 27 mg/100g, 192 mg/100g and 171 mg/100g, respectively for calcium, phosphorus and potassium. The sample of RWF in this study exhibited higher magnesium and zinc content than those reported previously (Okwu and Ndu, 2006).

The FYF and UYF have similar calcium content value of 22 mg/100g. These values are dissimilar to previous findings. Lower calcium amount of 7.69 and 10.67 mg/100g were reported for the raw and cooked samples of six *Dioscorea* species sourced from Nigeria (Oladimeji et al., 2000). Higher calcium value ranging from 96.4 to 238 mg/100g was reported. in the work of Bhandari and Kawabata (2004), who investigated four different wild yam species. Additionally, the author reported zinc value ranges of 1.13–1 .76 mg/100g, falls within the zinc value of our flour samples but significantly lower than the zinc value stated by Oladimeji et al.

(2000) where 7.69 and 12.13 mg/100g were, respectively, reported for raw and cooked yam samples.

Table 6. Mineral content of refined wheat flour, white yam and brown yam flour (mg/100g)

Sample	Calcium	Phosphorus	Magnesium	Potassium	Zinc	Sulfur
RWF	24a	144b	50b	143b	1.5c	172c
UYF	22a	158b	67c	119c	0.8b	151b
FYF	22a	77a	37a	845a	0.6a	53a

*Values with the same letter in the same column are not significantly different ($P<0.05$). RWF= refined wheat flour, UYF= unfermented-white yam flour; FYF= fermented-brown yam flour

Sugar composition of wheat and yam flour samples

Table 7 presents the sugar contents of the flour samples. Sugar content of all the samples were significantly ($P<0.05$) different. There was significant difference ($P<0.05$) in arabinoxylan (AX) and arabino-xylanose ratio (A/X) contents. RWF had the highest AX value of 2.53 and least A/X (0.75). This is similar with previous report where, Simsek et al. (2011) reported that AX content of wheat flour was ranged between 1.5–2.5%. UYF had the least of AX value and second highest A/X ratio, The A/X ratio was observed as highest and AX value ranked second for FYF. Arabinoxylan is an important major dietary fiber component with some beneficial effect including bulk motility improving, decreasing blood cholesterol and glucose, acts as prebiotic, constipation and cancer preventing (Căpriţă et al., 2010). AX has received attention due to their major effects and biological role in living organisms. AX is known to absorb large amounts of water and significantly influence the water balance, dough rheological properties, bread quality and starch retrogradation (Neyrinck, et al., 2011). So far, there has not been any report of arabinoxylans in yam flours.

Table 7. Sugar composition of refined wheat flour, white yam flour and brown yam flour

Sample	Mannose	Galactose	Glucose (%)	Arabinoxylan	A/X Ratio
RWF	0.14b	10.26a	56.93b	2.53c	0.75a
UYF	0.10a	11.94b	47.06a	0.93a	1.81b
FYF	0.35c	12.97b	50.49ab	1.40b	3.11c

*Values with the same letter in the same column are not significantly different ($P<0.05$).
RWF= refined wheat flour, UYF= unfermented-white yam flour; FYF= fermented-brown yam flour; A/X= arabinose/xylose ratio

Phytic acid, polyphenol oxidase and phenolic contents of wheat and yam flour samples

Phytic acid is the storage form of phosphorus that is usually in a bound form called phytate. It is considered an anti-nutrient because when bound to other mineral elements like calcium, zinc manganese, iron and magnesium in the digestive tract, it is converted to phytic complexes, which are indigestible substance, making them less available for body uses (Liu et al., 1998). However, phytic acid is also an anti-oxidant compound, as it prevents the formation of free radicals when bound with minerals. Likewise, it also acts as a chelating agent which binds heavy metals (e.g., cadmium, lead) and suppresses iron catalyzed redox reactions (Steffens, 1990).

Table 8 show that the phytic acid contained in the three flour samples are significantly ($P<0.05$) different. RWF had the highest value (2.25 mg/g) of phytic acid content, followed by that of UYF (0.53 mg/g) and then that of FYF (0.17 mg/g). Grains and beans were reported to have high phytic acid content while roots and tubers amount was reported to be relatively low phytic acid (Champ, 2002; Hurrell and Egli, 2010). This agrees with our findings whereby the phytic acid of FYF and UYF are significantly lower than that of RWF. Wanasundera and Ravindran (1994) reported higher phytic content value range of 0.59–1.98 mg/g of four *Dioscorea alata* species investigated. In the work of Bhandari and Kawabata (2004) who studied the anti-nutritional factor and some mineral bioavailability of some wild yam, phytate value ranging between 1.84–3.63 mg/g was reported for tuber *Discoreas* species of Nepal origin. These values are higher than those observed in the yam flour. The difference is attributed to the fact that hydrolysis and thermal treatment significantly reduce phytate level (Adewusi and Osuntogun, 1991). This explains why a phytate level between 0.06-0.19mg/g was reported in the uncooked yam while 0.04-0.12g/mg value was reported in its cooked counterpart (Oladimeji et al., 2000).

Table 8. Phytic acid, polyphenol oxidase, extractable- and hydrolysable-phenolic compounds of RWF, FYF and UYF

Sample	Phytic acid (mg/g)	PPO (ΔA475/min·g)	Phenolic compounds (mg FAE/g)	
			Extractable	Hydrolysable
RWF	2.25a	0.01b	3.94a	4.47a
UYF	0.53b	0.00c	1.64b	1.75b
FYF	0.17c	0.02a	0.57c	2.28c

*Values with the same letter in the same column are not significantly different ($P<0.05$). RWF= refined wheat flour; UYF= unfermented-white yam flour; FYF= fermented-brown yam flour PPO= polyphenol oxidase; FAE = ferulic acid equivalents.

The quantification of polyphenol oxidase (PPO) activity is also shown in Table 8. There was significant ($P<0.05$) difference among the flour samples. PPO was not detected in UYF, while that of FYF was highest followed by that of RWF. Polyphenol oxidase activity plays a significant role in enzymatic browning. The polyphenol oxidase activity presence in FYF is as a result of the enzymatic browning reaction when the polyphenolic compounds in yam undergo poly-phenolic oxidase-catalysed reactions during the fermentation stage to form o-quinones, which react with other components, triggering the generation of dark color pigments forming brown polymeric compounds (Farombi et al., 2000). Also, the lack of PPO in UYF might be due to the processing conditions which it passed through. Production of UYF required steeping and fast drying unlike FYF that required soaking in warm water overnight which causes natural fermentation to occur prior to sun drying. The study of effect of blanching and drying process on color and functional characteristics of yam (*D. rotundata*) flour revealed that blanching reduced peroxidase activity while fast drying reduced polyphenol oxidase activity. This might explained the observed result in lack of PPO activity in UYF that pass through similar conditions (Akissoé et al., 2003). The higher value of hydrolysable phenolic compounds in FYF compared to that of UYF can be also be related to fermentation process. This suggests that the phenolic compounds in yam were converted from soluble into insoluble form during fermentation.

Table 8 also presents the levels of extractable and hydrolysable phenolic compounds in the flour samples. Extractable phenolic compounds are those that can be extracted by shaking with acidified methanol:acetone:water at room temperature. There exists significant ($P<0.05$) difference in extractable phenolic compounds of all the flour samples. RWF had the highest extractable phenolic while those of the yam flours were significant lower. The hydrolysable phenolic compounds are extracted from the residue after removal of extractable phenolic compounds by hydrolysis with strong alkali at 30 °C. The hydrolysable phenolic content of all the flour samples exhibits significant ($P<0.05$) differences. The RWF had the highest value (4.47 mg/g), followed by FYF (2.28 mg/g) and UYF (1.75). Previous reports have equally reported a wide range in the total phenolic content of various yams. The amount of phenolic content of five different species from Nigeria was reported to be as low as 0.12 and high as 5.13 in the study conducted by Ozo et al. (1984).

Starch hydrolysis properties of wheat and yam flour samples

Resistant starch (RS) is of importance when evaluating the nutritional and functional properties of starch. RS is defined as the starch fraction that cannot be completely digested in the small intestine. It is classified as dietary fiber due to its ability to be partially fermented in the colon (Haralampu, 2000). Other starch fractions classified by their rate of digestibility are slowly digestible starch (SDS) and rapidly digestible starch (RDS). RDS mainly contains of amorphous and dispersed starch and conversion to the constituent glucose molecules takes place in 20 min of enzyme digestion. SDS consists of physically inaccessible amorphous starch and raw starch and digestion occurs more slowly in the small intestine (Sajilata et al., 2006). Figure 11a shows the starch hydrolysis properties of RWF, FYF and UYF.

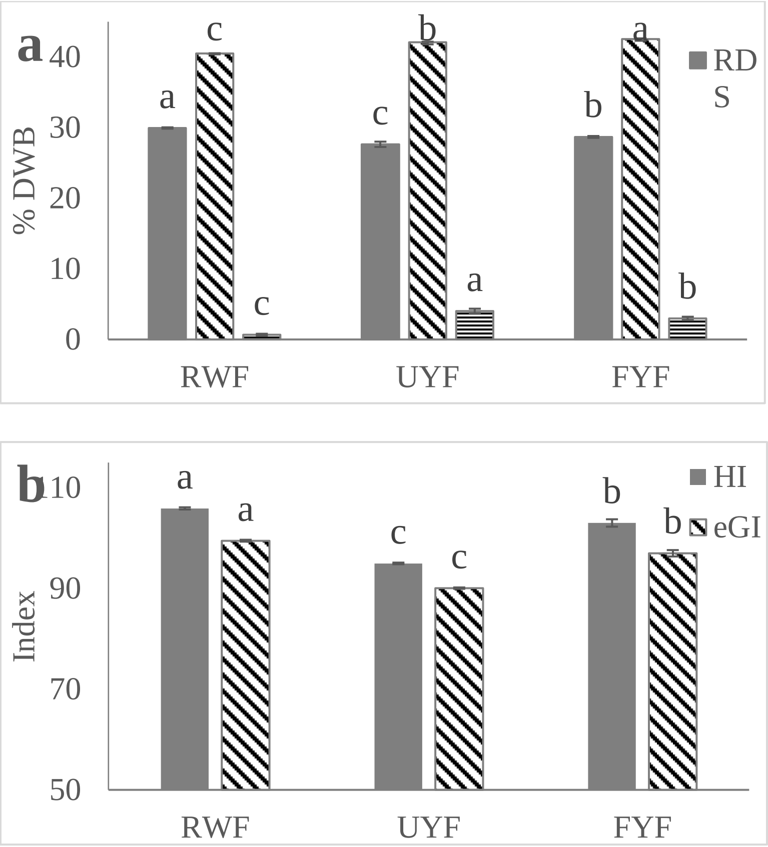

Figure 11. Starch fractions (a) and digestibility (b) of wheat flour, white and brown yam flours
*Values with the same letter for columns of the same pattern are not significantly different ($P<0.05$). Error bars represent standard deviation. RWF= refined wheat flour, UYF= unfermented-white yam flour; FYF= fermented-brown yam flour; RSD = rapidly digestible starch; SDS = slowly digestible starch; RS = resistant starch; HI = hydrolysis index; eGI= estimated glycemic index

Starch conversion to glucose is measured during 180 min of enzyme digestion. There was significant difference ($P<0.05$) in the total RS, RDS and SDS content for all the samples. The RS and SDS content of yam flours (FYF and UYF) were higher than those of RWF content. However, RWF exhibited higher content of RDS than that of yam flours. Of the two yam flours, there is more RS in the UYF than FYF and possibly because of presence of fiber that were not degraded due to fermentation process. The yam flours are a richer source of dietary fiber content than RWF.

The values of hydrolysis index (HI) and estimated glycemic index (GI) of the flour starch digestibility are illustrated in Figure 11b. The HI is the rate of starch hydrolysis in a specific food compared to the rate in a references food (Frei et al., 2003) which, in this case is white bread was used as reference in this study. The HI and GI of the yam flours were significantly ($P<0.05$) lower than that of RWF. The HI of RWF and UYF samples had above 100, suggesting that their starch had a higher rate of hydrolysis than the reference food 100. GI refers to the postprandial glycemic response of a test product compared to that of a reference food (white bread or glucose) (Daly, 2003; Monro, 2003). But when an in vitro assay methods are employed, the term estimated glycemic index (eGI) is used (Ovando-Martínez et al., 2011b).

Starch content, molecular weight and polydispersity index of wheat and yam flour samples

Starch, is a major plant metabolite and most important form of food reserve in wheat and yam flours. Starch is a macromolecule that is made up of amylose and amylopectin. Table 9 shows the molecular mass distribution and polydispersity index of amylose and amylopectin in the three samples. Statistical analysis revealed that there are significant ($P<0.05$) differences in the starch characteristics except their polydispersity index of amylose among samples. The values of RWF starch composition (25.1% amylose and 74.9% amylopectin) fall within the normal range for native wheat starch. Native cereal flour typically has around 25% amylose and around 75% amylopectin content (Simsek et al., 2013). The composition of the yam flour samples shows that the amylose content was 17.3% for UYF and 22.6% for FYF while the amylopectin was 82.7% for UYF and 77.4% for FYF. Other researchers have reported higher values of amylose in yam flours. According to Abiodun and Akinoso (2015), the contents of oven dried trifoliate yam flour were 24.68% , McPherson and Jane (1999) reported that the amylose content of yam was around 29.2% and Alves et al. (2002) reported 30% amylose in starch of *Discorea alata*. Although, the two yam flours had higher amount of amylopectin than amylose, the amylose content of UYF is lower compared to that of FYF. The generally principle is that the lower the amylose content, the higher the swelling power since amylose is proposed to act as a restraint to swelling (Abiodun and Akinoso, 2015), suggesting that UYF will probably swell better than FYF.

Table 9. Characteristics of wheat and yam flour starch

Sample	Starch %		Molecular mass (Da)		Polydispersity index	
	AM	AP	AM	AP	AM	AP
RWF	25.1a	74.9c	1.29×10^6a	1.11×10^7a	1.10a	1.57a
UYF	17.3c	82.7a	2.73×10^2b	3.09×10^6b	1.09a	1.36b
FYF	22.6b	77.4b	2.33×10^2c	2.57×10^6c	1.31a	1.20c

*Values with the same letter in the same column are not significantly different ($P<0.05$). RWF= refined wheat flour; UYF= unfermented-white yam flour; FYF= fermented-brown yam flour; AM = amylose; AP = amylopectin

Molecular mass is also an important characteristic of starch which could impact nutritional and end-product qualities. The starch molecular mass was significantly ($P<0.05$) difference among the flour samples. The molecular mass of amylose and amylopectin of the yam flours are smaller than that of RWF. This difference might be due to variations in their genetic make-up, processing condition and environmental condition. The variation in starch molecular mass can alter starch swelling and pasting characteristics which may influence end product quality (Sasaki and Matsuki, 1998).

Polydispersity is used to describe the degree of non-uniformity of a heterogeneous molecule in a distribution. It is an important measure used in determining width of molecular weight distribution. The apparent amylose polydispersity index value of 1.10, 1.09 and 1.31 respectively for RWF, UYF and FYF are similar to each other. RWF has the highest amylopectin polydispersity index value of 1.57, followed by UYF (1.36) and then FYF (1.20). This signifies that amylopectin in RWF has a broader width than those of yam flour samples which explains its larger molecular mass and FYF having narrower width than its UYF counterpart.

Thermal properties of wheat and yam flour samples

The thermal properties of the flour samples were determined using differential scanning calorimeter. Table 10 shows the result of onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c), and enthalpy of gelatinization (ΔH) of RWF, UYF and FYF. There exist significant ($P<0.05$) difference in the T_o, T_p and T_c value of among the flour samples which ranging from 60.20–76.21°C, 65.17–79.21°C and 70.18–81.84°C, respectively. FYF was highest whereas RWF was lowest, in terms of T_o, T_p and T_c. This corroborate with the finding of Zaidul et al. (2008), who reported higher T_p for yam flour than RWF.

Table 10. Thermal properties of flour samples determined by Differential Scanning Calorimeter

Samples	T_o (°C)	T_p (°C)	T_c (°C)	Peak height (mW)	Area (mJ)	ΔH (J/g)
RWF	60.20c	65.17c	70.18c	0.20b	6.60b	1.62b
UYF	65.19b	69.57b	74.80b	0.26b	8.98a	2.53a
FYF	76.21a	79.21a	81.84a	0.45a	9.18a	2.69a

*Values with the same letter in the same column are not significantly different ($P<0.05$). T_o= onset temperature; T_p= peak temperature; T_c= conclusion temperature; ΔH= enthalpy of gelatinization; RWF= refined wheat flour; UYF= unfermented-white yam flour; FYF= fermented-brown yam flour

Yam flour has higher gelatinization temperature and enthalpy of gelatinization value than refined wheat flour. These higher values indicate a higher crystalline and molecular order in yam composite flour than wheat flour. Thus, more energy is required to initiate gelatinization of their starch (Kaur and Singh, 2005). Yam starch undergoes relatively slow gelatinization process at higher temperature possible due to high energetic gelatinization process and low rate constant (Freitas et al., 2004). The difference in gelatinization temperature between the composite yam flours may be attributed to the differences in source of origin, starch characterization including: variation in size, form and distribution of starch granules and the internal arrangement of starch fractions within the granule. The peak height which measure the uniformity of gelatinization was highest for FYF (0.45 mW), followed by UYF (0.26 mW) and then RWF (0.20 mW).

Morphology of wheat flour and yam flour samples

The morphologies of the flour samples were determined using SEM at different level of magnifications (×100, ×750, ×2,500 and ×7,500) in Figure 12. The size of the particle varies, such that FYF < RWF < UYF. Increase in magnification showed that the particles of FYF are of consistent oval shaped, while that of RWF contained additional tiny particles distributed on the bigger ones. Also, at magnification of ×7,500, the smoothness of the RWF was more than that of FYF particles. Interconnecting fibril like strands is present on the particles of UYF but not on the particles of RWF and FYF. The fibrils are likely responsible for holding the UYF particles to retain the bigger compact shaped, by interconnecting smaller particles together. The lack of such networking fibrils in FYF suggest that fermentation process caused loosening of the plant materials therefore allowing the particle to be more separated resulting in the smaller size of the flour particles. This observation can further be related to the result of composition analysis of the yam flour. In Table 4, UYF has high protein content than FYF.

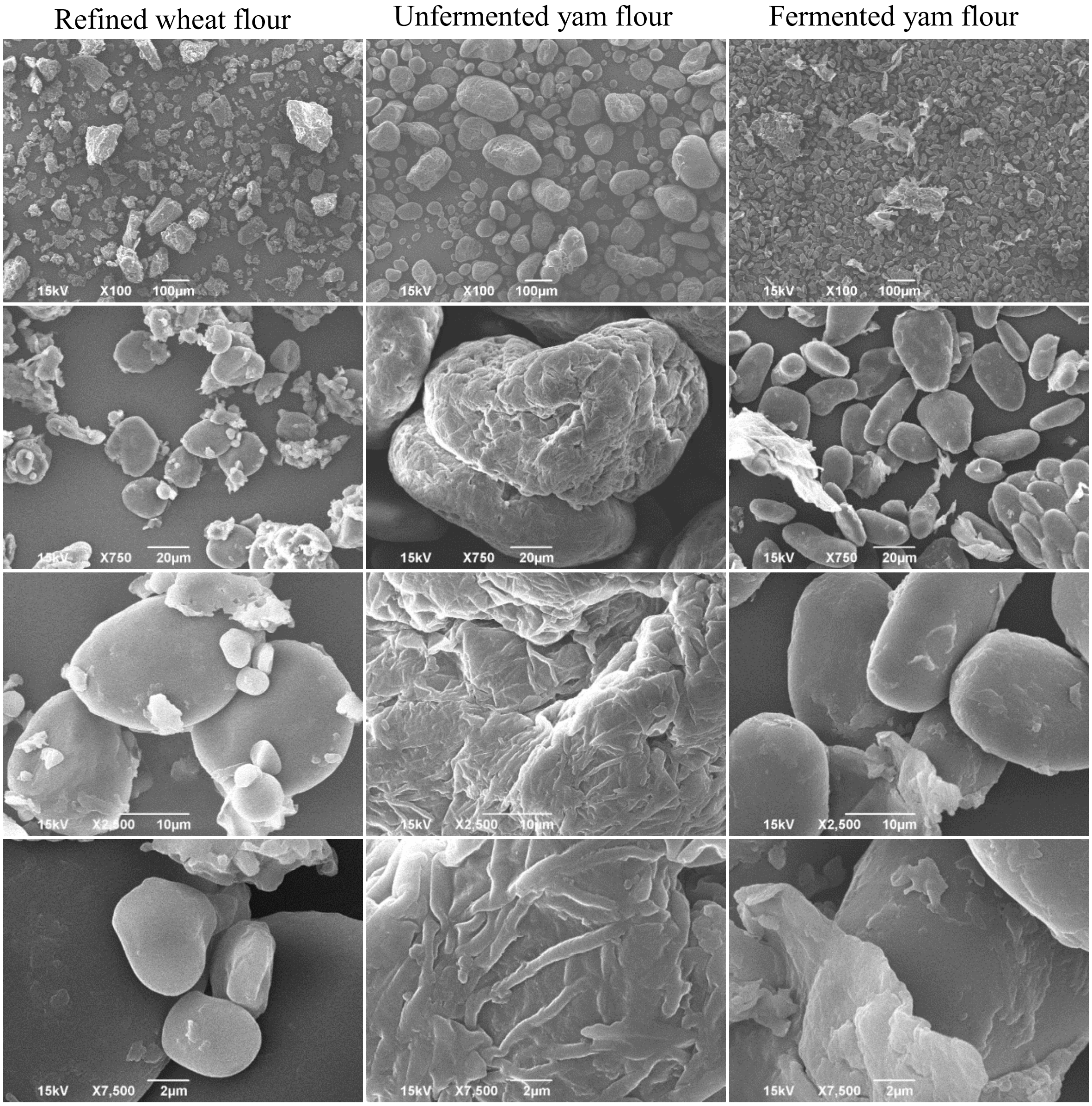
Refined wheat flour Unfermented yam flour Fermented yam flour

Figure 12. SEM images of wheat, unfermented-white and fermented-brown yam flour

Protein and phenolic compounds are known cross-linkers of food polysaccharides to form complexes (Delval et al., 2004; Mathew and Abraham, 2008). The morphology of yam flours can also be associated with the result of resistant starch or dietary fiber stated earlier in Figure 11a. The compact nature of the particles of UYF might explain the reason for its higher amount of resistance starch or dietary compared to that of FYF.

Pasting properties of paste from wheat flour, fermented and unfermented yam flour

The pasting properties of food ingredients (such as starch) are used in assessing their suitability as functional ingredients in food and other industrial products. Table 11 illustrates the values obtained from the pasting profile when the flour samples are subjected to the standard temperature procedure of heat-hold-cool-hold protocol. The temperature–time conditions included a heating step from 50 to 95°C at 6°C/min (after an equilibration time of 1 min at 50°C), a holding phase at 95°C for 5 min, a cooling step from 95 to 50°C at 6°C/min and a holding phase at 50°C for 2 min. The peak viscosity (maximum viscosity at 95°C, PV), hot paste viscosity (minimum viscosity at 95°C, HPV), breakdown (peak-hot paste,), final viscosity (viscosity at 50°C, FV), and setback (final-hot paste).

Significant ($P<0.05$) differences exist for all the pasting properties of the samples. The HPV was 396.3, 1018.0 and 3506.5 cP for RWF, UYF and FYF, respectively. All the pasting properties were highest in FYF, except the peak time which has the lowest value of 5.0 min. The HPV, FV, setback and pasting temperature of RWF were the lowest values, but its PV, breakdown, and peak time values were second in ranking. All the pasting parameters for UYF ranked second except with peak time, PV and breakdown which has the lowest values. This RVA results can be related with the amylose content of the flour samples. Generally, increase in amylose content of flour led to decrease in RVA parameter (Soh et al., 2006), this corroborate the result of our study whereby composite yam flour with lower amylose than wheat flour is high in most of RVA values. However, higher RVA parameter was obtained for FYF with higher amylose than UYF.

The short peak time in FYF signifies rapid swelling, and high PV which may be an indication of high swelling amount, causes increase in viscosity. Thus, subsequent higher degree of breakdown is expected. This is because high swelling power allows starch granules to swell faster and reach peak viscosity more quickly which causes the granule to be easily rupture due to weak intermolecular forces among starch molecules as a result of increased sensitivity to shear forces with increasing temperature (Zheng and Wang, 1994). From this it could be stated that FYF, followed by RWF are highly susceptible to shear and heat while UYF starch may better withstand this heating and shear stress.

Table 11. RVA results of the wheat flour and yam flour

Sample	PV (cP)	HPV (cP)	Breakdown (cP)	FV (cP)	Setback (cP)	Peak time (min)	Pasting temperature (°C)
RWF	1240.3b	396.3c	844.0b	957.3c	561.0c	5.3b	68.7c
UYF	1055.0c	1018.0b	37.0c	1810.5b	792.5b	5.4a	70.1b
FYF	5689.5a	3506.5a	2183.0a	6056.3a	2549.8a	5.0c	81.7a

*Values with the same letter in the same column are not significantly different ($P<0.05$). RWF= refined wheat flour; UYF= unfermented-white yam flour; FYF= fermented-brown yam flour; PV = peak viscosity; HPV = hot paste viscosity; FV = final viscosity; cP = centipoise

Setback from peak is an indicator of samples firmness and ranged from 561–2549.8 cP. The yam flours are firmer in texture than wheat flour, suggesting fast retrogradation in the yam starch gel which explains why their high setback values; a phenomenon associated with syneresis or weeping. So, RWF with the lowest value of setback is expected to be more resistant to retrogradation than the yam flour samples. All in all, fastest retrogradation process is projected to be seen in FYF starch gel, followed by UYF.

The peak time ranged between 5.0–5.4 min, while the pasting temperature of the flour samples ranged from 68.7–81.7°C. This means that the minimum temperature required to initiates the gelatinization process for yam flours exceed that of RWF. This has an implication on energy cost and formula stability with other components. The FV which indicate that ability of the samples to form a viscous paste or gel after cooking and cooling ranged from 957.3–6056.3 cP, respectively, for RWF and FYF. This implies that yam starch gel forms a more viscous paste than wheat gel.

Stickiness and firmness gel of wheat flour, fermented and unfermented yam flour

When aqueous slurry of starch granules is heated to a temperature above its initial gelatinization temperature, hydrogen bonds in the amorphous region become disrupted. Water is then absorbed resulting in swelling of starch granules, after which amylose leaches from the granule. Re-association between starch molecules occur during cooling resulting in gel formation (Zhou et al., 2015). Next is the retrogradation step, which involves synergies development in two stages: the first stage is recognized as conformational ordering of amylose which is completed within a few hours of storage, while the second stage involves the successive reordering and crystallization of amylopectin, which requires a few days. Figure 13a displays the changes in the firmness of starch gels.

Texture analysis of the gel samples was performed at day one to allow the retrogradation of amylose, and at seven days to allow the retrogradation (recrystallization) of amylopectin. There was significant ($P<0.05$) difference in the hardness of sample gels in day 1 and day 7. On day 1 and day 7, the FYF gel had the highest value of hardness, followed by that of RWF gel and then that of UYF gel. On day 7, as expected, hardness was significantly higher (P<0.05) for all samples. The gel firmness is caused by starch retrogradation process which is associated with the syneresis of water and crystallization of amylopectin leading to harder gels (Majzoobi et al., 2015). This phenomenon is more pronounced in FYF and least in UYF. The general hypothesis is that the amylose fraction of gelatinized starch during gelation and crystallization and upon cooling and storage has been associated with the short-term development of crystallinity (Fredriksson et al., 1998). The hypothesis is in lined with our result as observed that FYF with higher amylose exhibited higher firmness than UYF at day 1. Likewise, the long-term changes that occur during storage of starch gels resulting to more firmness have been attributed to the amylopectin fraction. Although UYF has higher amylopectin, lack of availability of amylopectin during gel formation might explain the reason for reduction in its firmness. Therefore, amylopectin is likely to be more available in FYF than in UYF hence, exhibiting more firmness at day 7 than UYF.

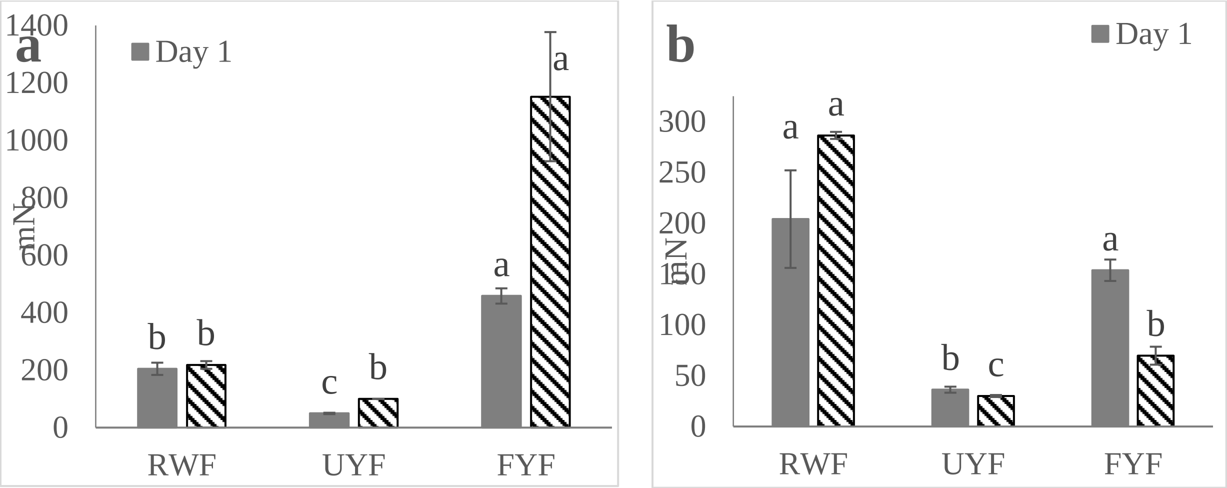

Figure 13. Firmness (a) and stickiness (b) of wheat and yam flour gels

*Values with the same letter for columns of the same pattern are not significantly different (P<0.05). Error bars represent standard deviation. RWF= refined wheat flour; UYF= unfermented-white yam flour; FYF= fermented-brown yam flour

It is possible that the compactness of UYF particles as revealed by morphological analysis is responsible for reduction in release of amylose and amylopectin during gel formation. Furthermore, response of amylose and amylopectin can also be affected by their molecular weight. Compared to FYF, higher molecular weight of amylose and amylopectin in UYF starch might reduce it gelling response, thus reduction in its gel firmness.

Figure 13b shows the gels stickiness at day 1 and day 7. The gel stickiness of the flour samples was significantly ($P<0.05$) different. The gel from RWF exhibited highest stickiness, followed by that of FYF and then UYF. From industrial perspective, dough with high dough stickiness may cause difficulties in machinability, in particular during automated process for large scale production (Hammed et al., 2016). The stickiness of gel samples decreased with increasing days except for that of RWF gel. It is possible to reduce the stickiness of RWF by substituting with yam flours.

Conclusions

The characteristics of wheat and yam flour were successfully determined. There exist significant ($P<0.05$) differences in the chemical composition, thermal properties, and rheological characteristics of the sample flours. Each flour has desirable and undesirable properties. The yam flours were rich in minerals, fiber, natural bioactive compounds, are of low stickiness, higher resistant starch and eGI, compared to that of RWF. The protein of yam flour is low compared to that of wheat flour. The distribution and composition of biomolecules in yam flour varies depending on the processing steps. The structure and functional properties of yam flours are affected by the distribution protein and phenolic compounds. The fermentation process in yam flour did not only affect their colors but also their composition, starch characteristics and functional properties. The morphology of flour particles is affected by the presence of proteins and phenolic compounds that exert interconnection between the flour biomolecules. The two yam flours will possibly have different impacts on wheat flour when used to formulate wheat-yam composite flour.

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EXPERIMENT 2: DOUGH RHEOLOGICAL CHARACTERISTICS AND BAKING QUALITIES OF BREAD MADE FROM WHEAT AND YAM COMPOSITE FLOUR

Abstract

Formulation of composite flours and products has been identified as an alternative way to improve nutritional and functional properties of wheat-based products. This study was conducted to study the changes in dough physicochemical, rheological, pasting properties, and nutritional quality of bread loaves made from wheat-yam composite flour. Composite flours were formulated by substitution of refined wheat flour (RWF) with different percentages (5, 10, 15 and 20%) of unfermented-white yam flour (UYF) or fermented-brown yam flour (FYF). The effects of the yam flours inclusion in RWF depend on the type of yam flour and the percentage of substitution. Although, the composite flours were of lower protein value, they enhance the ash and fiber content of RWF. The farinograph water absorption increased significantly ($p<0.05$) for blends prepared with UYF flour. The loaf volumes of the breads ranged from 958 to 1123 cc. The crumb firmness of the bread with UYF flour was similar to the control bread, but bread with FYF had significantly ($p<0.05$) higher crumb firmness. Overall, yam flour appears to be a promising candidate in increasing the nutritional composition of bread, and incorporation of 5% UYF flours appears to give acceptable quality traits in comparison to bread made with 100% of RWF.

Introduction

Wheat-based cereal products are among the most consumed food products in the world today. The continued increase in consumption of these products, especially bread, has prompted research into the discovery and development of alternative composite non-wheat flours, that are locally cultivated from cereals, legumes, and/or root and tuber source to partially substitute wheat flour to enhance the food value (Abdelghafor et al., 2011). Incorporation of pea and soy bean composite flour have been reported to increase the dietary fiber and protein content of the bread; however, the deleterious effect of soy-wheat and peas-wheat bread due to their beany and grassy flavors has resulted in low acceptance (Basman et al., 2003). Yam has a bland taste which does not impart undesirable flavor in bread. Blending of wheat flour with yam flour to make wheat-yam matrix of high fiber bread is a novel way to improve wheat-based product qualities.

Inclusion of unfermented-white yam flours (UYF) in wheat flours for bread making has been reported in previous studies (Chen and Hoseney, 1995; Ilia and Alikhan, 2016; Luz and Berry, 1989; Nindjin et al., 2011; Noorfarahzilah et al., 2014; Pius and Odjuvwuederhie, 2006). The sensory and mean score qualities of bread made from wheat-yam composite flour was reduced when substitution of more than 25 %wheat flour with UYF. It was suggested that the substitution of wheat flour with yam flour should be less than 25 % (Noorfarahzilah et al., 2014). Another study stated that compositing wheat flour with yam (*Dioscorea dumetorum*) flour is desirable in terms of chemical, pasting and functional characteristics (Chen and Hoseney, 1995). The study on technological properties of wheat-trifoliate yam (D. *dumetorum*) stated that the composite flours were similar to wheat flour in terms of physicochemical and functional properties. However, it was recommended that the composite flours were inappropriate for bread making due to their inadequate diastasic activity (Pius and Odjuvwuederhie, 2006). Although, the loaf volume of bread was decreased with addition of yam flour, increased antioxidant properties of wheat bread was achieved by inclusion of yam flour (Ilia and Alikhan, 2016). The effect of protein supplementation on the physicochemical sensory property of Amala (brown yam dumpling) was done. Pretreated soy flour up to 40% was supplemented with brown yam flour. Increase in the protein content of Amala (brown yam dumpling) with no changes sensory property in human feeding was reported (Achi, 1999). The Substitution of wheat flour with yam flour can thus offer development of possible health-promoting foods. In this study, the quality parameters of dough from composite flours (wheat flour containing fermented-brown and unfermented-white yam flour) were investigated. The end-product (breads) of the composite flours was also determined.

Materials and methods

Materials

All the chemicals and reagents were of analytical grade. Fermented and unfermented yam flour used in this study was obtained from Ibadan, Oyo state in Nigeria. The wheat flour used is hard spring wheat patent flour, provided by the Cereal science laboratory which was acquired from North Dakota Mill (Grand Forks, ND). The flour had a protein content of 13.8% and an ash content of 0.48% (14% moisture basis). Each of the unfermented-white yam flour, and fermented-brown yam flour was incorporated with wheat flour at 5%, 10%, 15%, and 20% level.

Flour composition and quality analysis

Proximate analysis on the refined wheat flour and composites flour blend was done to determine the flour quality. An air oven method according to the AACCI Approved method was used to determine the moisture content of the flours by drying the flour and weighing the residue (AACCI Approved Method 44-15.02). Protein content (14% moisture basis, mb) of each of the flours was determined in duplicate by the crude - combustion method according to AACCI Approved method using a LECO FP428 nitrogen analyzer (LECO Corporation, St. Joseph Michigan) (AACCI Approved Method 46-30.01). Ash determination was done using the AACCI Approved method by accurately weighing 3 g of sample to a pre-weight porcelain crucible. This crucible was then placed into a muffle furnace set at an initial temperature of 350^{o} C for one hour and then raised to 590^{o} C overnight. After 24 hours of ashing, the crucible was placed in a desiccator to cool and the weight of the crucible recorded for the final weight of the dried sample to be determined (AACCI Approved Method 08-01.01). Wet gluten was determined according to the AACCI Approved method through washing flour by an automatic gluten washing apparatus (Glutomatic 2200 S system (Perten Instruments, Springfield, IL, U.S.A.) and centrifuged on an especially constructed sieve under standardized conditions. Weight of the rubbery viscoelastic mass was determined. Next, difference in the weight of wet gluten forced through the sieve and the total weight of wet gluten (passed through and remaining on the sieve) was then determined for gluten index (AACCI Approved Method 38-12.02). Total starch of the flour blends samples was measured using AACC approved methods 76-13.01. The flour color was determined using a Minolta colorimeter to determine L*, a*, and b* values on the CIE Lab color scale: a black sample cell with quartz glass window.

Analysis of extractable polyphenols

Extractable polyphenol was determined using aqueous-organic solvents with some modifications (Yu, 2008). Samples (0.5 g) was placed in 50 mL screw cap centrifuge tube, mixed with 10 mL of acetone/methanol/water acidified with HCl (3.5:3.5:3.0, v/v/v) and vigorously stirred by shaking for 16 h at room temperature. The solution was then centrifuge at 3,000 Relative Centrifugal Force (RCF) at 25° C for 10 min and supernatant was recovered and transferred to 50 mL beaker. Next, 10 mL acetone/methanol/water (3.5:3.5:3.0) was then added to the residue, vigorously stirred for 1 h at room temperature, the solution was centrifuge (3,000 RCF for 10 min) and the supernatant recovered. The recovered supernatant was combined and the sample was then acidify to pH 2-4 with 2N HCl, thereafter, the solution was brought to a volume of 25 mL with acetone:methanol:water. This was used to determine extractable polyphenols. Ferulic acid was used to prepare a standard curve. Extractable polyphenols were determined by the Folin-Ciocalteau procedure (Saura-Calixto and Goñi, 2006). The results were expressed as ferulic acid equivalents. Residue of these extractions (EP-residue) was used for further analysis.

Analysis of hydrolysable polyphenols

Hydrolysable polyphenols was determined using alkaline hydrolysis (Yu, 2008). The residues of methanol/acetone/water extraction that was done for determination of soluble polyphenols residue was mixed with 10 mL 2N NaOH and incubated by placing in a water bath (Type: 89032, VWR International, PA, USA) with constant shaking at 30°C for 4 h. The solution (3,000 RCF for 10 min) was centrifuge, and supernatants recovered and transferred to beaker. Next, 2 washings of residue/pellets with 5 mL 2N NaOH each was done, followed by centrifuging (15 min, 25 °C, 3000 g) and recovered supernatants were combined. The solution was then acidified to pH 2-4 with HCl and brought to a volume of 25 mL with water. This was used to determine the hydrolysable polyphenols by the Folin Ciocalteu method with a ferulic acid standard curve (Saura-Calixto and Goñi, 2006). The results were expressed as ferulic acid equivalents.

Analysis of pasting properties with Rapid Visco Analyzer (RVA)

Pasting properties of the flour samples were evaluated following the AACCI Approved method by using a Rapid Visco Analyzer (RVA, Perten instruments, Springfield, IL) interfaced with a computer equipped with Thermocline software (Newport Scientific).

3.5 g of flour (14% moisture basis) was added to 25 mL deionized distilled water in an RVA canister. The rate of heating and cooling in the Std1 profile was 12 °C per min, idle temperature was 50 °C, with the total run time of 13 min (AACCI Approved Method 76-21.01). Parameters recorded were peak viscosity (PV), hot paste viscosity (HPV), breakdown (BKD), cold paste (CPV) and setback (STB) viscosity. Measurements were reported in centipoise.

Analysis of gel texture

The flour paste from the RVA was used to measure texture profile analysis (TPA) with a texture analyzer (TA-XT2i, Texture Technologies). The paste was stored at 4ºC for 24 h. Samples were penetrated with a TA-53 cylinder probe (3 mm, stainless steel) to a distance of 15 mm, following the conditions used by Chávez‐Murillo et al. (2008). The peak force of the penetration was reported as hardness (g-force) and the negative peak during retraction of the probe was reported as stickiness (g-force). The same analysis was done in samples stored at 4ºC for 7 days.

Microextensibility analysis of flour samples

Dough strength of the samples was measured by determining the resistance to extension using a texture analyzer with a Kieffer micro extension rig according to the method of Kieffer et al. (1998). The dough was mixed in 25 g pin mixer until optimum consistency was reached. Next, the dough pieces (10 g) were placed into the mold and rested for 40 min. The mold pressed the dough into several strips which were approximately 4 mm in width by 50 mm length. Dough strips were then placed into the micro extension rig and stretched vertically. The resistance to extension was measured as force against the hook in grams.

Farinograph analysis of flour samples

Dough rheological properties i.e the water-absorption (amount of water required to reach 500 BU consistency) and dough strength of the flours were determined by a Farinograph (C.W.

Brabender Instruments Inc., Hackensack, NJ) according to AACCI Approved Method 54–21.02. Farinograph measurements were determined in duplicate.

Gassing power measurement analysis of flour samples

The total gas production of yeast was determined to compare the gassing activity among samples treatment. Gassing power of each dough sample made from refined wheat and wheat/yam flour blend blends were measured using the AACCI Approved Method 89-01.01 with procedures modified for the ANKOM RF-Gas Production System (Ankom Technology Corp., NY, USA). Dough was prepared in accordance with AACCI Approved Method 10-09.01. Dough (50 g) was rounded then placed in 500 mL plastic coated glass bottle and allowed to ferment for 90 min at 30^{o}C. Pressure (psi) during the entire 90 min fermentation was recorded at 1 min interval.

Baking experiments

Bread loaves were baked on the same day, one control and two replicates of bread at each treatment level (5, 10 15 and 20%) according to AACCI Approved Method for straight dough bread baking method-Long Fermentation method (AACCI Approved Method 10-09.01) with some modifications; here, α- amylase was substituted for malt, 2 h fermentation were used instead of 3 h, and likewise instant dry yeast was used in place of compressed yeast. The ingredient used includes; (1% yeast, 25 mL of solution containing 5% sugar and 1% salt, 2% shortening α- amylase (around 15 SKB), and 10mg of $NH_{4(2)}PO_4$. The amount of water added was determined based on the Farinograph for water absorption value for each flour samples. Mixing time was determined as the time taken for the optimal dough development stage to reached window pane formation based on visual observation. The absorption value, mix time, the proof height, and baked weight for each treatment, were recorded. Specific volume was calculated by dividing the volume of individual loaves by their weight. The baked breads were allowed to return to room temperature and loaf volume was measured using rape seed displacement method (AACCI Approved Method 10-05.01). Next, the breads were subjectively scored for crust color symmetry and crumb grain and texture. Color of the crust was based on a subjective color evaluation chart ranging from one to ten; where ten was considered as the darkest color using AACCI Approved method of Guidelines for Scoring Experimental Bread (AACCI Approved Method 10-12.01). The crumb color was determined using a Minolta colorimeter to determine L, a, and b values on the CIE Lab color scale.

Bread firmness was done on the next day using Texture Analyzer TA-XT2i, Texture Technologies Corp NY using AACCI Approved method (AACCI Approved Method 74-09.01). Bread firmness was determined according to AACC approved method 74-09.01 (AACCI, 2009) using a texture analyzer (Texture Technologies, Hamilton, MA) with 25 mm acrylic cylinder probe with rounded edges.

Bread crumb image analysis (C-Cell)

A C-Cell imaging system and software (Calibre Control Intl. Ltd., UK) was used for image analysis of sliced bread. The bread was sliced (2 cm thickness) approximately 18 hours after baking and placed in plastic zip top bags prior to imaging.

Analysis of starch hydrolysis

Flour samples (0.3 g) with 0.1 mol/L sodium acetate buffer (20 mL, pH 5.2) were incubated at 37°C, 5 mL of enzyme mix solution (amyloglucosidase, invertase and pancreatin) was added at 1 min intervals to each tube. The enzyme solution prepared is as follows: amyloglucosidase solution (70 U mg^{-1}, 24 mg in 12 mL of deionized water), invertase solution (300 U mg^{-1}, 60 mg in 8 mL of deionized water, pancreatin solution (3 g in 20 mL of deionized water, stirred for 10 min at 4°C and centrifuged). Aliquots of the digest (0.5 mL) were taken every 20 min for 180 min, mixed with 5 mL of absolute ethanol and centrifuged to determine the amount of glucose released by reaction with glucose oxidase/peroxidase (GOPOD). A commercial white bread purchased from a local grocery store was analyzed and used as the reference material. The rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) were determined as expressed in %. The hydrolysis index (HI) was obtained by dividing the area under the hydrolysis curve of the sample by the area obtained for commercial white bread (hydrolysis curve, 0 min to 180 min). The estimated glycemic index (eGI) of the samples was calculated using the equation: eGI=8.198+0.862*HI (Ovando-Martínez et al., 2011).

Starch characterization in flour and bread samples

Changes in physicochemical properties, such as molecular mass, in starch of flour and baked breads were investigated. For the determination of starch molecular mass and apparent amylose content, starch was extracted from bread and flour blends using the method of (Simsek et al., 2013). Dried bread samples were ground using a food processor to a fine powder. Flour or ground bread samples (35–40 mg) were each placed into glass screw cap test tubes. To each sample, 2.5 mL of methanol was added and the tubes were vortexed and heated at 100°C for 30 min. The tubes were centrifuged and the supernatant was discarded. After draining and drying overnight, 0.9 mL of 1 M potassium hydroxide (KOH) and 0.1 mL of 6 M urea were added to the extracted starch and the pellet was dispersed. The tubes were then heated for 90 min at 100°C. The samples were then neutralized using hydrochloric acid and filtered before analysis by high performance size exclusion chromatography (HPSEC) with multi angle light scattering (MALS).

The dn/dc value for calculation of the starch molecular mass was 0.146 (You et al., 1999; You and Lim, 2000).

Statistical analysis

Each treatment and measurement was carried out in duplicate. The experimental data was subjected to statistical evaluation using analysis of variance (ANOVA) for a completely randomized design (CRD) using statistical analysis software package, SAS System for Windows version 9.3, (SAS Institute, Cary, NC, USA). Least Significant Difference test was used to determine the difference among means and the significance was defined at $P < 0.05$.

Results and discussion

Composition of wheat and wheat-yam flour blends

Table 12 shows the compositional analysis of the wheat and wheat-yam flour blends. All the parameters were significantly ($P<0.05$) different among the flour samples. The moisture content is the percentage water by weight of sample and indicates flour storability. The value of moisture contents of the samples ranged from 12.5–13.6 %. This is in agreement with the findings of Eke-Ejiofor and Owuno (2012) who reported moisture content of 7.36–11.42%. The moisture content of the blends increased as the FYF increased, but, that of UYF lack clear trend. Increase in moisture content with increase in level of yam flour substitution has been previously observed in wheat-yam composite flour (Eke-Ejiofor and Owuno 2012). The moisture content of the flour samples falls within the range recommended for flour with good shelf life.

Protein content ranged from 11.5–13.8%, respectively, for 20% FYF and RWF. The protein contents of the flour blends were lower than that of control flour. This is not unexpected since the protein contents of the yam flours were previously observed to be lower than that of RWF (in experiment 1). However, there was no significant ($P<0.05$) difference in the protein content among 5% UYF, all FYF blends and RWF samples. The range of protein of the flours is similar to the range (10.53–12.63%) reported for wheat-yam composite flour blends (Eke-Ejiofor and Owuno 2012). However, the values of protein content of the flour blends in this report are higher than those reported in previous works (Prasad et al., 1999; Sudha et al., 2007). Increase in percentage of substitution of wheat flour with yam flours resulted in decreased protein content. Substitution of RWF with non-leguminous flours usually resulted to decrease in protein content of the composite flour. This observation is common with tuber because of their initial low protein content compared to cereal flours.

The ash content of the samples ranged from 0.61–0.87 % and there are significant ($P<0.05$) differences between them. A wider range of ash content has been reported for wheat-yam flour blend, possibly due to the higher substitution percentages that was used in the work (Eke-Ejiofor and Owuno 2012). The amount of ash appears to be higher in the blends in comparison to RWF, with the ash content was highest in 20% UYF. The measure of ash content indicates the amount of inorganic constituent of metal ion of the flour sample. Increase in level of substitution resulted into increase in ash content of the flour blends.

Wet gluten is a measure of the quantity of gluten in wheat flour samples while the gluten index is a measure of gluten strength. There wet gluten was significant differences ($P<0.05$) between the control and all flour blends except 5 and 10% UYF blends. The wet gluten value ranged from 26.8–36.7%, while the gluten index ranged from 85–97. The 20% FYF with least wet gluten has the highest gluten index value (97%) and those with higher wet gluten have lower gluten index (85–86%). In general gluten index of FYF blends are the highest followed by that of the control and those of UYF blends. Overall, the FYF blends exhibited stronger dough strength while the UYF blend displays weak dough strength.

Total starch values of the flour ranged from 70.4–73.4%. Statistical analysis revealed that significant ($P<0.05$) differences exist between the RWF and the flour blends. Generally, the total starch values of the flour blends were significantly ($P<0.05$) higher than RWF. This is anticipated since, yam tuber is high in starch. However, there was no significant difference ($P<0.05$) between the total starch of 5% and 10% flour blends.

Table 12. Composition analysis of wheat and yam flour blends

Sample	Moisture (%)	Protein (14% MB)	Ash (14% MB)	Wet Gluten (14% MB)	Gluten Index	Starch (% DWB)	Color		
							L*	a*	b*
RWF	13.6c	13.8g	0.61a	36.6f	91b	71.1bc	89.28e	-0.71d	10.30c
5% UYF	13.0abc	13.3f	0.68ab	36.6fg	85a	70.5ab	89.36e	-0.77bcd	10.43cd
10% UYF	12.7ab	13.0e	0.75bcd	36.7fg	86a	70.5ab	89.16e	-0.82abc	10.44cd
15% UYF	12.5a	12.3c	0.82cd	33.2d	91b	71.3cd	89.01e	-0.86ab	10.48d
20% UYF	12.8ab	12.0b	0.87d	29.9b	87a	71.9d	88.98e	-0.92a	10.65d
5% FYF	13.2abc	13.2f	0.70abc	34.6e	92bc	70.4a	87.86d	-0.21e	9.78b
10% FYF	13.2bc	12.6d	0.76bcd	33.0d	92bc	71.7cd	86.99c	0.17f	9.73b
15%FYF	13.5c	12.1b	0.76bcd	31.1c	94cd	72.6e	86.27b	0.29g	9.21a
20% FYF	13.5c	11.5a	0.78bcd	26.8a	97d	73.4f	85.05a	0.55h	8.98a

*Values in the same column with the same letter are not significantly ($P<0.05$) different. RWF = refined wheat flour; UYF= unfermented-white yam flour, FYF= fermented-brown yam flour MB = moisture basis; L= whiteness; a= redness; b= yellowness

Flour color is essential for assessing the quality of flour. It is a strong determinant factor which plays a significant role in end-product quality and acceptability. L* value describes black to white (0-100), a* values describes red (positive) and green (negative), and b* values describe yellowness (positive) and blueness (negative). From Table 12, the L* a*, and b* values of the flour varied. In terms of color analysis, the brightness level of the wheat flour is similar to the UYF blends. The result shows that the L* value is not significantly different between the wheat flour sample and all the flour blends made, however, there appears to be differences between the blends made with fermented yam flour. The FYF blends appear to give a dark tone to the flour supported by the decrease in L* values. The b* value of the unfermented flour increases with increasing UYF in the blends and the highest was recorded when 20% UYF was used. However, decreasing b* value with increase in percentage substitution in FYF blends was observed and the least the b* value was obtained at 20% FYF. Additionally, it appears that all the FYF blends introduced more redness (negative a* values) to the blends contrary to effect of UYF (positive a* values). Overall, the data suggests that inclusion of either of the yam flours into RWF altered the compositions and color of the flour blends.

Phenolics content of breads made from wheat/yam flour blends

Figure 14 shows that the extractable phenolic compounds of the flour samples were significant ($P<0.05$). The extractable phenolic content of the bread samples ranged from 1.50 to 3.00 mg FAE/g. Inclusion of UYF and FYF resulted into higher amount of the extractable phenolics, compared to control. The 20% FYF formulation had about twice as much extractable phenolic compound as refined wheat bread. Among the flour blend samples, the amount of extractable phenolics was highest in 20% FYF blends but lowest in 5% UYF blends. Addition of the same percentage FYF contributed to more extractable phenolics compared to their respective UYF blend.

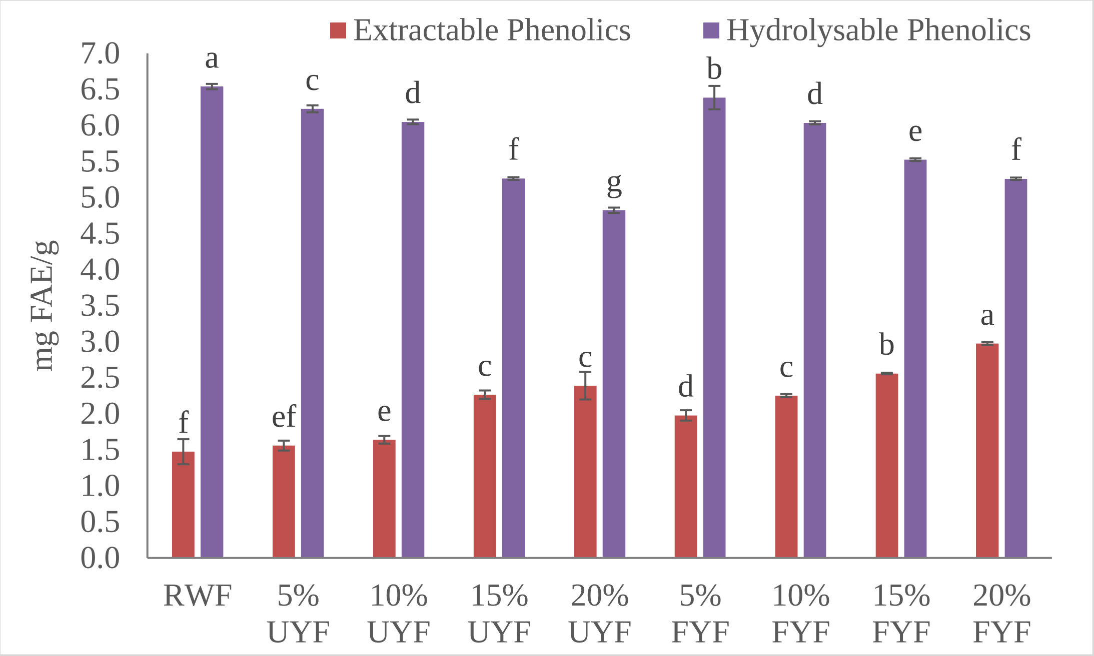


Figure 14. Phenolics content of breads made from wheat/yam flour blends

*Error bars represent standard deviation. Columns with the same letter are not significantly different (P<0.05). RWF = refined wheat flour, UYF= unfermented-white yam flour, FYF= fermented-brown yam flour

There were significant (P<0.05) differences in the hydrolysable phenolic compound between the refined wheat flour and the blends formulation. The hydrolysable phenolic content of the bread samples ranged from 4.80 to 6.52 mg FAE/g. The result showed that all blends contain significantly lower hydrolysable phenolics content compared to the control. The amount of hydrolysable phenolics in the flour blends reduced as the concentration of the FYF and UYF flour increased, contrary to the trend observed in extractable phenolics content, where increase in UYF and FYF in the blends caused increase in the extractable phenolic contents. Generally, the hydrolysable phenolic levels are higher than the extractable phenolics content in the bread samples. This might be due to the enzyme hydrolysis during baking which increases the detectable levels of hydrolysable phenolics. Musingo et al. (2001) reported increase in the hydrolysable phenolic content after heating.

Pasting profile of wheat/yam flour blends

Table 13 depicts the pasting profile results obtained when flours were subjected to the standard heating, holding and cooling temperature procedure in RVA. The peak viscosity (PV) ranged from 1074.8 to 1614.0 cP. There were significant differences ($P<0.05$) between the RWF and other flour blends. The highest PV value was obtained in 20% FYF blends and the least in 20% UYF blends. Compared to the control sample, all UYF blends exhibited lower PV values while all FYF exhibited higher PV values. Increase in concentration of UYF in the blends caused reduction in PV values, unlike what was observed with increase in addition of FYF that resulted in increase in PV values. Previous study has shown that increase in substitution of wheat flour with yam (*D. dumentorum*) flour resulted into decrease in PV (Eke-Ejiofor and Owuno 2012). This suggests that the roles of UYF and FYF were different and opposite with respect to their contribution to PV values.

Similarly, the values of the hot paste viscosity (HPV) were lower in all UYF blends compared to that of FYF blends. Increase in concentration of UYF and FYF in the flour blends resulted into slight increase in HPV. The HPV of 20% was significantly ($P<0.05$) highest among all the samples. The results of breakdown values of all UYF blends were lower, while that of FYF blends were higher compared to that of RWF. Increase in concentration of FYF is directly proportion with breakdown value, while increase in concentration of UYF resulted into reduction in breakdown value. Reduction in breakdown viscosity has been observed with increase in substitution of RWF with yam flour. Interestingly, the effect of increase in concentration of FYF and UYF follow the same trend with PV values. This is an indication of possible relationship between PV and breakdown.

Breakdown viscosity reveals the stability of the paste during processing while high PV denotes rapid swelling resulting from quick and easy rupture of starch granule. Weak intermolecular forces in ruptured starch granules led to higher degree of breakdown (Singh et al., 2003). It could be deduced from this result that UYF blends are less susceptible to shear and heat in comparison to RWF and FYF blends. This observation from UYF blends can be related to previous findings regarding the UYF flour particles in Figure 12. It was observed that UYF has a more compact particle that might be responsible for low gelatinization during heating.

Table 13. Pasting profile of wheat/yam flour blends.

Sample	PV (cP)	HPV (cP)	Breakdown (cP)	FV (cP)	Setback (cP)	Peak time (min)	Pasting temperature (°C)
RWF	1240.3e	396.3ef	844.0c	957.3ef	561.0e	5.3b	68.7c
5% UYF	1150.0f	373.3f	776.8d	913.3f	540.0e	5.4ab	69.0c
10% UYF	1159.3f	420.5de	738.8d	985.0de	564.5e	5.4a	69.1c
15% UYF	1074.8g	414.3e	660.5e	955.8ef	541.5e	5.4ab	69.3c
20% UYF	1075.8g	447.5cd	628.3e	999.5de	552.0e	5.4a	69.1c
5% FYF	1303.8d	426.0de	877.8bc	1041.3d	615.3d	5.4ab	69.1c
10% FYF	1376.8c	470.3c	906.5b	1133.0c	662.8c	5.4ab	79.3b
15% FYF	1526.8b	543.5b	983.3a	1276.3b	732.8b	5.4ab	82.4a
20% FYF	1614.0a	623.5a	990.5a	1433.0a	809.5a	5.4a	82.3ab

*Values with the same letter in the same column are not significantly different ($P<0.05$). RWF= refined wheat flour, UYF= unfermented-white yam flour, FYF= fermented-brown yam flour, PV = peak viscosity, HPV = hot paste viscosity, FV = final viscosity, cP = centipoise

The final viscosity (FV) indicates the ability samples to form a viscous paste or gel after cooking and cooling (Delcour and Hoseney 2010). The FV of RWF is higher than UYF blends but lower when compared to that of FYF blends. The lowest value (913.3 cP) was obtained for 5% UYF, and highest (1433 cP) in 20% FYF. This implies that wheat starch gels form a more viscous paste than UYF blends but lower viscous paste in comparison to FYF blends.

Setback from peak has been well correlated with texture and it indicates firmness of samples (Delcour and Hoseney, 2010). Generally, the setback value for wheat and UYF blends were significantly ($P<0.05$) lower than FYF blends. Statistical analysis showed that the control and UYF blends where not significantly different ($P<0.05$). The setback values increased with increasing percentage of FYF in the samples. This implies that the FYF blends were firmer in texture than wheat and UYF blends. Furthermore, the setback values is directly proportion with onset of syneresis or weeping (Whistler and BeMiller, 1997). Thus, UYF blends with the low value of setback were expected to be more resistant to retrogradation than FYF blends.

A peak time of 5.3 min was recorded for RWF and all the flour blends had equal value of 5.4 min. The peak time of RWF was significantly ($P<0.05$) different from that of 10% UYF, 20 UYF and 20 % FYF. Pasting temperatures of the flour samples ranges from 68.7 °C to 82.3 °C. The wheat flour exhibited the lowest pasting temperature while the highest is observed for 20% FYF blends. There was no significant ($P<0.05$) change in the different levels of UYF blends; however, pasting temperature increases with higher level of FYF incorporation. This implies that the minimum temperature required initiating the gelatinization process for yam flour exceeds that of wheat flour. This is in agreement with the work of Zaidul et al. (2007) who reported higher gelatinization temperature for yam composite flour in comparison to wheat flour. The gelatinization temperature has effects on energy cost and formula stability with other components.

Texture of gels from wheat flour and wheat-yam blends

Starch granules are semi-crystalline particles. During the heating process of an aqueous slurry of starch granules to higher temperatures, hydrogen bonds in the amorphous region are disrupted and water is absorbed. Subsequently, the granules will swell after which amylose leaches from the starch granule. Then, re-association of starch molecules occur during cooling resulting in gel formation occur which is followed by the retrogradation process (Ratnayake and Jackson, 2007). This is associated with water syneresis consist of two stages; the first stage of synergies development which involves conformational ordering of amylose is completed within few hours of storage, and the second stage involves the successive reordering and crystallization of amylopectin, which takes place after few days.

The texture profile of gels obtained from RWF and flour blends is shown in Table 14. The firmness of the sample gels ranged from 187–227mN and 218–267 mN, respectively, for day 1 and 7. The firmness of 15% UYF and 15% FYF were highest among their respective blends. The firmness of gels from all samples was significantly higher ($P<0.05$) in day 7 compared to that of day 1. This is expected, since gel firmness is as a result of starch retrogradation which is associated with water syneresis and crystallization of amylopectin consequently leading to harder gels (Sandhu and Singh, 2007). After day 7, all blends exhibited higher firmness compared to that of the control (RWF). Compared to that of control, most of the contribution to firmness as a result of yam flour additions were not significantly ($P<0.05$) different, except in 5 and 20 % FYF blends. Hence, it is suggested that addition of UYF to wheat flour did not result in increased syneresis and amylopectin crystallization.

Several factors have been identified as the cause of dough stickiness. They include flour extraction, differences in protein composition, amount of water-soluble pentosans, alpha-amylase activity proteolytic enzyme activity and degree of hydration of gluten molecules (Chen and Hoseney, 1995). Dough stickiness is an important quality parameter for measuring flour process ability in bakery products. Sticking of dough to proofing baskets and conveyor belts can create problems in automated bakeries (Jekle and Becker, 2011). The result of stickiness of sample gels ranged from 204–238 mN and 205–286mN, respectively, for day 1 and 7.

Table 14. Texture of gels from wheat flour and wheat-yam flour blends

Sample	Firmness (mN)		Stickiness (mN)	
	Day 1	Day 7	Day 1	Day 7
RWF	205ab	218c	204ab	286a
5% UYF	200ab	222c	191b	261ab
10% UYF	202ab	235bc	216ab	277a
15% UYF	227a	247abc	217ab	287a
20% UYF	218a	242abc	238ab	270a
5% FYF	209ab	267a	225ab	266a
10% FYF	187b	232bc	233ab	258ab
15% FYF	219a	244abc	245a	226bc
20% FYF	201ab	259ab	226ab	205c

*Values with the same letter in the same column are not significantly different (P<0.05). RWF= refined wheat flour, UYF= unfermented-white yam flour, FYF= fermented-brown yam flour

In day 1, the gels from all blends, except for that of 5% UYF, exhibited higher stickiness compared to that of control, although, the values were not significant (P<0.05). Compared to gel from day 1, there was increased stickiness in gel from all samples, except for that of 15% FYF and 20% FYF, at day 7. Yam flours caused significant increase in stickiness of gels at day 1 and day 7 for the UYF blends. unlike the stickiness of gels from more than 10% FYF blends that followed a reduction trends, at day 7. Hence increase in concentration of FYF in refined flour increased gel firmness and reduced gel stickiness after 7 days. This might be due to the property of the FYF flour since development of crystallinity in starch gels is attributed to the gelation and crystallization of the amylose fraction (Fredriksson et al., 1998). From Table 9, FYF has higher amylose content than UYF.

Dough resistance to extension and extensibility

Rheology, the study of deformation and flow of matter in response to applied stress or strain, is valuable tool in quality assessment of flour as well as the end products. Dough rheology provides details about mechanical properties, molecular structure and composition of dough (Kieffer and Stein, 2006). Dough elasticity is the ability of the dough to resist deformation. This elastic behavior is an integral feature of doughs. Extensibility is related to the dough tensile strength which evaluate dough strength property (Menjivar, 1990). When dough is stretched, it returns to its original shape when released from stretching. Higher extensibility is preferred in bread making however, this has to be in good correlation with resistance to extension, to prevent rupture and collapse of dough gas cells (Skaf et al., 2009).

The dough strength and extensibility result of RWF and sample blends are presented in Table 15. The results show that dough resistance to extension and extensibility of samples are significantly different ($P<0.05$). Resistance to extension of the sample treatment ranged from 248.40–608.03 mN. The resistances to extension of the doughs from UYF blends are lower than that of FYF blends suggesting that addition of UYF caused significant decrease in reduction to extension of doughs compared to addition of FYF. Increase in concentration of UYF and FYF caused reduction in resistance of extension of flours.

Table 15. Dough resistance to extension and extensibility

Sample	Resistance to extension (mN)	Extensibility (mm)
RWF	509.88c	67.58a
5% UYF	318.88f	59.49b
10% UYF	296.29g	56.92c
15% UYF	286.52g	55.06c
20% UYF	248.40h	51.43de
5% FYF	608.03a	51.87d
10% FYF	562.58b	49.68def
15% FYF	425.61d	49.29ef
20% FYF	382.66e	47.28f

*Values with the same letter in the same column are not significantly different ($P<0.05$). RWF= refined wheat flour, UYF= unfermented-white yam flour, FYF= fermented-brown yam flour.

FYF up to 10% exhibited higher resistance to extension of dough compared to that of control. This result is consistent with what was reported with increased chickpea addition with wheat flour (Mohammed et al., 2012). The results of dough extensibility of samples were significantly different and ranged from 47.28–67.58 mN for 20% FYF and RWF, respectively. Dough containing yam flour exhibited lower extensibility than the control. Also, the doughs from flours containing UYF exhibited higher extensibility than that containing the same concentration of FYF. Increase in concentration of FYF and UYF in flour blends resulted in decreased dough extensibility. This is mainly because extensibility characteristics are heavily dependent on the protein quality of the dough (Dobraszczyk and Morgenstern, 2003). The presence of sulfhydryl group (SH) proportion and the formation of SH-bonds in disulfide bond has been reported to be responsible for extensibility characteristics of dough (Mohammed et al., 2012).

Farinograph dough rheology of wheat/yam flour blends

The results of farinograph quality assessment of wheat flour (RWF) and wheat-yam flours blends (UYF and FYF) are shown in Table 16. The farinograph peak time (FPT), farinograph stability and mixing tolerance index (MTI), are indicative of flour dough strength. The peak time gives the baker an idea of how much energy is needed to mix dough to a maximum consistency. The stability and MTI reveal how tolerant the dough is to over-mixing. The statistical analysis shows significant ($P<0.05$) differences exist between the samples. From the result of farinograph water absorption (FWA), all the UYF blends absorb more water than the control and the brown yam flour blends. The control has higher FWA than all the FYF blends. Increased in FWA with increasing in the % level of UYF in the flour blends was observed and that 20% UYF was highest in FWA. This could be attributed to the high level of damaged starch since the contribution of damaged starch to FWA is well established (Roels et al., 1993). In agreement with this finding, increase in FWA flour blends was observed with increase in substitution level of wheat flour with yam flour (Chen and Hoseney, 1995), taro flour (Ammar et al., 2009), and chickpea (Mohammed et al., 2012). However, dissimilar pattern was observed in the FYF blends. Reduction in the FWA with increase in level of FYF addition was observed therefore, 20% FYF blends was the least FWA value. This could be as a result of reduced amount of insoluble fiber in the fermented flour.

The effect of yam flours inclusion on the flours strength shows an interesting result. With reference to the FPT, there was significant differences ($P<0.05$) between the control and the UYF blends but not with BFY blends. The FPT values ranged from 3.1 to 7.9 min. There was a decrease in FPT with increased substitution in the composite flour with both the UYF and FYF blends. Furthermore, the stability was significantly different ($P<0.05$) between the control and the composite flour samples. The stability varied widely, ranging from 3.0 to 13.0 min. The result of stability followed the same pattern as FPT described earlier. The RWF had 13.0 min stability and was the longest of the samples. The results show a drastic decline with increasing level of UYF and a slight decrease with increasing FYF. This observation is expected since fiber in the UYF and FYF blends weakens the flour. This reason could be attributed to gluten dilution in blends containing yam flour which gave rise to the changes of dough characteristics and reduce the overall gluten content of the flour. A similar observation has been recorded with wheat-taro composite flour whereby increase in taro flour resulted into decrease in dough stability and FPT (Ammar et al., 2009). This is also in agreement with previous findings where cassava flour was used (Khalil et al., 2000). Weakening of dough has also been reportedly increased with increase in substitution level of wheat flour with taro flour (Ammar et al., 2009). The MTI values were significantly different ($P<0.05$) between the control and UYF blends and the 20% FYF blend but not with other FYF blends. The MTI of the samples ranged from 28.5 to 115.0 BU. In the blend samples, the rise in MTI with increase in percentage of UYF was drastic while that of FYF blends was less drastic. The stability values of the blends decreased while their MTI values increased.

Table 16. Farinograph dough rheology of wheat/yam flour blends

Sample	% Water Absorption (14% MB)	Peak time (min)	Stability (min)	MTI (BU)	FQN (cm)
RWF	62.9cd	7.1d	13.0g	28.5a	118f
5% UYF	66.5e	4.5c	6.2e	56.5d	69c
10% UYF	70.0f	3.8abc	4.3d	79.0e	54b
15% UYF	74.2g	3.5ab	3.0a	115.0f	45a
20% UYF	75.7g	3.1a	3.4a	111.5f	47ab
5% FYF	62.1bcd	7.9e	12.1c	35.0ab	119f
10% FYF	61.0abc	6.4d	11.9bc	35.0ab	105e
15% FYF	59.9a	6.3d	11.1b	42.0abc	97de
20% FYF	60.4ab	6.7d	10.1f	53.0cd	92d

*Values with the same letter in the same column are not significantly different ($P<0.05$). RWF= refined wheat flour, UYF= unfermented-white yam flour, FYF= fermented-brown yam flour, MB = moisture basis, MTI = mixing tolerance index, BU = brabender unit, FQN = farinograph quality number

Furthermore, significant ($P<0.05$) differences exist in the farinograph quality number (FQN) between the control and other samples except with the 5% FYF blend. RWF has the highest FQN and the lowest was observed in the 20% UYF blend. Among the blends of the same percentage, FQN values of UYF blends were lower than their respective FYF blends. As the yam flour percentage in UYF and FYF flour blends increase, the FQN decreased steadily. The observations in this study is in agreement with previous report where composite flour addition caused a reduction in stability, FQN and increased MTI (Mohammed et al., 2012). Between the sample blends, UYF with relatively low quality thus indicate poor flours which weaken quickly. As such, the farinograph data clearly indicates that both the UYF and FYF composite flours are weaker than RWF.

Gassing power of refined wheat flour (RWF) and composite flour blends

Gassing power was calculated at 90 min fermentation time. The gassing power is extensively used to investigate yeast strains that have high freeze tolerance in frozen dough (Inoue and Bushuk, 1992; Van Dijck et al., 1995). Higher amount, associated with high pressure, is attributed to more carbon dioxide production in the dough system; thus, resembles the high yeast activity during fermentation.

According to Figure 15 result, the gassing power of samples varied significantly (P<0.05) and ranged from 4.8–3.6 psi, respectively, for RWF and 20% UYF. All blends exhibited significantly (P<0.05) lower gassing power compared to the control (RWF). There were no significant (P<0.05) differences in samples containing FYF, unlike those containing UYF. Increase in concentration of UYF resulted in significant (P<0.05) decrease in gassing power.

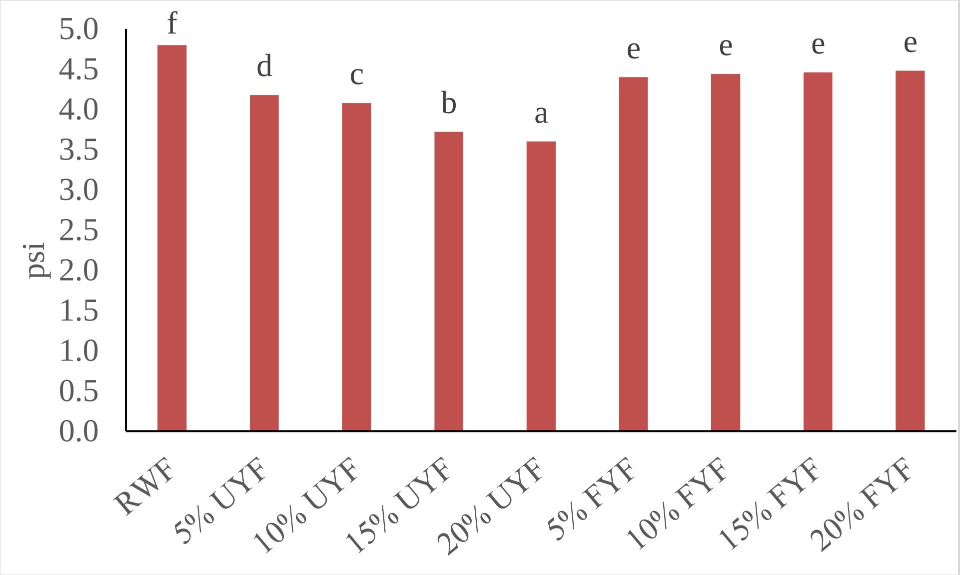


Figure 15. Gassing power of refined flour (RF) and composite flour blends

*Columns with the same letter are not significantly (P<0.05) different. RWF = refined wheat flour, UYF= unfermented-white yam flour, FYF= fermented-brown yam flour

In general, low yeast activity was exhibited when there was increase in the blends formulation of dough. This indicates that composite flour inclusion may not actively propagate yeast activity to produce more carbon dioxide. The UYF exhibited lowest activity among the blends. This could be attributed to high phenolic presence in the UYF as presented previously from Table 8 results. Although, minerals; calcium, magnesium, potassium, and sulfur are essential for yeast growth and health (Kadan and Phillippy, 2007), phenols has shown to form complexes with proteins (Winters and Minchin, 2005), bind with water-extractable pentosans in bread making (Wang et al., 2002) and interact with protein to form haze in beer, wine and fruit juices (Siebert, 1999). Likewise, its antimicrobial and antioxidant property has been associated with ferulic acid presence (Ou and Kwok, 2004). Ferulic acid has been reported to inhibit bacteria, fungi and yeasts growth (Lattanzio et al., 1994).

Mixing characteristics of wheat and yam flour blends

Table 17 shows mixing characteristics result of wheat and sample blends. Significant ($P<0.05$) differences exist between the bake absorption of the control and that of other flour blends, except that of the 5% FYF blend. The bake absorption ranges from 67.2 to 83.9%. Increase in the bake absorption was observed with increase in percentage of UYF in blends; however, there was not much change in the bake absorption of FYF blends. In comparison to control, all the UYF blends have higher bake absorption while that of FYF blends were lower. Although, the mix time was higher in blends containing FYF, there was no significant difference ($P<0.05$) from control.

Table 17. Mixing characteristics of wheat and yam flour blends

Sample	% Bake absorption (14% MB)	Mix time (min)	Dough handling (1-10)
RWF	69.4b	3.6cd	10e
5% UYF	73.2c	3.5bcd	9d
10% UYF	78.1d	3.4bc	8c
15% UYF	82.4e	3.3ab	7b
20% UYF	83.9f	3.0a	6a
5% FYF	68.4ab	3.8d	9d
10% FYF	67.4a	3.5bcd	9d
15%FYF	67.2a	3.6cd	9d
20% FYF	67.7a	3.6cd	8c

*Values with the same letter in the same column are not significantly different ($P<0.05$). RWF= refined wheat flour, UYF= unfermented-white yam flour, FYF= fermented-brown yam flour

Dough handling is associated with optimization score with value ranges from 1–10. The dough handling data shows, there was significant different ($P<0.05$) between the dough optimization scores for control and the UYF and FYF flour blends. The dough optimization scores for all the flour blends are lower than the control, and decrease in value was observed with higher % level of UYF. The mixing time for the blends to reach optimal dough development stage (window pane formation) decreases with increase in the substitution level with 20% UYF having the least value. The decreased mixing time and dough optimization indicate weakening of dough strength. The reason could be due to the presence of high amounts of fiber.

Baking quality of wheat/yam flour blends

Numerous studies on effect of inclusion of different non-wheat flour into RWF on bread qualities have been reported in literature. The effects on bread qualities varied considerably depending on source, percentage of substitution and pretreatment of flour. Composite flour can result into higher or lower loaf volume. For instance, inclusion of roasted legumes flours was reported to enhance the loaf volume of bread (Baik and Han, 2012) while reduction in loaf volume was reported with inclusion of flour from cocoyam, cassava, rice, taro, maize, chickpea (Mohammed et al., 2012; Noorfarahzilah et al., 2014). It was proposed that reduction in loaf volume is a result of reduction in generation of steam due to high water absorption capacities of some non-wheat flours (Mohammed et al., 2012).

Table 18 shows the bread baking quality parameters including the proof height, baked height, oven spring, baked weigh, loaf volume and specific volume. The proof height was measured using the proof height meter and while bread was still in the pan, their baked height was measured for calculation of oven spring value which is the difference between the baked height and the proof height. Likewise, objective measurement for the baked weight and bread loaf volume were determined using weighing balance and loaf volume meter, respectively. The specific volume was calculated by dividing the loaf volume by their respective baked weight.

Table 18. Baking quality of wheat/yam flour blends

Sample	Proof height (cm)	Bake height (cm)	Oven spring (cm)	Weight (g)	Loaf Volume (cc)	Specific volume (cc/g)
RWF	9.1a	12.4e	3.3d	133ab	1123e	8.5e
5% UYF	9.5bc	12.2de	2.8cd	137b	1115d	8.2de
10% UYF	9.6c	11.9c	2.3bc	138bc	1078cd	7.8bcd
15% UYF	9.4bc	11.6b	2.2b	144c	1075c	7.5bc
20% UYF	9.4bc	10.7a	1.3a	145d	958a	6.6a
5% FYF	9.1a	12.0cd	3.0d	133ab	1060c	8.0cde
10% FYF	9.1a	12.0cd	2.9d	133ab	1058c	8.0cde
15%FYF	9.3ab	11.6b	2.3bc	134ab	1005b	7.5bc
20% FYF	9.1a	11.1ab	2.1b	130a	965a	7.4b

*Values with the same letter in the same column are not significantly different ($P<0.05$).

RWF= refined wheat flour, UYF= unfermented-white yam flour, FYF= fermented-brown yam flour

As expected, the quality traits of the bread produced from the samples were different. The oven spring values of the loaves baked with UYF and FYF blends were lower than that of the control. The values for oven spring of UYF blends were significantly ($P<0.05$) different from the control, except for the 5% UYF blend. However, the values for oven spring of FYF blends were not significantly ($P<0.05$) different compared to that of the control sample, except for the 15 and 20% FYF blends. The differences in oven spring could be due to the low gluten forming proteins in the blends. Poor gluten network formation in the samples explained their low expansion capacity of the loaves compared to that of control. Further increase in percentage of FYF and UYF resulted in decrease in oven spring thus, corroborate the weakening of their respective dough.

The oven spring behavior of bread samples can be well related to their gassing power reported in Figure 15 above. This is possible because increase in gas production during fermentation will amount to dough rising during baking. Reduction in gassing power in UYF samples explained the reduction in oven spring with increase in level of substitution. (Mohammed et al., 2012). Although, the gassing power of FYF samples remained relatively equal, their oven spring followed decreasing trend. This could possibly be explained with the reduction in their wet gluten (Table 12). Low gluten will not allow retention of gas produced therefore result in reduced oven spring.

The bread weight of the control was significantly ($P<0.05$) different from that of 15 and 20% UYF blends, but not with that of breads made from FYF blends. The weights of the bread loaves were higher in UYF blends possibly due to the use of high bake absorption. In addition, the UYF blends were high in fiber which is responsible for absorption of high amounts of water needed for hydration. The statistical analysis revealed that loaf volumes of the samples were significantly ($P<0.05$) different. The loaf volume showed a decreasing trend when the percentage of UYF and FYF was increased in the composite flours. It could also be attributed to the reduced amount storage protein and presence of high amount of fiber in the blends, which interferes with the gluten network resulting to weaker dough. The result of specific volume shows that inclusion of > 5% UYF and > 10% FYF in the flour blends resulted to significant difference ($P<0.05$) compared to control.

External and internal quality scores data for bread prepared from wheat/yam flour blends

Consumer perception of product color has been associated with quality. The level of substitution in composite flour should not cause significant change in product color. The crust color of bread has also been reportedly affected by addition of non-wheat flours. Increase in L* value was reported when pumpkin and lesser-yam were used for wheat-based composite flour (Noorfarahzilah et al., 2014). Maillard reaction known as non-enzymatic browning is the chemical reaction of amino acids with reducing sugars in the presence of heat. This reaction has been implicated to be responsible for crust color when level of sugar become high. Also, the darkening effect of chickpea was attributed to increase in Maillard reaction due to increase in protein level (Mohammed et al., 2012).

Table 19 shows the subjective measurement based on mental perception of baking quality of bread loaves which includes; symmetry score, crust color, grain and texture and crumb color. Compared to the control, the scores for symmetry were only significant difference ($P<0.05$) in 20% FYF and > 10% UYF containing flour blends. Decrease in loaves score was observed as the level of unfermented-white and fermented-brown yam flour incorporated increase. In the blends formulation, loaves prepared with 20% UYF and FYF exhibited the lowest score 7 and 8.5, respectively. All loaves were given a score of above 6, therefore the symmetry did not appear to be unsatisfactory.

Table 19. External and internal quality scores data for bread from wheat/yam flour blends

Sample	Symmetry (1-10)	Crust color (1-10)	Crumb grain (1-10)	Crumb Color L*	a*	b*
RWF	9.5de	9.0c	7.0c	82.92d	-1.02a	15.41a
5% UYF	10.0e	8.0b	7.0c	84.61e	-1.08a	16.10abc
10% UYF	9.0cd	7.5ab	6.5bc	84.77e	-1.15a	15.91ab
15% UYF	8.0b	7.0a	6.0b	83.65de	-1.01a	16.01abc
20% UYF	7.0a	7.0a	5.0a	82.51d	-1.06a	15.89ab
5% FYF	9.5de	9.5cd	7.0c	80.87c	0.41b	17.01c
10% FYF	9.0cd	9.5cd	6.0b	79.29c	0.91c	16.20abc
15%FYF	9.0cd	10.0d	6.0b	78.12b	1.74d	16.24abc
20% FYF	8.5b	10.0d	5.0a	76.52a	2.34e	16.62bc

*Values with the same letter in the same column are not significantly different ($P<0.05$). RWF= refined wheat flour, UYF= unfermented-white yam flour, FYF= fermented-brown yam flour, L= whiteness, a= redness, b= yellowness

In this work, the darkening effect of FYF samples can be attributed to the enzymatic browning reaction during the yam peeling process for the flour production**.** The crust color of the bread from all samples were significantly different ($P<0.05$) except for that of 15 and 20% FYF blends. The crust color for all the UYF blends were relatively low compared to control. However, crust color became progressively darker, as concentration of FYF was increased in the formulation. The dark crust color could also be due to non-enzymatic browning that took place during the heating/fermentation process of the FYF.

The result of crumb grain shows significant different ($P<0.05$) between the samples, except for that of 5 and 10% UYF blends. Generally, the grain crumb score decreases with higher level of FYF and UYF. This implies that bread crumb from the control has a smooth texture than those with composite flour, with the coarsest crumb texture observed in the 20% flour substitution. Therefore, the usage of yam flour may have affected the grain in a negative manner. This could be due to the presence of fiber and the low amount of gluten which results in potentially less gas cells in the crumb.

Crumb quality is an essential factor in assessing loaf bread. Crumb color is a degree of color darkness in the crumb ranging from creamy to white. Consumers mostly prefer white color for bread made from refined wheat flour. L* value describe black to white (0-100), a* values describe red (positive) and green (negative) and b* values describe yellowness (positive) and blueness (negative). There exists significant difference ($P>0.05$) in L* value of the control when compared to all sample blends except for 15% and 20% UYF. The L*, a*, and b* values of the bread crumb varied from 76.52 to 82.92, -1.15 to 2.34 and 15.41to 17.01 respectively. Bread crumb color became more bright (higher L*), but redness remained the same (alike a*) as the percentage of UYF increased. The statistical analysis shows significant reduction in brightness of the FYF blends. Decreases in brightness occurred when the amount of FYF was increased in the blends. The bread appeared to have taken a darker shade with increasing level of FYF blends.

Crumb firmness of breads made with wheat/yam flour blends

Staling is a term which indicates decreasing consumer acceptance of bakery products caused by changes in crumb firmness, crust, and organoleptic properties. However, in white pan bread, the most widely used indicator of staling is measurement of the increase in crumb firmness. Although bread staling has been studied for more than a century and a half, it has not been eliminated and remains responsible for huge economic losses to both the baking industry and the consumers (Gray and Bemiller, 2003). Bread staling is a gradual retrogradation process whereby amylopectin fraction of starch recrystallizes changing from amorphous to crystalline forms thus resulting to toughening of the crust, increase in opaqueness, loss of flavor, decrease in soluble starch and firming of the crumb. The firmness of bread varies with position within a loaf, with maximum firmness occurring in the central portion of the crumb (Lin and Lineback, 1990). The result of crumb firmness measurements of baked breads loaves with the flour samples are shown in Figure 16. Statistical analysis revealed that there is significant ($P>0.05$) difference between the crumb firmness of loaves of RWF and 15 and 20% FYF blends.

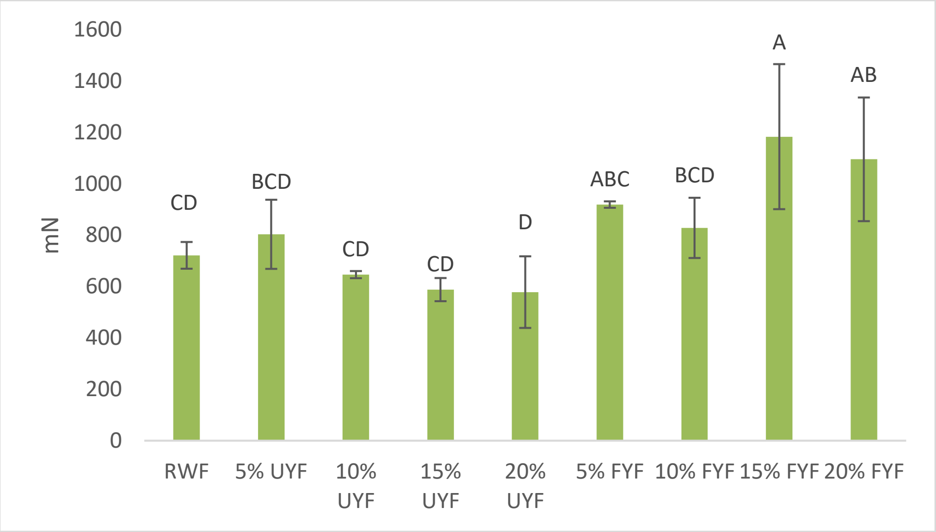


Figure 16. Crumb firmness of breads made with wheat/yam flour blends

*Error bars represent standard deviation. Columns with the same letter are not significantly different ($P<0.05$). RWF = refined wheat flour, UYF= unfermented-white yam flour, FYF= fermented-brown yam flour

Crumb firmness is mostly associated with retrogradation of starch. Since when starch retrogrades, it reverts in part from an amorphous state to a less hydrated crystalline state, with simultaneous release of water that is presumably absorbed by the gluten proteins (Morgan et al., 1997). Addition of chickpea to RWF was reported to have resulted in marked increased crumb hardness as a result of thickening of the crumb walls (Mohammed et al., 2012). Likewise, increase in bread crumb firmness was reported when composite flour of sweet potato, maize and soybean was incorporated to wheat flour for bread making (Julianti et al., 2015). This is similar with the result obtained from 15 and 20% FYF blends where significant increase in crumb firmness was observed. Likewise, Trejo-González et al. (2014) reported, significant increase in bread crumb firmness with increase in level of sweet potato flour inclusion. Contrary to what was observed with FYF blends, the firmness of the loaves made from UYF blends decreased as level of substitution increased. This is similar with what was observed in the work of Ilia and Alikhan (2016) where substitution of pregelatinized maize flour was reported to retard staling process during storage. In addition, the inclusion of 35% malted rice flour was stated to results in increased gas production in the dough, gives a better crumb moisture retention, and enhanced flavor development (Veluppillai et al., 2010). Samples with 20% UYF had the least firmness result suggesting that UYF lack accelerating effect on staling, unlike FYF blends which makes the bread firm quicker.

C-Cell analysis of baked bread loaves

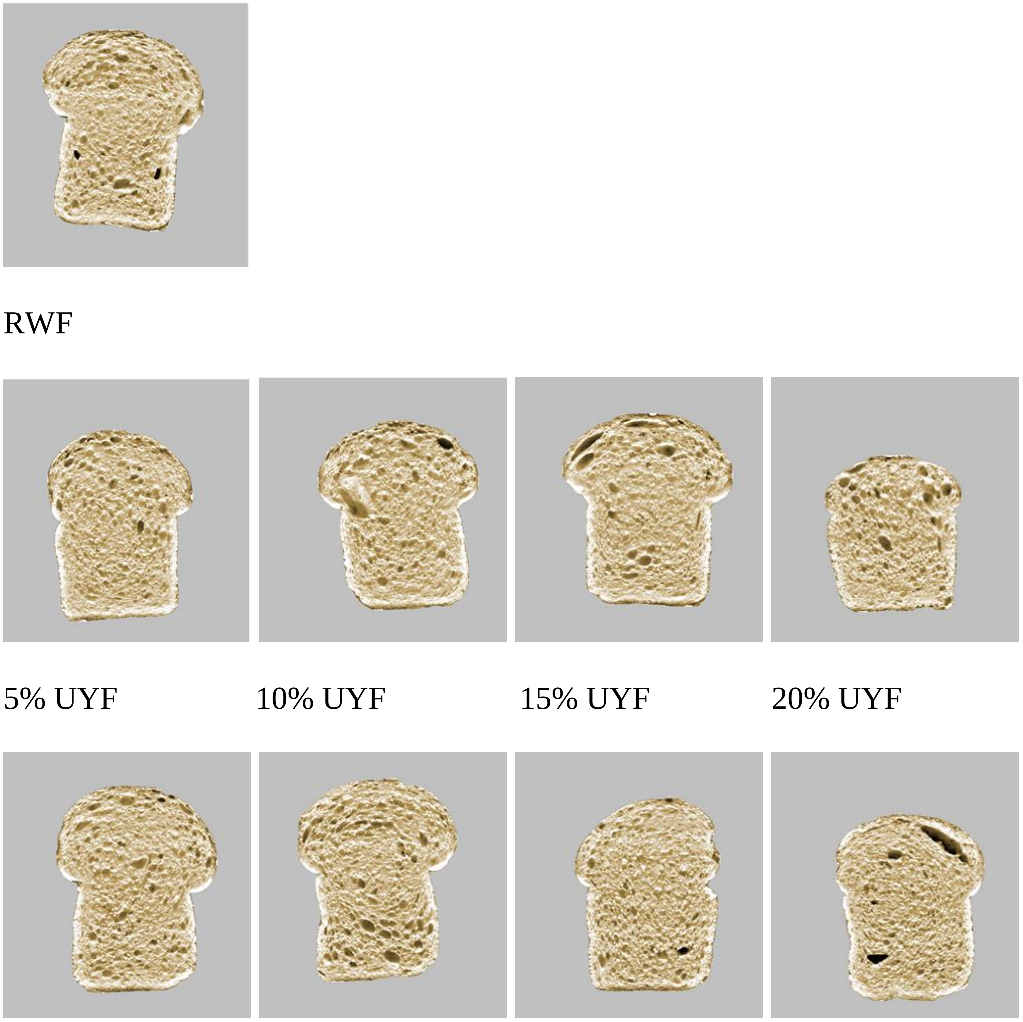
C-cell analysis was conducted on baked bread loaves (Figure 17) made from the sample flours. Many characteristics were obtained from the C-Cell analyzer, such as slice brightness, cells contrast, number of cells, cell wall thickness, cell diameter, cell volume, coarse cell volume and cell elongation. Table 20 shows that all the parameters obtained from C-cell analysis were significantly different ($P<0.05$), except cell volume and cell contrast.

The slice brightness ranged from 74.80–85.55. The loaf from 20% FYF blend had the least slice brightness value which was significantly ($P<0.05$) different from that of control and the UYF blends. The number of cells ranged from 3298–3958. A great number of cells imply that bread is less firmness with soft crumb texture desired by consumers. Therefore, inclusion of FYF and UYF into wheat flour reduced the crumb softness of bread. The cell wall thickness ranged from 2.98–3.13 μm, respectively, for 10% FYF and 20% UYF blends. Compared to control, the cell wall thickness of loaf from 20% UYF blends was significantly ($P<0.05$) higher, while that of 10% FYF blends was significantly ($P<0.05$) lower. The cell diameter of the loaves ranged from 13.74–17.22, respectively, for 20% FYF and 20% UYF blends.

Table 20. C-Cell analysis of baked bread loaves

Sample	Slice brightness	Cell contrast	Number of Cells	Cell wall thickness (μm)	Cell diameter (mm)	Cell volume (mm^3)	Coarse cell volume (mm^3)	Cell elongation
RWF	85.6c	0.70a	3958c	3.03abc	15.11ab	6.89a	12.78ab	1.65bc
5%UYF	81.2bc	0.69a	3826c	3.05abc	16.55ab	7.79a	14.43ab	1.63abc
10% UYF	83.3bc	0.68a	3662bc	3.08bc	16.63ab	7.93a	17.46c	1.58ab
15% UYF	81.5bc	0.67a	3298ab	3.11c	16.74ab	8.04a	16.14b	1.56a
20% UYF	82.3bc	0.68a	2961a	3.13d	17.22b	8.33a	14.81ab	1.60ab
5% FYF	80.5abc	0.67a	3745c	3.02abc	15.98ab	7.53a	15.90ab	1.70c
10% FYF	77.2ab	0.68a	3855c	2.98a	14.25ab	6.65a	12.13ab	1.68c
15% FYF	79.5abc	0.68a	3748c	3.03abc	14.00ab	6.65a	11.32ab	1.68c
20% FYF	74.8a	0.69a	3551bc	2.99ab	13.74a	6.51a	10.45a	1.64bc

*Values with the same letter in the same column are not significantly different ($P<0.05$). RWF= refined wheat flour; UYF= unfermented-white yam flour, FYF= fermented-brown yam flour



RWF

5% UYF 10% UYF 15% UYF 20% UYF

5% FYF 10% FYF 15% FYF 20% FYF

Figure 17. Cell images of white and composite (unfermented-white and fermented-brown yam) bread loaves

Cell diameter of all loaves from all UYF were higher, while that of loaves from FYF blends, except in 5% FYF, were lower, compared to control. Interestingly, increase in concentration of UYF caused increased cell diameter of loaves, contrary to effect of increase in concentration of FYF in the flour blends.

Coarse cell volume ranged from 10.45–17.46 mm^3. Increase in concentration of FYF in flour blends resulted in decreased coarse cell volume of loaves; however, increase in concentration of UYF lacked specific trend. The values of cell elongation of the loaves ranged from 1.56–1.70. All loaves from UYF blends were of lower cell elongation, compared to that of the control. Except 20% FYF, all the FYF blends exhibited higher cell elongation than the control. Increase in concentration of FYF in the flour blends resulted in decreased cell elongation.

Starch hydrolysis properties of baked bread loaves

Starch can be broadly classified as resistant starch (RS), rapidly digestible starch (RDS) and slowly digestible starch (SDS) based on their behavioral pattern with enzymes action. This section focuses on the total RS, RDS and SDS content of the flour samples. The RS resists digestion in the small intestine but is fermented in the large intestine by gut microbes. RDS mainly contains amorphous and dispersed starch. Their conversion to constituent glucose molecules takes place in 20 min of enzyme digestion. SDS consists of physically inaccessible amorphous starch and raw starch and digestion occurs more slowly in the small intestine. Their conversion to glucose is measured after 100 min of enzyme digestion (Sajilata et al., 2006).

The starch components and properties needed to be investigated to determine the effects of starch on bread quality. Table 21 shows that the starch hydrolysis properties of starch fractions obtained from the breads prepared from the flour samples were significantly different (P<0.05). The total starch (TS) value ranged from 58.8% to 62.4%. The refined wheat flour has the highest total starch content. The starch content progressively decreased, as concentration of unfermented-white and fermented-brown yam flour increased in their bread samples. This agrees with the work of Kiin-Kabari and Giami (2015) where significant decrease in total starch was observed with an increase in the amount of banana composite flour.

RS has demonstrated similar physiological benefits as dietary fibers and it has been proposed that RS should be included in the definition of dietary fibers (Goodlad and Englyst, 2001). The RS ranged between 1.65–2.60% and 1.41–2.84% respectively for UYF and FYF. Increase in concentration of UYF and FYF in the blends led to increase in the values of RS of their breads. In our result, the RS % level for the FYF was higher when compared with its UYF counterpart. This negates the claim that fermentation decreases the amount of RS (Kavita et al., 1998). RS has a small size particle with bland flavor and low water holding capacity. Its desirable physicochemical properties including increased viscosity, swelling, water binding capacity and gel formation has make it more useful in different food varieties (Nugent, 2005). Thus, composite bread made with more than 10% flour inclusion are expected to provide a good handling processing and crispness, expansion and improved texture in the final product. However, dough expansion during baking decreased with increased level of composite flour as observed in Table 18. The range of SDS was from 32.15 to 37.89%. In the UYF sample blends, decrease in RDS was observed with an increase in percentage in the bread samples, but SDS in the formulation follow an opposite trend. Nonetheless, RDS and SDS decline with gradual increase in FYF concentration in the breads.

The hydrolysis index (HI) is determined as the rate of starch hydrolysis in the target food compared to starch hydrolysis rate in a references food (Frei et al., 2003). Glycemic index (GI) refers to the postprandial glycemic response of a test product compared to that of a reference food. Glycemic index (GI) is originally developed for diabetic patients to avoid highly digestible starchy foods that cause a rapid increase in postprandial blood glucose response. Here, commercial white bread purchased from a local grocery store was used as the reference material in this study. Several studies (Englyst et al., 1999; Englyst et al., 2003; Wolever et al., 1991) have indicated that higher SDS and RS contents in diets reduce the rate and extent of in vivo starch digestion and thus maintain sustained and lower postprandial glucose responses in peripheral circulation.

Table 21. Starch hydrolysis properties of baked bread loaves

Sample	% Dry weight basis					
	TS	RS	RDS	SDS	HI	eGI
RWF	62.3a	2.0c	24.5bc	35.7b	93.3d	88.6d
5% UYF	61.6c	1.7cd	25.8a	34.2d	86.7e	82.9e
10% UYF	61.3d	1.7cd	24.2bc	35.4cb	85.1f	81.6f
15% UYF	60.7e	2.1bc	20.7d	37.9a	87.3e	83.5e
20% UYF	59.8h	2.5ab	20.1d	37.2a	85.8f	82.2f
5% FYF	62.1b	1.4d	25.7a	35.3bcd	99.0a	93.5a
10% FYF	60.3f	1.7cd	24.3bc	34.3cd	96.2b	91.1b
15%FYF	59.8g	2.8a	24.8ab	32.2e	95.5b	90.5b
20% FYF	58.8i	2.8a	23.8c	32.2e	94.5c	89.7c

*Values with the same letter in the same column are not significantly different ($P<0.05$). RWF= refined wheat flour; UYF= unfermented-white yam flour, FYF= fermented-brown yam flour; RDS = rapidly digestible starch; SDS = slowly digestible starch, TS = total starch, RS = resistant starch; HI = hydrolysis index; eGI = estimated glycemic index

The hydrolysis index (HI) and estimated glycemic index (eGI) of the samples were respectively in the range of 85.12% to 98.98% and 81.57 to 93.52. All the bread samples all had HI below 100, which imply that the starch in these samples had a lower starch hydrolysis rate than the reference food. The HI and eGI of the flour blends exhibited an inverse proportion with the RS. The HI and eGI trends for all the bread samples follow similar pattern. There was significant ($P<0.05$) differences between the control and all the flour blends formulation with respect to HI and eGI. The HI and eGI of the UYF breads was significantly ($P<0.05$) lower than the control and their FYF bread counterparts. Compared to the control, the HI and eGI were lower in bread made from UYF blends. The HI and eGI was highest in bread made from 5% FYF, but lowest in that of 10% UYF flour blends. The FYF exhibited higher indices than the control sample, a phenomenon that may also be dependent on the physical structure of the final product. Results indicate that FYF are easily hydrolyzed and they give a spike in the glucose response. Hence, the UYF with low eGI are a better source of indigestible carbohydrate than their FYF counterpart. This is because a low-GI food is perceived as a healthy food choice since ingesting a high-GI food increases the blood glucose concentration rapidly to above physiological range.

Amylose, amylopectin, molecular weight and polydispersity index of starch in flour and bread

Table 22 shows the percentage content of amylose and amylopectin, their molecular mass and polydispersity index of flours and breads. Enzyme hydrolysis of starch molecules to produce glucose is important to provide energy for plant metabolism, food, and ethanol production. The starch granules are hydrolyzed at a slower rate by enzymes than the gelatinized, amorphous starch molecules. However, starch in bread is hydrolyzed more rapidly and extensively than that of from flour. The susceptibility of the starch granules depends on the granular size, the polymorphism, the structure of the amylopectin, the amylose content, the lipid content, and the reaction pattern of the enzyme. In general, the larger starch granules are normally digested at a slower rate than the smaller starch granules because the larger granules have a smaller relative surface space for enzyme hydrolysis (Tester et al., 2004). The A-type polymorphic starch granules, such as waxy amaranth starch and waxy rice starch is more easily hydrolyzed by enzyme than the B- and some C-type polymorphic starch granules, such as potato starch, green banana starch, and high-amylose maize starch (Jane et al., 2003). This is attributed to that the branching points of the amylopectin in the A-type polymorphic starch are scattered in both amorphous and crystalline regions, creating weak points in the crystalline regions for enzyme hydrolysis, whereas those of the B-type counterparts are mostly located at the amorphous region, resulting in a more perfect crystalline structure (Jane et al., 1997). The amylose content is known to be negatively correlated with the starch susceptibility to amylase hydrolysis (Dombrink-Kurtzman and Knutson, 1997; Jane 2006).

Table 22. Amylose, amylopectin, molecular weight and polydispersity index of starch in flour and bread

	Sample	%		Molecular Mass (Da)		Polydispersity Index	
		AM	AP	AM	AP	AM	AP
Flour	RWF	25.1a	74.9n	1.29x10^{6}a	1.11x10^{7}a	1.10k	1.57a
	5% UYF	24.7c	75.3l	1.22x10^{6}b	7.14x10^{6}b	1.29gh	1.43b
	10% UYF	24.3d	75.7k	1.00x10^{6}c	7.12x10^{6}b	1.15ij	1.35c
	15% UYF	23.9f	76.1i	9.97x10^{5}d	6.81x10^{6}c	1.55c	1.24d
	20% UYF	23.3h	76.7g	7.70x10^{5}i	6.24x10^{6}d	1.78a	1.32c
	5% FYF	24.9b	75.1m	7.05x10^{5}j	4.11x10^{6}e	1.44de	1.04h
	10% FYF	24.7c	75.3l	6.52x10^{5}l	3.68x10^{6}f	1.41ef	1.11fg
	15%FYF	24.4d	75.6k	6.21x10^{5}n	3.20x10^{6}g	1.42e	1.18e
	20% FYF	24.1e	75.9j	6.01x10^{5}o	3.12x10^{6}h	1.50cd	1.20e
Bread	RWF	21.4n	78.6a	8.03x10^{5}f	2.59x10^{6}j	1.06k	1.11fg
	5% UYF	21.6m	78.4b	7.77x10^{5}h	2.56x10^{6}k	1.27hi	1.12g
	10% UYF	22.2l	77.8c	7.76x10^{5}h	2.53x10^{6}l	1.25hi	1.11fg
	15% UYF	22.5k	77.5d	6.89x10^{5}k	1.93x10^{6}o	1.45de	1.13f
	20% UYF	23.1i	76.9f	6.28x10^{5}m	1.64x10^{6}p	1.63b	1.21de
	5% FYF	22.2l	77.8c	8.46x10^{5}e	2.78x10^{6}i	1.18j	1.07gh
	10% FYF	22.5k	77.5d	7.97x10^{5}g	2.55x10^{6}kl	1.23hij	1.10fg
	15%FYF	22.7j	77.3e	6.01x10^{5}o	2.24x10^{6}m	1.34fg	1.14f
	20% FYF	23.5g	76.5h	5.56x10^{5}p	2.04x10^{6}n	1.40ef	1.18e

*Values with the same letter in the same column are not significantly different ($P<0.05$). RWF= refined wheat flour; UYF= UYF= unfermented-white yam flour, FYF= fermented-brown yam flour; AM = Amylose; AP = Amylopectin

Starch is the main constituent of wheat flour and bread and it is exclusively made up of the amylopectin and amylose (Capron et al., 2007). Starch granule, an orderly semi-crystalline structure and birefringent, has its molecules radially arranged containing the crystalline region that are associated with an alternating layer of amorphous region. Amylopectin component is in the crystalline region of the starch granule while amylose is involved with the amorphous region of the granule (Noda et al., 2005; Tang et al., 2000). The starch in cereals and cereal products cannot be considered an isolated system because once amylopectin and amylose are leached from damaged granules, they come into direct contact with proteins and other components such as fats and fiber. Chemical properties of starch were investigated to evaluate its impact on the bread quality. Statistical analysis shows significant differences ($P>0.05$) exist in the amylose and amylopectin contents of the starches extracted from the flour and bread samples. The amylose contents of the wheat flour was 25.09%, which falls within the normal typically range of about 25% for native wheat starch (Eliasson, 2004). The amylose contents of the flours blends were lower and their amylopectin content were higher than the control. After baking, significant ($P<0.05$) decrease in the amylose content for all bread samples occur. This is predictable due to amylose leaching from the starch granule during the starch gelatinization. This indicates that amylose are more readily available for hydrolysis than the amylopectin (Eliasson, 2004).

The characteristics of the different types of resistant starch reflect the effect of processing, starch granule characteristics, and gelatinization on the starch structure. Heating starch in the presence of adequate water contributes to starch gelatinization and an increase in digestibility. With cooling, starches with high amylose contents retrograde and form crystalline regions not accessible to enzymatic hydrolysis (Sharma et al., 2008). However, swelling and gelatinization of high-amylose starches are reduced compared with normal starches as a result of the higher degree of crystallinity (Hallström et al., 2011). Cooked potatoes administered to patients with an ileostomy showed only 0.82% resistant starch in freshly cooked potatoes, whereas potatoes that had been allowed to cool showed 1.60% resistant starch when analyzed (Englyst and Cummings., 1987). The differences between freshly cooked and cooled potato meals were attributed to retrogradation of amylose and long amylopectin chains characteristic of potato starches. Also, in the work of Faisant et al. (1995) who investigated digestibility of green banana starch in human ileostomates, reported that resistant oligosaccharides and intact granular starch comprising of 83.7% of the original starch weight were observed.

Molecular mass is also an important characteristic of starch and could affect the nutritional and end-product of the bread quality. The amylose and amylopectin molecular mass significantly differed from the control and among flour sample blends and those of bread. The amylose and amylopectin molecular mass of all the treatment were higher than those obtained for the bread samples after baking. This reduction in molecular mass in the bread samples is related to the level of starch hydrolysis that occurred during fermentation and baking process. The molecular mass of amylose and amylopectin in all flour samples progressively decreased with increased UYF and FYF concentration. Similar trend was observed in the breads samples. This variation in starch molecular mass has been associated with sample genetic make-up and environmental differences. This could alter wheat starch swelling and pasting characteristics which invariably affect the end-product quality (Shibanuma et al., 1996; Simsek et al., 2013). Amylose has a smaller molecular mass than amylopectin, but it has significant functionality in wheat flour. The bread formulations with the least amylose molecular mass implies its high starch hydrolysis level. Bread made from the 20% blends with the least amylose has poor texture in comparison to others sample treatment as earlier mentioned. The amylose molecule prevent collapse by providing a significant amount of structure and texture to bread (Hung et al., 2007).

Polydispersity is also an important measure used to describe the degree of non-uniformity of molecule through width of molecular weight determining in a distribution. The amylose polydispersity index of flour and breads were significantly ($P<0.05$) different in all the treatment samples. The flour apparent amylose polydispersity index value ranged from 1.10 to 1.78 respectively, for RWF and 20% UYF. For bread, their apparent amylose polydispersity index value ranged from 1.06 to 1.63 respectively for RWF and 20% UYF. Therefore, the values of amylose polydispersity in RWF were the least, while that of 20% UYF blend were the highest in flour and bread samples. This means that amylose in 20% blends have a broader width than those of other treatments. Likewise, there exist significant difference ($P<0.05$) in the amylopectin polydispersity index of flour and bread samples. The flour amylopectin polydispersity index value ranged from 1.04 to 1.57 respectively, for 5% FYF and RWF. The amylopectin polydispersity index value of bread ranged from 1.07 - 1.21 respectively 5% FYF and 20% UYF

Conclusions

The formulation of wheat-yam composite flours was conducted using UYF and FYF. The properties of the composite flours varied depending on the type of yam flour and the level of substitution. Although, composite flours exhibited low protein and wet gluten content compared to RWF, the composite flours were more beneficial in terms of ash, starch and extractable phenolic contents. The color of composite flours was affected when FYF was used, but not with UYF. The pasting profile of gels from the flour samples showed that the composite flours of UYF have lower pasting property compared to that of its FYF counterpart. The structure of the composite flour particles played important roles in the pasting profile of the flours. The compactness of UYF particles might have been responsible for their reduced response to swelling and gelatinization process. Inclusion of yam flour contributed to stickiness in day 1 but not in day 7 compared to the stickiness RWF gels. Although, the measurement of gels' firmness in day 1 and 7 showed that the composite flour will retrograde quicker than RWF, the inclusion of 5 and 10% of UYF did not cause significant retrogradation effect. Low level of substitution of RWF with UYF did not affect dough resistance to extension unlike that of UYF. FYF (5%) also reduced extensibility of dough greatly. In terms of water absorption, substitution of RWF with UYF is more preferred than FYF, but the dough is less stable. Dough stability is enhanced by substitution of RWF with FYF. The gassing power of composite flours containing UYF followed decreasing trend as substitution level increase, unlike that of FYF that were relatively unchanged. Substitution of 5% of RWF with yam flour did not cause much effect on dough handling and mixing time while bake absorption was more enhanced with UYF than FYF. The bread qualities were affected by inclusion of yam flours. Breads from 5% level substitution with UYF appeared to be of similar quality like that of control in terms of oven spring, bake height, weight and specific volume. The crumb color attributes were not affected by inclusion of UYF, unlike FYF that altered the whiteness and redness. Substitution of RWF with 5 % FYF yam flour and to a lesser degree was of satisfactory features for bread making.

A crucial aspect of our result is the increase in gluten index of FYF blends, even though, the wet gluten was low. More so that the increase gluten index did not cause increased loaf volume. It is possible that the PPO activity in FYF sample interfered with the sample protein and thus the value of gluten index. Future works should investigate the use of different ratio of FYF and UYF for formulation of wheat-yam composite flour. Also, the rate of fermentation could also be controlled to developed tailor made flour.

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EXPERIMENT 3: EFFECT OF YAM-WHEAT COMPOSITE FLOUR ON THE COMPOSITION AND PROPERTIES OF TORTILLA

Abstract

The production of tortillas from composite flours is a strategy to improve nutritional intake by consumers. The hot-press method which is the most popular commercial tortilla production was employed in this study. The effects of different levels of substitution in wheat-yam composite flour on the end-use qualities of tortilla were investigated. Refined wheat flour (RFW) was substituted with different percentages (5, 10, 15 and 20 %) of fermented-brown (FYF) and unfermented-white (UYF) yam flours. Results shows that protein content was significantly ($p<0.05$) lower in the composite flours compared to RFW. The farinograph water absorption increased significantly ($p<0.05$) for blends prepared with UYF and the values obtained were related to the tortilla qualities. The properties and composition of sample blends significantly affect tortilla quality. Tortilla made from flour blends was thicker and heavier but decrease in diameter than that of RWF. The baked tortillas were stored at room temperatures for 7 days and the quality was evaluated at day 0, 1, 2, 5 and 7. Tortilla moisture increased with storage period except for the control which decreased in moisture throughout the 7-day storage period. Also, initial increase in moisture was observed for 5 % and 10 % UYF, which then decreased after day 0 throughout the storage period. Rollability decreased with increase in number of days. For color, the brightness of tortillas made from all the sample flours reduces with the increase in number of days. Tortilla made with FYF exhibit greater strength and toughness while those made from UYF had good extensibility and rollability. Substitution of RWF with UYF would be suitable for making tortilla.

Introduction

Tortillas can be generally produced by three basic methods: hot pressing, die cutting, and hand stretching. The hot-press method, which represents more than 90% of commercial tortilla production was employed in this study. Hot-press wheat flour tortillas, compared to die-cut or hand-stretched products are smoother in surface texture, more elastic, slightly chewy, and resistant to tearing and cracking (Anton, 2008). In the hot-press method, rested and relaxed dough pieces are transferred onto a heated conveyor plate where a hydraulic press device is typically used to form discs from dough balls. A thin skin is formed during pressing, which helps to seal the tortilla and limits the release of steam and carbon dioxide generated during baking. This contributes to the typical puffed characteristic of the tortilla (Waniska, 1999).

Wheat flour tortillas are unfermented flat breads, which have received increased acceptance by consumers in Mexico and the United States. In fact, the popularity of tortillas is more than bagels, croissants, English muffin, pitas and other type of ethnic bread (Friend et al., 1993). As of 2000, the sale of Tortilla totaled more than $4 billion US as stated in the report “State of the Tortilla Industry 2000” (Anton, 2008).

Similar with other wheat-based foods, wheat flour tortillas are rich in carbohydrate with high glycemic index. Consumers are worried about health implication of wheat tortillas and now demand increased nutritional value of tortillas (Anton et al., 2008). This initiated the ongoing research efforts toward improvement in nutritional values of wheat tortillas. Out of several methods that have been investigated, production of tortillas from composite flour has the potential as a pragmatic approach (Barros et al., 2010). This is achieved by substitution of wheat flour with other flour to make healthier tortillas.

Composite flours contain mixture of flours from different sources. Numerous composite flours have been formulated and investigated to develop food products with improved functionalities. Mixture of whole and refined red or white wheat flours were used to prepare tortillas of increased fiber content (Friend et al., 1992). In addition, increase in dietary fiber of tortillas was achieved by using composite flour containing soy and oat fiber (Seetharaman et al., 1994). Different bean flours combined with wheat flour resulted into increased antioxidant and protein nutritional value of tortillas (Anton et al., 2008). Substitution of wheat flour with oatmeal and inulin resulted in tortillas with 45 % less fat and 71 % more dietary fiber than refined flour tortilla while textural characteristics remained equal (Heredia-Olea et al., 2015)

Refined wheat based composite flours have been studied using flours from different sources for production of various baked products. This includes the use of cassava flour in bread making (Shittu et al., 2008), plantain flour in bread and biscuit production (Mepba et al., 2007), black rice flour in bread (Jung et al., 2002), soybeans flour in biscuit making (Oluwamukomi et al., 2011), oat and barley flour in sourdough and bread (Rieder et al., 2012), tiger nut flour in cake baking (Chinma et al., 2010), and sorghum flour in bread production (Abdelghafor et al., 2011). Some studies on use of wheat-yam composite flour for the production of bread, cake and cookies have been performed (Amandikwa et al., 2015; Falade et al., 2012; Ranaivosoaa et al., 2009). However, there has not been any studies on wheat-yam composite flours for production of tortillas. Substitution of wheat flour with other flours reportedly results in alteration of the physicochemical properties of wheat flour (Jung et al., 2002; Oluwamukomi et al., 2011). Prior study of physicochemical and end-product quality is required for formulation of composite flour that will meet market acceptability. Composite flour can exhibit novel properties that can be tailor-made to achieve intended product quality (Noorfarahzilah et al., 2014). The main objective of this research work was to investigate the physicochemical properties of composite flours (wheat-yam flour) and their end-product (tortillas) properties.

Materials and methods

Materials

All the chemicals and reagents were of analytical grade. White and brown yam flour used in this study were obtainable at Oja Oba local market Ibadan, Oyo state in Nigeria. The wheat flour used is hard spring wheat patent flour, a laboratory sample from the Cereal science laboratory obtained from North Dakota Mill (Grand Forks, ND). The flour had a protein content of 13.8% and an ash content of 0.48% (14% moisture basis). Each of the white and brown yam flour was substituted with wheat flour at 5%, 10%, 15%, and 20%.

Proximate analysis of flour composition

Determination of proximate analysis on the refined wheat flour and composites flour blend for flour quality was done. An air oven method according to the AACCI Approved method was used to determine the moisture content of the flours by drying the flour and weighing the residue (AACCI Approved Method 44-15.02). Protein content (14% moisture basis, mb) of each of the flours was determined in duplicate by the combustion method according to AACCI Approved method using a LECO FP428 nitrogen analyzer (LECO Corporation, St. Joseph Michigan) (AACCI Approved Method 46-30.01). Ash determination was done using the AACCI Approved method by accurately weighing 3 g of sample to a pre-weight porcelain crucible. This crucible was then placed into a muffle furnace set at an initial temperature of 350^{o} C for one hour and then raised to 590^{o} C overnight. After 24 hours of ashing, the crucible was placed in a desiccator to cool and the weight of the crucible recorded for the final weight of the dried sample to be determined (AACCI Approved Method 08-01.01). Wet gluten was determined according to the AACCI Approved method through washing flour by an automatic gluten washing apparatus (Glutomatic 2200 S system (Perten Instruments, Springfield, IL, U.S.A.) and centrifuged on an especially constructed sieve under standardized conditions. The weight of the rubbery viscoelastic mass is the wet gluten and difference in the weight of wet gluten forced through the sieve and the total weight of wet gluten (passed through and remaining on the sieve) was determined as Gluten index (AACCI Approved Method 38-12.02). The flour color was determined using a Minolta colorimeter to determine L*, a*, and b* values on the CIE Lab color scale.

Pasting profile of wheat and yam flours

Pasting properties of the flour samples were evaluated following the AACCI Approved method by using a Rapid Visco analyzer (RVA, Perten instruments, Springfield, IL) interfaced with a computer equipped with Thermocline software (Newport Scientific). Flour (3.5 g, 14% moisture basis) was added to 25 mL deionized distilled water in an RVA canister. The rate of heating and cooling in the Std1 profile was 12 °C per min, idle temperature was 50 °C, with the total run time of 13 min (AACCI Approved Method 76-21.01). Parameters recorded were peak viscosity (PV), hot paste viscosity (HPV), breakdown (BKD), cold paste (CPV) and setback (STB) viscosity. Measurements were reported in centipoise.

Farinograph determination of yam flour blends

Rheological dough properties i.e the water-absorption (amount of water required to reach 500 FU consistency) and dough strength of the flours were determined using a Farinograph (C.W. Brabender Instruments Inc., Hackensack, NJ) according to AACCI Approved Method 54–21.02. Farinograph measurements were determined in duplicate.

Tortilla preparation

The formulation and production of the flour tortillas was performed following the method of Whitney et al. (2011) with little modification The formulation of the tortillas included flour (100%), water (90% of the farinograph absorption), table salt (1.5%), vegetable shortening (6%), sodium bicarbonate (0.4%), sodium aluminium phosphate (0.3%), sodium propionate (0.4%), potassium sorbate (0.4%), sodium stearoyl lactylate (0.2%), DATEM (0.2%), and fumaric acid (0.3%). Wheat starch contains ~ 0.4% protein. Gluten forms a continuous network when blended with water in which hydrated starch granules get trapped. Salt gives taste and strength to tortillas. Shortening gives soft texture to tortillas. Sodium bicarbonate is necessary to get leavening effect in tortillas. Preservatives such as potassium sorbate are added in tortillas to counter mold growth and thus prolonging shelf life of product. Acidulant like fumaric acid is used as pH modifier which enhances preservative function of the product.

All ingredients were mixed to optimum consistency with a pin mixer (National Manufacturing Co., Lincoln, NE). The dough was rested and hand rounded, rested again and pressed on a CucinaPro Electric Tortilla Maker attached with a custom hydraulic handle to increase consistency in pressure during the tortilla press. The tortillas were baked in an impingement oven (Lincoln Foodservice Products, Inc., Ft. Wayne, IN) for 50 s on each side and cooled on wire racks prior to packing into plastic zip top bags.

Physical measurement of tortillas characteristics

Tortillas were evaluated for moisture content, weight, thickness, diameter, color and rollability. The moisture of the fresh tortillas was performed according to AACCI Approved Method 44-15.02. The weight of five tortillas was taken and divided by five to get the average weight. The thickness of five tortillas was measured with a calliper at three points and averaged and divided by five to get the average thickness of a single tortilla. The diameter was measured at the widest and most narrow points of three tortillas, and then averaged. Rollability was measured following the method of Kelekci et al. (2003). One tortilla was rolled around a 1.0-cm dowel and evaluated subjectively on a scale from 1 to 5 (1 = unrollable, 2 = breakage on two sides, 3 = breakage on one side, 4 = slight cracking, 5 = easily rollable). Tortillas extensibility was determined by measuring the force and distance to break a strip of the tortilla. The extensibility test was performed on a TA-TX2*i* Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) according to the procedure of Suhendro et al. (1999). Color of Tortilla was measured by light reflectance using a Minolta Color Difference Meter (Model CR410, Minolta Camera Co., Japan). The values were expressed using the CIE Lab color scale for L*, a*, and b* values. L* describe black to white (0-100); a* values describe redness (positive) and greenness (negative) and b* values describe yellowness (positive) and blueness (negative). Data for color are mean of three replicate readings along the tortilla.

Statistical analysis

Each treatment and measurement was carried out in duplicate. The experimental data was subjected to statistical evaluation using analysis of variance (ANOVA) for a completely randomized design (CRD) using Statistical Analysis System (SAS Institute, Cary, NC, USA). Least significant difference was used to determine the difference among means and the significance was defined at $P < 0.05$.

Results and discussion

Proximate composition of wheat flour and wheat/yam flour blends

The results of proximate composition and color of RWF, FYF and UYF shown in Table 23 and were significantly ($p<0.05$) different among the different composite flours. The composite flour compositions ranged from 13.2–13.8% for moisture, 10.2–12.3% for protein, 0.39–0.77% for ash, 25.9–35.2% for wet gluten, and 72–93 for gluten index. Increase in concentration of UYF and FYF in flour blends caused reduction in moisture and protein content. However, increase in concentration of UYF and FYF in the flour blends lead to increase in ash content, which would increase healthfulness of the tortillas by increasing mineral content. Increase in concentration of UYF in the flour blends lacks specific trend with regards to wet gluten but decreases in gluten index were observed. Which means that there was not enough UYF yam flour addition to significantly ($p<0.05$) effect the gluten content, but the presence of UYF had a significant ($p<0.05$) impact on gluten quality. Increase in concentration of FYF in the flour blends caused slight reduction in wet gluten, but no specific trends were observed in the gluten index. Inclusion of > 5% of UYF resulted in increase in wet gluten and the gluten index was higher at 5 and 10 % UYF, compared to the control. Statistical analysis of the gluten index of all the samples were not significant ($p<0.05$) different except that of 20% UYF blends. The wheat protein fractions have been reported to play an important role in wheat flour properties most especially the tortilla quality (Pascut et al., 2004).

Table 23. Proximate composition of wheat flour and wheat/yam flour blends

Sample	Moisture %	Protein %	Ash %	Wet gluten %	Gluten Index	Color L*	a*	b*
RWF	13.8a	12.3a	0.39g	32.7bc	89a	89.93a	-0.63e	9.34e
5% UYF	13.7b	11.8b	0.47e	32.3bc	93a	89.68d	-0.65f	9.42d
10% UYF	13.6c	11.5c	0.53d	34.2ab	92a	89.80c	-0.69g	9.46cd
15% UYF	13.3d	11.3c	0.60bc	33.5ab	86a	89.88b	-0.74h	9.63b
20% UYF	13.2d	10.9d	0.61b	35.2a	72b	89.72d	-0.76h	9.78a
5% FYF	13.8a	11.8b	0.42f	30.9cd	89a	88.66e	-0.12d	9.15g
10% FYF	13.7b	11.3c	0.49e	30.0ed	91a	87.34f	0.33c	9.47c
15% FYF	13.7b	10.8d	0.58c	28.1e	89a	86.68g	0.62b	9.30f
20% FYF	13.5c	10.2e	0.77a	25.9f	91a	85.85h	0.86a	9.46c

*Protein, ash and wet gluten are presented on a 14% moisture basis. Values in the same column with the same letter are not statistically significant ($P<0.05$), RWF = refined wheat flour, UYF= unfermented-white yam flour, FYF= fermented-brown yam flour

The color of the composite flours ranged from 85.85–89.93, -0.65–0.86 and 9.30–9.78, respectively, for brightness (L*), redness (a*) and yellowness (b*). All composite flours had significantly ($p<0.05$) L* values than the RWF, however only the composites with FYF differed visually from the RWF. The a* values of RWF, UYF and 5% FYF exhibited negative values which implies no redness in the flour sample. However, upon increase in concentration FYF in composite flours, a* values increased significantly ($p<0.05$), indicating increased redness with increasing in the concentration of FYF. The b* value followed an increasing trend as the concentration of UYF increase in composite flour. Increasing composite flour concentration results in decreased whiteness of flour blends.

Pasting profile of wheat/yam flour blends

Table 24 shows the pasting profiles of the flour samples, which provides information about the gelatinization properties of the flour during heat processing. Retaining tortilla texture over time is much more complicated. Tortillas stale through a complicated process of starch retrogradation. During baking, expansion from steam and gases begins at the top of the disk and small interior air cells are formed (Wiggins and Cauvain, 2007). Gluten network begins to trap air, as starch granules begin to gelatinize near surfaces, due to water dehydration. As the gluten network continues to trap steam, starch granules are partially gelatinized near the surface and gelatinization then begins in the center (Oates, 2000). Thereafter, the gluten network is then fully formed, amylose leached out of the granules resulting in full gelatinization of starch granules. After the tortillas are baked, the starch immediately begins to retrograde. The amylose and amylopectin complex together form a matrix that stiffens the tortilla.

Table 24. Pasting profile of wheat/yam flour blends

	PV cP	HPV Cp	Breakdown cP	FV cP	Setback cP	Peak Time Min	Pasting Temperature °C
RWF	1353bc	486c	868c	1168c	683b	5.57bc	69.8b
5% UYF	1290bcd	474c	817d	1131c	658b	5.60ab	70.2b
10% UYF	1277cd	500c	778de	1171c	672b	5.60ab	69.8b
15% UYF	1271cd	538bc	733e	1219c	681b	5.63ab	70.2b
20% UYF	1219d	578ab	641f	1250bc	672b	5.70a	70.2b
5% FYF	1394b	492c	902bc	1196c	704b	5.47c	84.0a
10% FYF	1515a	579ab	936ab	1379ab	800a	5.53bc	83.6a
15% FYF	1580a	642a	938ab	1493a	851a	5.53bc	83.2a
20% FYF	1596a	644a	952a	1498a	854a	5.53bc	83.2a

*Values in the same column with the same letter are not statistically significant ($P<0.05$); PV = peak viscosity, HPV = hot paste viscosity, FV = final viscosity, RWF = refined wheat flour, UYF= unfermented-white yam flour, FYF= fermented-brown yam flour

There are significant ($P<0.05$) differences in the pasting properties of the composite blends of gel samples. The peak viscosity (PV), hot past viscosity (HPV), breakdown, final viscosity (FV), setback, peak time and pasting temperature ranged between 1219–1596 cP, 474–644 cP, 641–952 cP, 1131–1498 cP, 658–854 cP, 5.47–5.70 min and 69.8–84.0ºC, respectively. Except peak time, all pasting properties of FYF composite blends of the gel are higher than that of UYF of the same concentration. The peak time increased as the concentration of UYF increased, but decreased as the concentration of FYF increased in the composite blends of the gel samples. All composite blends containing FYF exhibited higher PV and breakdown values than that of RWF. The high PV with short peak time duration in FYF signifies peak viscosity is reached more quickly, and more rapid swelling of starch granules. Likewise, the higher breakdown value is anticipated due to higher viscosity which causes the granule to collapse easily because of weak intermolecular forces among starch molecules due to increased sensitivity to shear forces (Zheng and Wang 1994). This suggests that FYF blends of the gel are more highly susceptible to shear and heat than the control and UYF composite gels of the blends samples.

All composite flours containing UYF exhibited lower PV and breakdown values than RWF as previously observed in the Table 11 results. This finding agreed with the previous report that stated that increase in fiber content caused decrease in PV (Goldstein et al., 2010). From this, it could be inferred that UYF may withstand heat and shear stress better than the control. The HPV and FV values of all composite flours, except those of 5% UYF, are higher than RWF, and increase in concentration of UYF and FYF in composite flours resulted into increase in their HPV and FV values. Setback from peak, which indicates firmness of samples ranged from 657.5–853.5 cP. Statistical analysis revealed no significant ($p<0.05$) difference in the control and the UYF. For the blends, setback increased as the concentration of FYF increased, but lacked specific trend for UYF. This suggests that FYF with higher setback may exhibit firmer gel suggesting fast retrogradation and high syneresis. So, UYF with lower value of setback was expected to be more resistant to retrogradation than FYF. This might also be a result of FYF having higher amylose amount than UYF. Since, amylose readily diffuses out of starch granules when during gelatinization and rapidly recrystallizes when it cools after gelatinization (Zhou et al., 2015). The pasting temperature of composite flours decreased as concentration of FYF increased, but lacked specific trends as concentration of UYF increased. The pasting temperature for FYF is significantly higher than the control and UYF. This implied that the minimum temperature required to initiate the gelatinization process for FYF exceed that of UYF. Thus, more energy cost and formula stability will be needed than that of its counterpart. Overall, tortillas made with FYF are expected to retrograde fastest and those made with UYF are projected to have same duration of storage shelf life as that of the control.

Dough quality measured by farinograph of wheat/yam flour blends

All the farinograph dough quality measurements, shown in Table 25, are significantly ($P<0.05$) different among the composite flour samples. Water absorption, peak time, stability, mixing tolerance index (MTI) and farinograph quality number (FQN) ranged from 60.50–77.10 14% MB, 1.85–6.75 min, 3.50–13.65 min, 17.0–135.5 BU and 28.5–117.5 cm, respectively. UYF blends have significantly ($p<0.05$) higher water absorption and MTI than FYF and control. Increase in concentration of UYF in composite flours caused increase in water absorption and MTI. The higher water absorptions value of UYF is attributed its higher level of starch damage and fiber contribution. This is in agreement with previous report that increase in cellulose fiber caused increase in water absorption of dough (Goldstein et al., 2010).

Table 25. Dough quality measured by farinograph of wheat/yam flour blends

	% Water Absorption (14% MB)	Peak time (min)	Stability (min)	MTI (BU)	FQN (cm)
RWF	62.4e	6.8a	13.7a	26.5c	118a
5% UYF	65.5d	3.9b	6.9d	58.0bc	70bc
10% UYF	69.8c	2.8bcd	4.4e	94.0ab	48cd
15% UYF	74.1b	3.2bc	3.5e	118.0a	46cd
20% UYF	77.1a	3.8b	3.9e	135.5a	49cd
5% FYF	61.5ef	6.6a	12.8a	33.0c	110a
10% FYF	61.0f	2.1cd	9.8b	17.0c	88ab
15% FYF	60.5f	1.9d	8.6bc	30.0c	54cd
20% FYF	60.6f	1.9d	7.3cd	47.0bc	29d

*Values in the same column with the same letter are not statistically significant ($P<0.05$); MB = moisture basis, MTI = mixing tolerance index, FQN = farinograph quality number, RWF = refined wheat flour, UYF= unfermented-white yam flour, FYF= fermented-brown yam flour

Although, increase in concentration of FYF in the composite flour caused decrease in water absorption, there was not significant ($P<0.05$) difference. The peak time for the blends of UYF and FYF are lower than the control. This implies that more time is needed for baker to reach dough of maximum consistency in the control than the samples blends. Increase in concentration of FYF in composite flour resulted into decrease in peak time, stability and FQN. The FYF composite flours are more stable than that of UYF composite flours, but not that of control.

The quality of dough will have significant effects on processing parameters and final quality of tortillas. Generally, high water absorption, as was obtained for 15% UYF and 20% UYF, is desirable for processors. Since dough with higher absorption will contain more water which is a relatively low-cost ingredient compared to flour. Processors would also require a certain level of mixing tolerance, indicated by the stability value. FYF had a lower effect on stability than addition of UYF. Therefore, processors would have to take more care during mixing of tortilla dough containing UYF. The lower peak time of dough with UYF and FYF may be beneficial to processors, since less time and energy would need to be expended to mix the dough.

Physical characteristics of tortillas made from wheat/yam flour blends

In any food product, both producers and consumers demand consistency. Therefore, physical characteristics need to be measured to ensure consistency and identification of negative effects due to formulation and processing change. The tortillas produced in this study are shown in Figure 18. The images of the tortillas show that the addition of UYF and FYF has effect on the size, texture and color of the tortillas. The composition of flour has impact on wheat flour tortillas. Inclusion of yam flour seemed to greatly affect the products, creating tortillas that were smaller, thicker, and heavier. Table 26 shows the physical characteristics (weight, diameter and thickness) of tortillas made from RWF, FYF and UYF. Statistical analysis shows there were significant ($P<0.05$) differences in all the samples. The weight of the tortillas ranged between 33.04–36.69 g, tortilla diameter ranged between 146.33–157.17 mm, and the thickness of tortillas ranged from 3.29–2.75 mm.

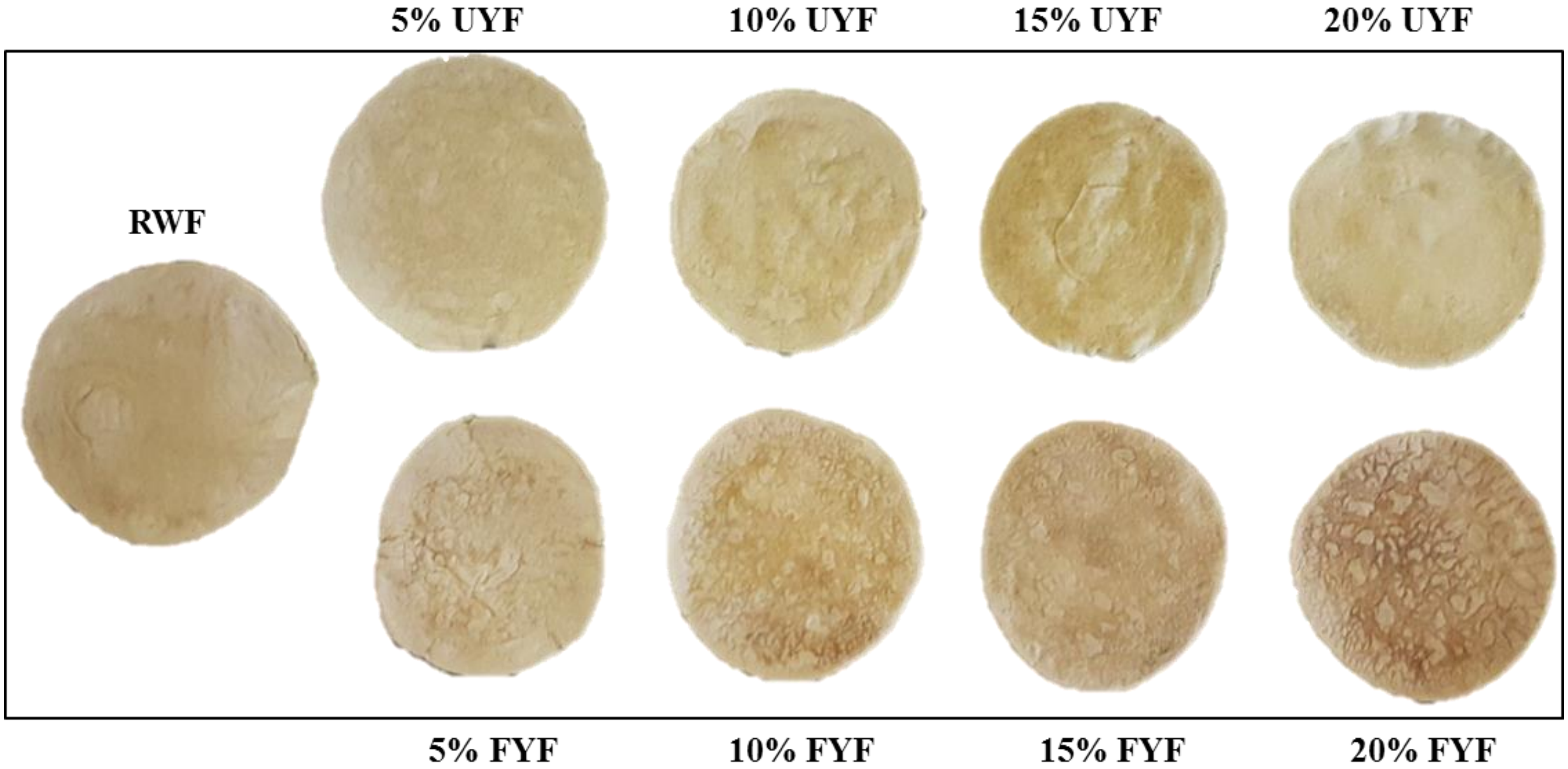

Figure 18. Tortillas made with refined wheat and composite yam flours blends.

All tortillas made from composite flours are of higher thickness than that of RWF, except that of 20% UYF. Increase in concentration of UYF in composite flours resulted in decrease in the diameter and thickness of tortillas. Increase in concentration of FYF in composite flours increased thickness, but lacked a specific trend for weight and diameter of tortillas and the inclusion of 5% and 10% of UYF lacked significant effect on tortillas diameter and weight, respectively.

Table 26. Physical characteristics of tortillas made from wheat/yam flour blends

	Weight G	Diameter Mm	Thickness Mm
RWF	33.0e	157.2a	2.8d
5% UYF	34.7bcd	154.5ab	3.0bc
10% UYF	34.5cde	150.2bcd	3.0bc
15% UYF	33.8de	147.7cd	2.9c
20% UYF	34.3cde	149.2bcd	2.6e
5% FYF	33.8de	152.7abc	2.9cd
10% FYF	36.7a	146.3d	3.2ab
15% FYF	36.1ab	144.3d	3.3a
20% FYF	35.8abc	148.3cd	3.3a

*Values in the same column with the same letter are not statistically significant ($P<0.05$); RWF = refined wheat flour, UYF= unfermented-white yam flour, FYF= fermented-brown yam flour

In a comparative study of whole and refined wheat flour, tortillas made from whole-wheat flour were reported to be larger, less opaque and thinner compared to refined flour tortillas (Barros et al., 2010). It was explained that the possibility of difference in whole and refined wheat tortillas was due to high fiber content of whole-wheat tortillas that was responsible for weakening of gluten network. This observation disagreed with the findings in this report; whereby composite flour with high fiber content (Table 4) resulted in tortillas with reduced diameter and thicker compared to RWF tortillas. Another opinion suggests that the presence of crosslinking resistance starch might be responsible for increase in diameter of tortillas (Jondiko et al., 2012). This might have explained the observed higher diameter of UYF tortillas compared to FYF tortillas. The presence of higher crosslinking polymers in UYF flour has been previously reported on page 69-70 in the first stage of this work. In the U.S, many consumers prefer fluffy, thick, and opaque tortillas (Waniska, 1999). Tortilla samples from UYF are better fit than their FYF counterpart. However, compared to control, the diameter is lesser so, might not be able to hold as much filling as the RWF tortillas, or processors may have to scale out larger dough pieces to make tortillas of the same diameter.

Effect of storage on color of tortillas

The storability of tortillas is very important to industries as well as the consumer. From industrial perspective, tortillas must be able to keep its freshness from the production point until it reaches the consumer to be more acceptable. Also, it is economical that consumer can keep products for some time to reduce the frequency of going to stores as well as reduce waste. Addition of new ingredient to tortillas flour has impact on the shelf life of tortillas and required adequate investigation. It is desirable that inclusion of non-wheat flour into RWF should not cause significant effect on tortillas quality attributes including color changes during storage.

Table 27 shows the color of tortillas made from sample flours during storage for seven days. The colors of tortillas were significantly different among the sample flours. Generally, the brightness (L*) of tortillas made from all the sample flours decreased with storage time. Comparing day 0 and 7, significant ($P<0.05$) difference were only noticeable in yellowness of the tortillas made from all FYF, 5% and 15% UYF composite flours. In terms of redness, FYF flour resulted in higher value than that of UYF, even throughout the storage period. Higher concentration of FYF in composite enhanced redness of tortillas and the redness attribute was maintained after 7 days of storage.

Table 27. Color of tortillas made from wheat/yam flour blends during seven days of storage

		RWF	5% UYF	10% UYF	15% UYF	20% UYF	5% FYF	10% FYF	15% FYF	20% FYF
Day 0	L*	79.78a	77.73ab	76.95ab	76.50b	76.38b	75.99b	69.16c	67.67c	63.36d
	a*	0.26e	0.42e	0.09ef	-0.36fg	-0.56g	1.98d	3.33c	3.93b	4.91a
	b*	18.09bc	20.34ab	21.97a	22.37a	22.77a	18.44b	18.61bc	17.51bc	17.45c
Day 1	L*	78.34a	77.60a	77.44a	77.94a	76.95a	73.46b	69.93c	66.70d	63.36e
	a*	0.15e	0.21e	-0.01ef	-0.29ef	-0.55f	2.30d	3.35c	4.13b	5.05a
	b*	21.13ab	21.01ab	22.21a	21.59ab	22.31a	20.20ab	19.43bc	17.35c	17.44c
Day 2	L*	77.32bc	78.89a	77.60b	78.49ab	76.39c	73.46d	68.60e	67.14f	63.21g
	a*	0.41e	-0.18f	-0.23f	-0.52f	-0.52f	2.34d	3.48c	4.02b	5.06a
	b*	21.55b	20.76bc	22.52ab	20.74bc	23.54a	19.67cd	18.43de	17.28e	17.50e
Day 5	L*	78.33a	78.38a	76.82bc	77.40ab	75.95c	73.84d	68.63e	67.20f	64.26g
	a*	0.01d	-0.06d	-0.20d	-0.57e	-0.23de	2.07c	3.84b	4.14b	4.71a
	b*	21.00c	20.91c	22.85ab	21.40bc	23.31a	20.08c	20.33c	17.67d	17.09d
Day 7	L*	77.84ab	78.34a	76.60ab	77.29ab	75.96b	72.89c	68.51d	68.23d	63.88e
	a*	0.12d	0.04de	0.08d	-0.15de	-0.49e	2.38c	3.72b	4.17b	4.95a
	b*	20.83bc	20.70c	22.65ab	21.52bc	23.44a	19.85cd	18.09de	17.81e	16.92e

Values in the same row with the same letter are not statistically significant ($P<0.05$); RWF = refined wheat flour, UYF= unfermented-white yam flour, FYF= fermented-brown yam flour, L= brightness; a*= redness; b*= yellowness

The images of the tortillas (Figure 18) clearly show increasing levels of redness in tortillas with higher levels of FYF. The redness of the tortillas with FYF may be attributed to the polyphenol oxidase (PPO) content of the flours. UYF did not have any PPO activity, while a small amount of PPO was detected in FYF. Since a good tortilla also has a uniform satiny white appearance with few browned spots. The FYF tortilla samples might be unappealing to consumer due to the dark shade of red color in the samples. However, consumers who regularly consume whole wheat tortillas may not be bothered by the difference in color between RWF tortillas and tortilla containing FYF.

Effect of storage on moisture content of tortillas

The moisture content in food products is among important parameters that determine shelf life stability, textural characteristics and mouth feel. Moisture content of the tortillas produced from the sample flours over a period of 7 days is presented in Figure 19. Statistically, there were significant ($P<0.05$) differences between the moisture of content of the tortillas samples. The trend in variability of the moisture content of the tortillas made from RWF decreases gradually during the storage period. Inclusion of yam flours altered the sorption behavior of the tortillas made from composite flours compared to that of RWF. Inclusion of 5% and 10% of UYF cause initial high moisture content, which then reduced as storage period increased. This observation can be related to their initial high water absorption and thickness that might be responsible reduction in dehydration rate during baking process (Barros et al., 2010).

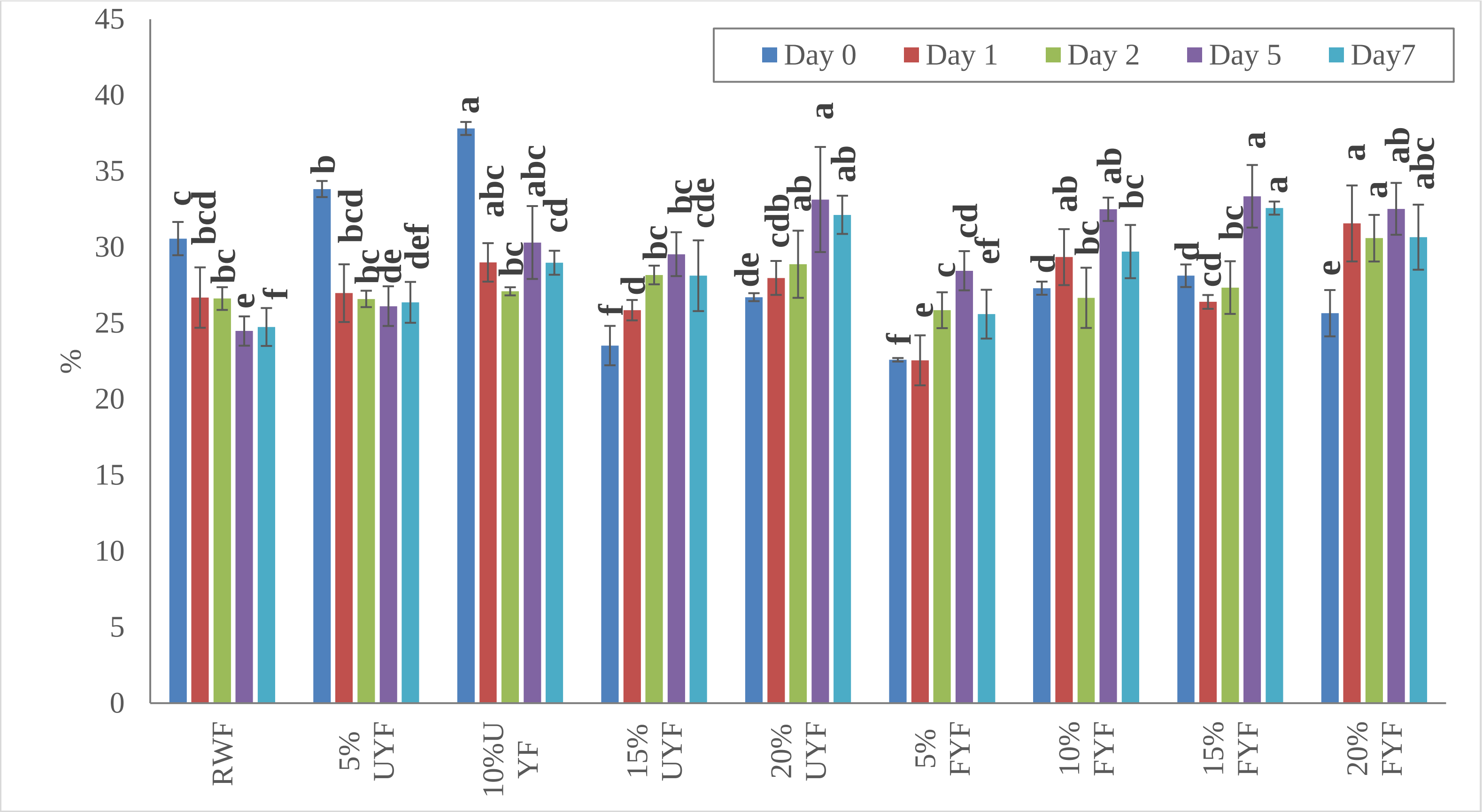

Figure 19. Moisture content of tortillas made from wheat/yam flour blends during seven days of storage

*Bars of the same color with the same letter are not statistically significant (P<0.05); RWF = refined wheat flour, UYF= unfermented-white yam flour, FYF= fermented-brown yam flour

Inclusion of different polysaccharide in flour resulted into reduction of dehydration kinetic during processing and storage of tortillas (Arámbula et al., 1999). The moisture sorption behavior of tortillas from other composite flours followed increasing trends throughout the storage period. This might be due to the high absorption rate of the composite flour. The increase in composite yam flour inclusion, which results in weight increase in (Table 26), might be responsible for retention of moisture.

Effect of storage on rollability of tortillas

The rollability is a measure of the ability of tortillas to fold without breaking. The result of rollability as shown in Table 28 are significantly ($P<0.05$) different after day 0. All samples exhibit good rollability and were not significantly ($P<0.05$) different at day 0. In all samples, the rollability of tortillas decreased as the number of days increased. Rollability was significantly affected by differences in formulation and storage time. In the work of Bejosano et al. (2005), higher percent of leavening reportedly caused thicker tortillas, which then hindered their rollability. This finding negates the result of our study. Composite yam flour inclusion gives a thicker tortilla, but the thickness does not interfere with the rollability. All the tortillas made with composite flour are thicker and exhibited better rollability than the control.

Freshly made tortillas (day 0) could be differentiated by their rollability from 1-day-old tortillas. This observation was similar with the previous study where it was stated that rollability of tortillas of whole and refined wheat flours reduced as the duration of storage increased (Barros et al., 2010). Likewise, in agreement with this report, rollability of tortillas were stated to have reduced during storage even with the addition of different hydrocolloids (Friend et al., 1993; Platt-Lucero et al., 2012).

Table 28. Rollability of tortillas made from wheat/yam flour blends during seven days of storage

	Rollability (Score of 1-5)				
	Day 0	Day 1	Day 2	Day 5	Day 7
RWF	5.0a	4.7abc	3.3b	2.3d	1.3f
5% UYF	5.0a	5.0a	4.2a	2.2de	1.7ef
10% UYF	5.0a	4.7abc	4.3a	3.3b	2.7b
15% UYF	5.0a	4.8ab	4.5a	3.8a	2.8ab
20% UYF	5.0a	5.0a	4.7a	4.2a	3.2a
5% FYF	5.0a	4.7abc	4.2a	2.8c	2.0de
10% FYF	5.0a	4.5bcd	3.0b	2.8c	2.5cb
15% FYF	5.0a	4.3cd	3.3b	2.2de	2.2cd
20% FYF	5.0a	4.2d	3.2b	1.8e	2.0de

*Values in the same column with the same letter are not statistically significant ($P<0.05$); RWF = refined wheat flour, UYF= unfermented-white yam flour, FYF= fermented-brown yam flour

The decrease in rollability has been attributed to starch reorganization after its preparation, where the adjacent linear chain of amylose or amylopectin form double helices via hydrogen bonding, and consequently aggregate to produce crystalline. The amylose was stated to change during storage and lead to the formation of order in the amylose structure (Whitney et al., 2011). This agrees with the work of Platt-Lucero et al. (2012) who studied the viscoelastic and textural characteristics of masa and tortilla from composite flour, and reported decrease in the rollability and pliability of tortillas with increase in time storage. The type of wheat flour, the protein content and quality are important attributes for making good quality tortillas (Waniska, 1999). High rollability score in UYF tortillas can be associated to their high protein content as observed in Table 23. The 20% UYF blends with the highest wet gluten and gluten index, which signifies protein quality, may enhance tortilla storage stability and decrease in the breakage amount during rolling and handling of the stored tortillas.

Effect of storage on resistance to extension of tortillas

The ability of tortilla to resists tearing is also one of its important characteristics and quality attributes. Figure 20 shows the changes in resistance to extension of tortillas made from the flour samples during seven days of storage. There were significant ($P<0.05$) differences in the resistance to extension of tortillas. The trend in changes to resistance to extension in tortillas made from RWF exhibited initial increase after day 1 and then decrease through day 7. However, tortillas from composite flours follow increase in resistance to extension.

The rate of change in resistance to extension by tortillas from UYF blends is lesser than rate of change in resistance to extension in that of FYF blends. The rate of change in resistance to extension in all tortillas made from UYF and FYF blends followed similar trends. During the day 0 to day 7 storage period, the change in resistance to extension in tortillas from FYF blends is pronounced in 5% FYF blend, followed by that of 20% FYF, then 15% FYF and then 10% FYF blends. The FYF blends exhibited a very tough tortilla strength hence, UYF is a better option between the composite-made-tortillas since, very tough tortilla would be unsuitable as a wrapper or carrier for different fillings (Ramírez-Wong et al., 2007). Compared to FYF tortillas, the RWF and UYF tortillas are more tender. Previous finding reported that substitution of RWF with cross-linked resistant starch resulted in tortillas that were more tender (Jondiko et al., 2012). Therefore, it is possible that UYF contain cross-linking polymers that evinced the low resistance to extension. Thus, substitution of RWF with UYF will not alter the tenderness of tortillas.

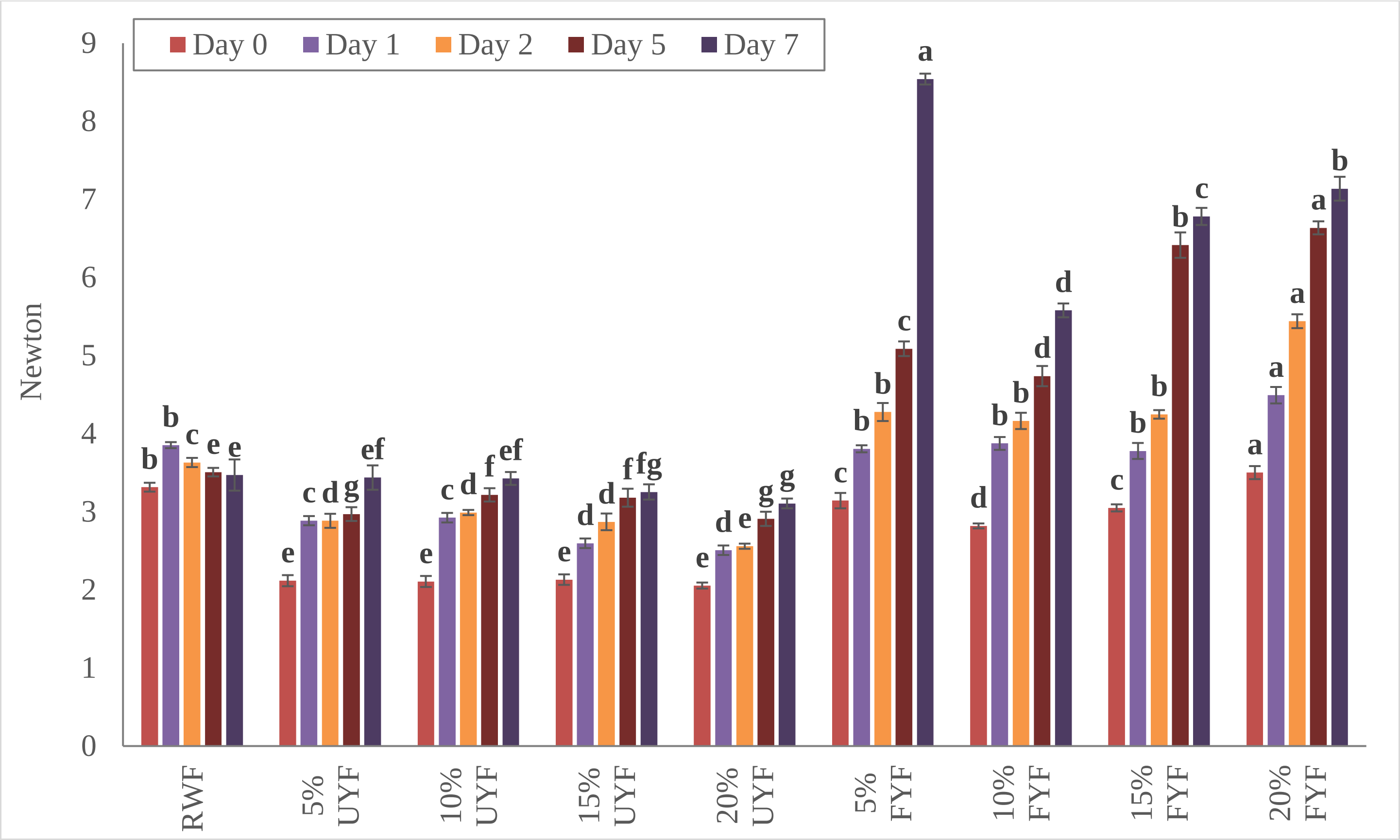

Figure 20. Resistance to extension (strength/toughness) of tortillas made from wheat/yam flour blends during seven days of storage

*Bars of the same color with the same letter are not statistically significant (P<0.05); RWF = refined wheat flour, UYF= unfermented-white yam flour, FYF= fermented-brown yam flour

Effect of storage on extensibility of tortillas

The extensibility/stretchability of the flour tortillas is expressed as the maximum force and rupture distance required to completely puncture the tortillas. The greater the distance at the point of rupture the more stretchable the product, and the greater the force at the point of rupture the stronger the product (Mao et al., 2002). Flexibility is one of the most significant textural characteristics of tortilla. A flexible tortilla will tolerate folding and rolling without cracking or breaking. Figure 21 shows the changes in extensibility of tortillas made from RWF, FYF and UYF blend samples during the 7 days storage period. There exist significant ($P<0.05$) differences in the changes of extensibility of tortillas made from flour samples. In day 1, substitution of RWF with 5 and 10 % of yam flours caused reduction in tortillas extensibility while increase in level of substitution in flour blends causes increase in tortillas extensibility.

This observation is in agreement with previous report that stated that increase in the substitution level with xanthan gum in RWF resulted in increase in tortillas extensibility (Román-Brito et al., 2007). Fresh tortillas are softer and more extensible than aged tortillas, an observation that is similar to previous work (Román-Brito et al., 2007). All tortillas samples exhibited decreased in their respective extensibility throughout the storage period. The extensibility of tortillas made from composite flours containing higher concentrations of yam flours are comparable with that of the control. The decrease in crust softness, and crumb puffiness during storage might be attributed to the decline in flexibility (Bello et al., 1991). The characteristics of flour have been reported to affect the extensibility of tortillas. Tortillas from flour of different genotype of spring wheat exhibited varying extensibility (Whitney et al., 2011).

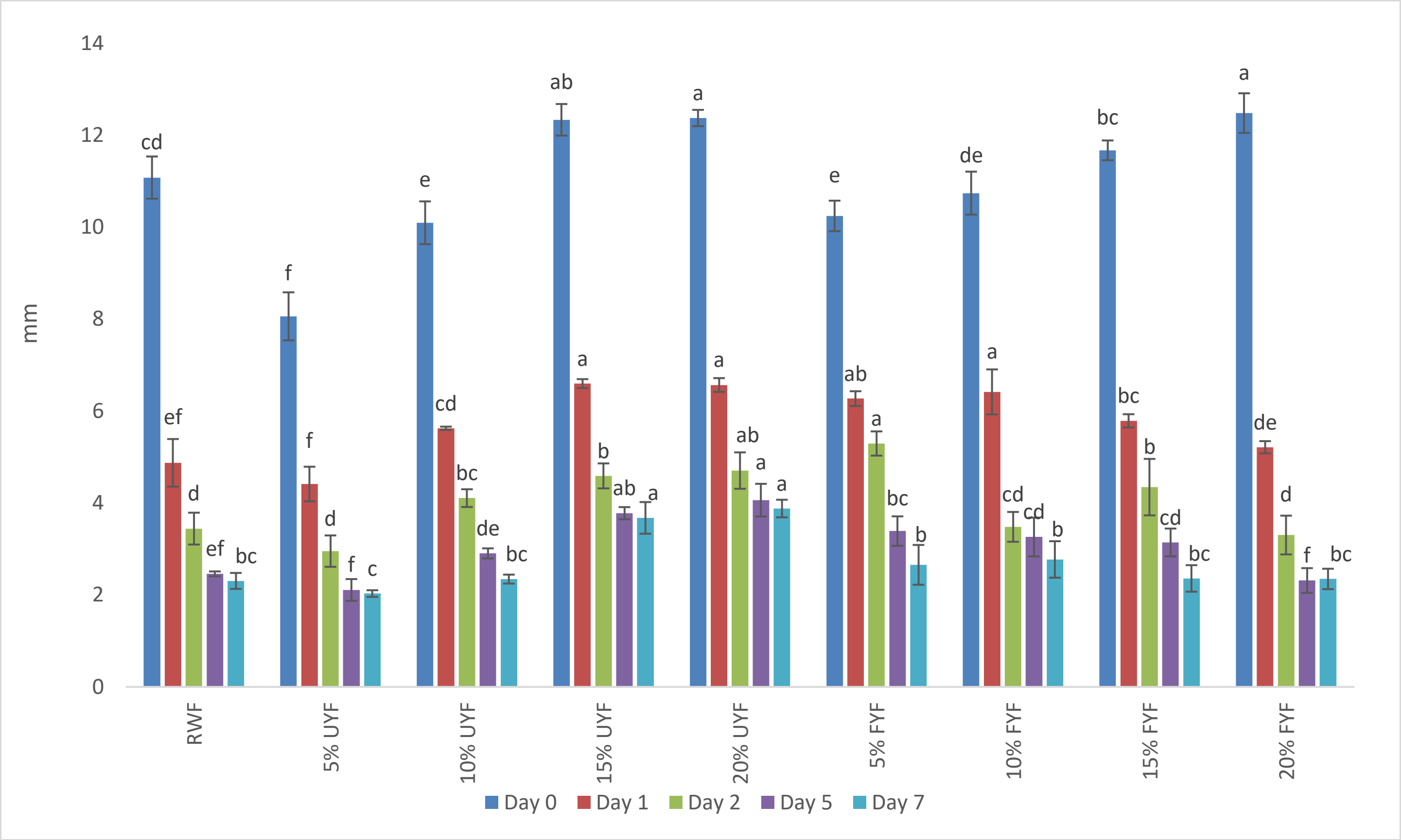

Figure 21. Extensibility of tortillas made from wheat/yam flour blends during seven days of storage

*Bars of the same color with the same letter are not statistically significant ($P<0.05$); RWF = refined wheat flour, UYF= unfermented-white yam flour, FYF= fermented-brown yam flour

Conclusions

Composite flour substitution significantly affects the dough properties and physical characteristics of tortilla. The protein, ash, wet gluten, gluten index and moisture content depend on the level of substation and type of yam flour. Increasing composite flour concentration of flour blends results in decrease in the whiteness. The UYF blends with low setback value are expected to be more resistant to retrogradation while fastest retrogradation process is expected more in FYF samples. The higher pasting temperature implies more energy needed for composite flour than wheat flour during gelatinization process. Composite flour addition reduce stability, FQN and increased MTI shows low quality and weakened dough except 5% FYF which exhibit no significant difference in the farinograph characteristics with that of control. Inclusion of UYF resulted in increase in protein and wet gluten and present of crosslinking polymers in UYF might be responsible for the attributed tortilla qualities and shelf stability. Inclusion of UYF with a good flexible texture would be more suitable for making.

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OVERALL CONCLUSIONS

Several interesting conclusions can be made from these studies. The wheat and yam flour exhibited different characteristics in their chemical composition, thermal, and rheological properties. The source of the composite flour (tuber) greatly affects its protein content. However, it is rich in minerals, fiber, natural bioactive compounds. The preparation process of the composite flour affected the proximate composition, amino acid, mineral content, phenolic content and starch hydrolysis properties. Yam flour has less sticky gel compared to wheat flour, but resistant starch and eGI was higher. The structure and functional properties of yam flours are affected by the distribution of protein and phenolic compounds. The activities of PPO in yam flour did not only affect their colors but also their composition, starch characteristics and functional properties. The morphology of flour particles is affected by the presence of proteins and phenolic compounds that exert interconnection between the flour biomolecules. The thermal property is greatly impacted by the compactness of the flour particle. Unfermented-white yam flour (UYF), which is more compacted and denser has reduced response swelling and gelatinization.

The properties of the composite flour varied depending on the type of yam flour and the substitution level in the formulation. The composite flour inclusion in the blends altered the dough farinograph parameter, dough strength, and greatly impacted the end-product baking qualities; which were loaf volume, crumb score, symmetry, color and crumb firmness. While composite flour of blends had lower protein and wet gluten content than refined wheat flour, they had more fiber, starch and extractable phenolic compounds. The dough properties and bread quality were impacted by the levels and types of yam flours inclusion. Inclusion of UYF contributed to stickiness, while fermented (brown) yam flour (FYF) contributed to firmness which implies quicker retrogradation. However, inclusion of 5% FYF did not cause significant retrogadation effect. The gassing power of composite flours containing FYF was relatively unchanged. Dough stability was enhanced by substitution of RWF with FYF. 5% of FYF substitution did not cause much effect on dough handling and mixing time. Loaf volume, breads crumb, loaf symmetry and color with up to 10% substitution level with FYF was of satisfactory features for bread making.

Composite flour substitution significantly affected the dough properties and physical characteristics of tortillas. The protein, ash, wet gluten, gluten index and moisture content depend on the level of substitution and yam flour type. Increasing FYF concentration of flour blends resulted in decreased whiteness. The higher pasting temperature implies more energy needed for composite flour than wheat flour during gelatinization process. The UYF blends with low setback value were expected to be more resistant to retrogradation. Inclusion of UYF yam flour resulted in increase in protein and wet gluten and present of crosslinking polymers in UYF might be responsible for the attributed tortilla qualities and shelf stability. Incorporation of 20% UYF has a good flexible texture, rollability, and acceptable color would be more suitable for making tortilla.

FUTURE RESEARCH DIRECTIONS

The results of these studies present some interesting opportunities for additional research and areas where further investigation may be required. These are listed below:

1. Further study of the fine structure and additional characterization of unfermented and fermented yam starch.
2. Determination of specific phenolic compounds and other phytochemicals present in the unfermented and fermented yam flours.
3. More detailed study of how the fermentation process effects the protein, starch and other components of the yam flours
4. Use of composite flours in other products such as, cookies, crackers or cakes which may allow for the use of the yam flours at a higher percentage.