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African Journal of Food Science

Full Length Research Paper

Profiling of processors for baked and fried wheat based products in Nairobi Kenya

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This study aimed at profiling bakers and fryers of wheat products in Nairobi to inform decisions leading towards incorporation of Orange Fleshed Sweet Potato (OFSP) puree in these products. An exhaustive sampling was carried out and 748 processors were interviewed in Nairobi County. The results indicate that even though there were more female processors than men, this difference was not significant ($p>0.05$). Majority of processors and consumers were youths and there was low adoption of OFSP as an ingredient (4%). However, about 78% of the processors were willing to adopt OFSP puree as an ingredient. Moreover, the youths dominated the micro-enterprises presumably because they have a lot of energy as well as huge potential for innovation. Major customers were street passerby as majority operated roadside kiosks or hotels while location had significant ($p<0.05$) influence on willingness to adopt OFSP, production trends, main customers as well as markets for the products. The survey recommends capacity building among the Micro-Small-Medium-Enterprises (MSMEs) in order to be able to adopt nutritious ingredients such as Orange Fleshed Sweet Potato (OFSP) puree as a way of improving food and nutrition security for the masses that rely on fried and baked products.

Key words: Bakers, fryers, orange fleshed sweet potato, micro-small-medium-enterprises, wheat products.

INTRODUCTION

Fried and baked products play a key role in food and nutrition security of many populations given that a number of people rely on these products in their daily meals beginning from breakfast to lunch and supper (Williams, 2014). The enticing flavour and convenience make fried and baked products preferred by many consumers and hence their popularity (Nwosu et al., 2014). Among the most popular baked and fried products include bread, doughnuts (KDF), chapattis, cakes, bans and rolls all of which differ in their frequency and occasions they are required. Bread baking, for instance, is an old process that dates back to over 12,000 years ago being a deliberate experimentation with water and grain flour (Arranz-Otaegui et al., 2018). Bread is a widely consumed breakfast cereal globally with diverse recipes (Williams, 2014) with production being spread all over the

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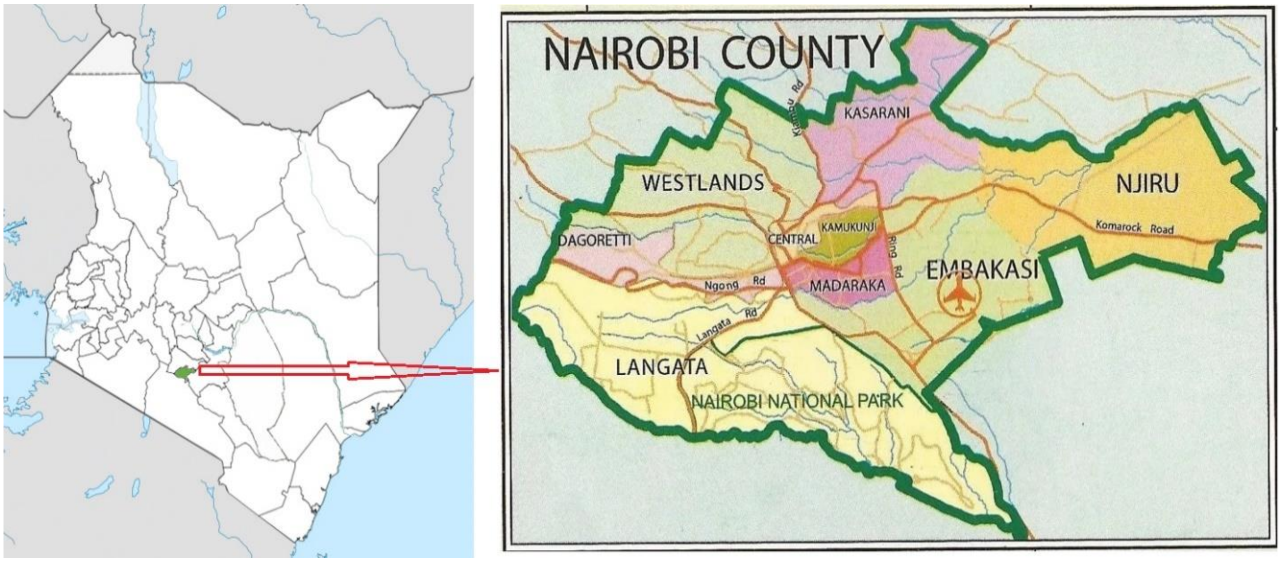

Figure 1. Study area, Nairobi County.
Source: https://softkenya.com.

world with different countries having different kinds of domesticated bread production methods (Adiguzel et al., 2019). Though initially crude, bread production has evolved over the ages in terms of ingredients used with the latest developments in bread production leading to the advancements in the bread industry that have enabled the use of various composite flours including purees to produce bread for improvement in the sensory acceptability and physico-chemical quality (Adeyeye and Akingbala, 2015; Julianti et al., 2015; Muzhingi et al., 2018).

There are different types of bread but the two main categories are leaven and unleaven breads. Leavened breads make use of yeast as the main fermenting agent and hence have large volumes (Nwosu et al., 2014). On the other hand, unleaven breads are usually flat given that no yeasts or fermentation agents are used. Processing of baked and fried products are carried out by diverse groups of processors ranging from small scale kitchen and street processors to medium and large scale processors of bread and cakes. There is no doubt that regulation of this sector is quite challenging, from quality and public health perspective. Products arising from the diversity of processors also vary in their quality and safety depending on the location and market base (Ijah et al., 2014; Nwosu et al., 2014).

Most of the industrial production of fried and baked products such as bread, doughnuts, cakes among others in sub-Saharan Africa (SSA), Kenya included, relies on wheat as the raw material. To change this scenario, alternative locally available, highly nutritius and more affordable raw materials such as orange fleshed sweetpotato (OFSP) puree need to be adopted. There is therefore need to understand the current processing industry.

There is a huge diversity processed and baked wheat products in Nairobi that leads to huge variations in terms of quality and safety of processed products that are offered to consumers whose information is limited. Understanding this sector and characteristics of the products currently offered in the larger Kenyan market, Nairobi city, will provide a path on which OFSP puree products can get into the existing market. Consequently, this will also inform marketing strategies that will assure uptake and incorporation of OFSP based products as a way of scaling up. The objective of this study was to profile processors of baked and fried wheat products in Nairobi County in Kenya, with emphasis on assessing the formal and informal bakeries or fryers based on their location, size and nature of operation, range of products and their market base.

MATERIALS AND METHODS

Study area

This study was carried out in Nairobi County, Kenya. The county hosts the capital city of Kenya and has nine sub-counties: Makadara, Embakasi, Starehe, Langata, Kasarani, Westlands, Kamukunji, Dagorreti and Njiru (Figure 1). The county's population is estimated to be over 4.4 million according to the latest census (Kenya National Bureau of Statistics, 2019). Most of the population are low-income earners hence dwell in slums. The county has many markets offering food stuffs with most of these food markets being open air markets. For the purpose of this study, all sub-counties were sampled.

Study design

The study design was a cross-sectional study design employing qualitative data collection methods through interviews and observation.

Study population and sampling technique

The study consisted of street processors of fried and baked products as well as industries that are involved in processing baked and fried products commercially traded in Nairobi Kenya. A total of 748 respondents were exhaustively sampled from the survey. Since the study was carried out during COVID-19 pandemic period, the number that was surveyed may not include those who may have temporarily stopped processing.

The survey instruments

A semi-structured questionnaire was used for this study. The tool was written in English and captured information on ownership, size and years of operation, main ingredients, range of products and market base as well as any other relevant information. The tool was pre-coded in Computer Aided Personal Interview (CAPI) which facilitated the use of Open Data Kit (ODK) in data collection.

Data collection

The data collection was carried out in the year 2020 between the month of May and August. The questionnaire was administered to all processors, both small, medium and large-scale bakeries and informal street processors. For formal registered companies, visits to supermarkets/kiosks were made to map out all baked and fried products being sold, key ingredients and contacts of the same were picked to trace processors for interview. Kenya Association of Manufacturers (KAM) data base was consulted to ensure all formal bakeries are reached. Since informal processors are not easy to trace from their products most of which have no labels, all streets in sub-counties were scanned by research assistants. Data was collected using the ODK tool.

Study ethics

Before answering any question, consent was sought from the respondents. The respondents were taken through the purpose of the study, asked to voluntarily participate in the study and assured of confidentiality of their responses. They were then asked to give consent before proceeding with the study. A considerable distance was kept between the enumerators and the respondents as well as having mask on during the interview process; this was in compliance with the ministry of health protocols as the study was carried during Covid-19 pandemic.

Data analysis

Data obtained was coded and entered into SPSS for Windows software (IBM version 21) and analyzed. Descriptive statistics were used to summarize the data while associations were tested using appropriate inference statistics. Chi-square test of significance was used to test for any existing significant associations between the various variables under study with a *p-value* less than 0.05 being set as the level of significance.

RESULTS

Socio-demographic characteristics

Table 1 shows the socio-demographic characteristics of the respondents.

Most of the respondents involved in baking or frying business were of female gender (56%) compared to males (44%); this difference was, however, insignificant ($p>0.005$) and hence the industry could as well be considered as an adventure for both genders. At least 80% had completed secondary school or colleges and university hence considered literate. It was therefore easy to converse with them during the interviews. Fifty-four percent of the respondents were the owners of the business while 46% were employees that could mean that a lot of youths either own or employed in this sector given, they were the majority respondents. The businesses could also be easy to start and may require smaller capital compared to other businesses. Promotion of these businesses should therefore target the youth.

Nature of business

Table 2 summarizes the nature of bakery/fryer businesses in Nairobi Kenya. Most (70%) of the respondents have been operating for the last 1 or more years hence were in a position to answer to questions regarding their operations. More than 50% have only been in the business for two years which could translate to the sector having progressive growth in terms of those getting into the sector and/or value chain.

Majority (94%) of the businesses were micro enterprises having between 1 and 10 employees and they processed either once or twice daily (80%), while others processed more than twice a day (7.5%). There were differing opinions on business trends. Those who indicated that the trend was increasingly attributed it to mushrooming new outlets, high customer demand, product diversification and good products quality.

On the other hand, others noted that there has been decreasing business trend attributed to COVID-19 pandemic partial lock down given that most clients closed down especially those who relied on schools that were shut for long periods, changing consumer preferences, shifting demand for homemade foods and alternatives such as sweet potatoes and the safety concerns from consumers.

Nature of products

Chapatis are the main products (74.5%) processed by the respondents followed by doughnuts (mandazis/KDF) (Table 3). The key ingredients for the baked and fried

Table 1. Socio-demographic characteristics of bakers/fryers in Nairobi Kenya.

Description	Number of respondents (N)	Respondents (%)
Gender		
Male	344	46
Female	404	54
Education Level		
College/University	231	30.9
Completed secondary	439	58.7
Completed primary	45	6
Dropped out from primary	3	0.4
Dropped out from secondary	12	1.6
In primary	2	0.3
In secondary	14	1.9
Never been to school	2	0.3
Age		
Teens (12-17)	11	1.5
Youth (18-35)	613	82
Middle age (36-60)	105	14
Not answered	19	2.5

Table 2. Nature of bakery/fryer businesses in Nairobi Kenya.

Description	Number of respondents	Respondents (%)
Years in business		
<1 year	226	30.2
1-2 years	200	26.7
> 2 years	322	43.1
Size		
Micro enterprise (<10 employees)	703	94
Small enterprise (11-50 employees)	38	5.1
Medium enterprise (51-250 employees)	6	0.8
Large enterprise (>250 employees)	1	0.1
Frequency of operation		
Once a day	285	38.1
Twice daily	401	53.6
Once a week	1	0.1
Twice a week	5	0.7
Others	56	7.5
Business trends		
Increasing	233	29.8
Decreasing	306	40.9
Indifferent	219	29.3

products include wheat flour, fats/oil, sugar/sweetener, baking powder and salt. Other ingredients used by a few processors (12%) included carrots, lemon, pumpkin, milk, coriander, sweet potato, ginger, eggs and margarine.

Table 3. Nature of products and main ingredients used by processors in Nairobi.

Description	Number of respondents	Percentage
Main products		
Bread	42	5.6
Donuts	128	17.1
Cakes	137	18.3
Chapati	565	74.5
Others*	473	63.2
Main ingredients		
Wheat flour	743	99.3
Fats/oil	742	99.2
Salt	737	98.5
Sugar/sweetener	576	77
Baking powder/yeast	476	63.6
Others	86	11.5
Type of flour		
All-purpose wheat flour	665	88.9
Baking flour	269	36
Soft wheat flour	22	2.9
Others (self-raising wheat)	16	2.1
Unit of packaging		
Less than 20 kg	646	86.4
30 kg	64	8.6
50 kg	20	2.7
70 kg	3	0.4
Others (more than 70 kg)	15	2

*Others= Mandazi, Bhajia, KDF, biscuits confectionary, ngumu, mahamri, pastries, pizza, kebab, cookies.

Table 4. Names of premises incorporating of orange fleshed sweet potato in their production process.

Constituency of operation	Number	Name/contact
Dagorreti North	1	Kibanda
Dagorreti South	2	Wema Hotel
Langata	2	Tuskys Karen, The Mayura – Hub Karen
Kibra	1	Kwa Davie
Roysambu	4	Café 316 Fast Foods; Kini's Kitchen; Vale's Cakes; Victoria Eats
Kasarani	2	Farm fresh milk and Bakery; Mashan Café
Ruaraka	7	Cake Shop, Hotels and 5 Vibandas
Kamukunji	2	Mawan Hotel; Shawarma Hotel
Starehe	1	Tuskys Pioneer – Moi Avenue;
Total	21	

*These come from the 17 constituencies in Nairobi that were surveyed.

Majority of the processors use all-purpose wheat flour while a few uses self-raising wheat flour (2.1%). Majority package their products in quantities less than 20 kg, justifiably because most of them are micro-enterprises and they depend on customers most of whom require convenient sizes.

Orange Fleshed Sweet Potato (OFSP) has only been used by 4% of the respondents (Table 4). However,

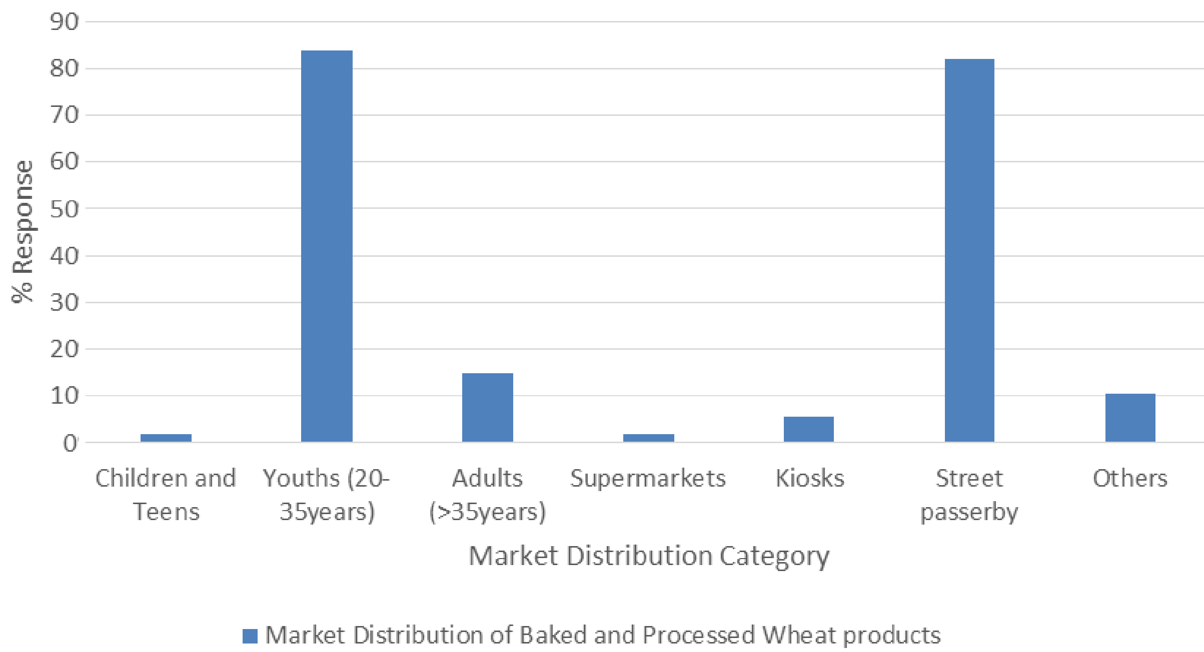

Figure 2. Market distribution of baked and processed wheat products based on age and outlets.

majority (78%) were willing to incorporate if it would improve health and volume of products. Sixty percent of processors were willing to participate in technology demonstration for incorporating OFSP into their products.

Marketing and customer base

Majority had youths as their main customers (84%) as shown in Figure 2. However, some of the respondents indicated that it was difficult to categorize who the main customers were. Street passersby are the main markets for most of the respondents justifiably because many processors are micro and street based as subsequently shown.

Food safety and training

Almost half of the respondents have not undergone any form of training on food safety and hygiene (55%). However, to ensure that hygiene and safety is kept at the operation area, the respondents have different copying mechanisms that include: cleaning their work place on a daily basis, try to comply with safety and health guidelines, using proper packaging materials, using proper packaging materials and sanitizing as part of the Ministry of Health (MoH) guidelines, equipping employees with safety gears. Some premises needed an overhaul of the set up to be a food processing business.

Associations between socio-demographics and other parameters

Table 5 shows the associations between socio-demographic characteristics and other practices.

DISCUSSION

The age of the respondents was significantly associated ($p<0.05$) with adoption of Orange Fleshed Sweet Potato (OFSP) in the production, size of operation, frequency of production and main customers. Similar studies have reported that the elderly are less likely to venture into new technologies and/or innovations, as their energy is limited (Berkowsky et al., 2017). On the other hand, gender only influenced frequency of production, with majority being youth and risk takers especially the female gender (Canevari-Luzardo, 2019). The dominance of any business is determined by a number of factors, food business especially in the African context would be determined by the social culture where most of the cooking is usually left to the female gender (Gurung et al., 2016). This could explain the slightly higher numbers of females in this industry.

Education level was significantly associated ($p<0.05$) with products produced, role played in business, main customers, main market, and size of operation. The level of literacy was quite high and agrees with the report by the Kenya National Bureau of Statistics that puts literacy

Table 5. Associations (p values) between socio-demographic characteristics and other practices.

Parameter	Gender (df=1)	Age	Education level (df=8)	Location (df=14)	Products	Production trends
Adoption of OFSP	0.986	0	0.405	0.001	-	-
Willingness to adopt OFSP	0.955	0.289	0.005	0	-	-
Size of operation	0.201	0.001	0.001	0.125	0	0.209
Production trends	0.024	0.12	0.015	0	0.023	
Scale/Frequency of production	0.001	0	0.025	0	0	0.296
Unit of package	0.083	0.916	0.046	0.008	0	-
Type of floor used	0.035	1	0.982	0	0	-
Main market	0.134	0.359	0	0	0	-
Main customers	0.102	0	0	0	0.013	0
Role in business	0.013	0	0	0.003	-	0.181
Products	0.346	0	0	0	-	-
Ingredients used in production	0.329	0.063	1	0	1	-

Association significant when the p-value is equal to or less than 0.005.

level at more than or equal to 82% (Kenya National Bureau of Statistics, 2019). The level of literacy could also be linked to the age of the respondents.

Majority of the respondents who engage in processing baked and fried wheat products being youths aged between 18 and 35 years old at 82% followed by the middle aged at 14%. With more than half of the country's population being youths, majority of them are engaging in agri-food entrepreneurship and value addition (LEO, 2016). Moreover, studies have indicated that with more knowledge acquired, individuals are able to make informed decisions on which business to venture into, technology to use and best markets hence improved productivity and returns (Mustapha et al., 2020; Raja and Nagasubramani, 2018).

More than 50% have only been in the business for two years which could translate to the sector having progressive growth in terms of those getting into the sector and/or value chain and that it is the quickest way many can earn a living (Canevari-Luzardo, 2019). It is not clear what was the contribution of COVID-19 that led a number of restrictions (UNDP, 2020), despite many attributing low business to the global pandemic (UNDP, 2020).

Location (constituency of operation) had significant ($p<0.05$) relationship with incorporation of OFSP into the production, willingness to integrate OFSP, production trends, frequency of production, type of floor used, main market, main customers, main ingredients, products and role in business. There is need to increase puree use, improve nutrition and volume, there is need to target replacement or minimizing wheat flour (Gurung et al., 2016). According to other studies (Mukanyandwi et al., 2019), location determines production trends and frequency of operation as it has direct impact on customers' preferences and customers will shy away from unhealthy environments. Additionally, location determines the type of raw materials used in production as a result of social class and purchasing ability, hence the smaller MSMEs will go for what they can afford as opposed to what is currently trending as the best (Caswell et al., 2013). Larger enterprises are attributed to better packaging materials, frequency of operations and better markets as opposed to smaller MSMEs whose customers are majorly locals consisting of street passersby (Connor et al., 2020; Mukanyandwi et al., 2019).

CONCLUSIONS AND RECOMMENDATION

Majority of the bakers and fryers are micro-enterprises with gender mainstreaming almost even, just depicting how this sector is fast growing as the youths take center stage in entrepreneurship, with frequency of production being at least twice a day. OFSP adoption into the sector is very low, however, with majority willing to adopt it, mainstreaming of this through robust sensitization through capacity building trainings is eminent hence recommended.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Studies on some physico-chemical and engineering properties of *Musa* spp (ABB) starch flour

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This study investigated some physiochemical and engineering properties of *Musa* spp (ABB) starch flour using standard procedures with a view to providing data that will aid in process design, control and bulk handling of *Musa* spp (ABB) starch flour. Loose and packed bulk densities, the least gelation concentration, density ratio and porosity ranged between 0.47 to 0.70 g/mL, 0.60 to 0.95 g/mL, 8 to 16% (w/v), 74.25 to 77.26%, and 22.73 to 25.74% respectively. Similarly, the Carr index had a range of 29.11 to 35.78% and Hausner ratio ranged from 1.29 to 1.36. The amylose-amylopectin ratio content obtained range from 0.45 to 0.50. Also, the thermal properties of the samples measured using differential scanning calorimeter ranged between 79.3 and 92.8°C, 106.4 and 121.2°C, 106.2 and 122.8°C, 56.75 and 278.6 J/g, 21.4 and 94.743.5°C, 10.95 and 20.28 J/(gK), 0.50 and 0.705 W/m°C, and 0.090 and 0.094 m^2/s for onset temperature, peak temperature, end temperature, enthalpy, temperature range, specific heat capacity, thermal conductivity and thermal diffusivity, respectively. This study therefore provides engineering data in relation to process design, control and bulk handling with a view to extending the usage of *Musa* spp (ABB) starch samples in food process industries.

Key words: *Musa* spp (ABB), Starch, physico-chemical and engineering properties, bulk handling.

INTRODUCTION

Musa spp (ABB) also known as bluggo (common name) is a perennial crop that grows quickly and bears fruit all year round in the tropics and sub-tropics of Asia, America, Africa and Australia where favourable conditions for its growth are met. Its harvest falls in the dry season when most other starchy staple foods are in short supply. It is grown in about 130 countries with an annual output of 106 mt annually (FAO, 2005; Idoko and Nwajiaku, 2013). In most regions of the world, the fruits are largely cultivated on small plots, garden and orchards where statistics is poorly documented (Uma, 2006). In many tropical countries, the bulk of the fruits produced are consumed and traded locally, thereby playing a crucial role in food security (Daniells et al., 2001). In Nigeria, its cultivations are concentrated in the Southern part of the country with approximately 60% postharvest loss due to lack of appropriate technologies for handling, storage and processing (FAO, 2005). It is widely

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consumed by millions of people in the tropics to serve as a good source of carbohydrate and vitamins which competes favourably with that of sweet potato, cassava and potato (Daramola and Osanyinlusi, 2006; Adeniji et al., 2007; Adeniji and Tenkouano, 2008). It is also a good source of mineral especially iron, calcium and potassium which meets daily diet recommendation (Aurand, 1987; USDA, 2009; Yarkwan and Uvir, 2015); and also serves as a commercial source of starch for food, textiles, cosmetic, paper, pharmaceutical and beverages industries.

The diverse industrial usage of starch is premised on its availability at low cost, high caloric value, inherent excellent physicochemical properties and ease of its modification to other derivatives (Omojola et al., 2010). There are a number of chemical modifications made to starch to produce many different functional characteristics. Starches are modified to change the properties of unmodified starch, and chemical modification on starches has markedly altered physicochemical properties compared with their parent starches (Rusli et al., 2004).

It has been shown that when native starch is modified, it generally shows better paste clarity, better stability, increased resistance to retrogradation and increased freeze-thaw stability (Zheng et al., 1999). Starch citrate has also been reported as a resistant starch in food industry (Xie and Liu, 2004).

Recent advances in computer software and micro-electronics are now applied to bulk handling of particulate, powdered and liquid foods using PLC based logic controllers to avoid risk of contamination and other benefits associated with the advances. Therefore, information needed by the PLC based logic controllers are obtained from sensors which detect, measure and interpret engineering properties related to bulk handling of foods. Therefore, studying of physico-chemical and engineering properties of *Musa* spp (ABB) starch flour will provide data to aid in process design, control and bulk handling with a view to extending the usage of *Musa* spp (ABB) starch flour in food process industries.

MATERIALS AND METHODS

Sources

Freshly harvested matured bunches of *Musa* spp (ABB) also known as bluggoe banana (Plate 1) at stage one maturity using colour as basis of classification (Ahenkora et al., 1997; Dadzie and Orchard, 1997) were obtained from Obafemi Awolowo University Teaching and Research Farm, Ile-Ife. Commercial potato starch flour was purchased from Niji Foods Farms and all chemicals used were of analytical grades.

Samples preparation

About 4 kg of freshly harvested debunched *Musa* spp, (ABB) fruits were sorted and extraneous materials removed. The cleaned fruits were debarked using a stainless steel kitchen knife and the pulp diced while immersed in an aqueous solution of sodium metabisulphite (1.25 g/L) to prevent enzymatic browning reaction (Gbadamosi and Oladeji, 2013). The pulp was drained and rinsed with portable water. The pulp was then macerated at low speed using a Stephan universal machine (Western Germany, Model No-P33/E) for 5 min. The homogenate slurry obtained was sieved using an electrical SWECO separator (Belgium, Model No- S18). The filtrate was subsequently left to settle for 3 h in a stainless decanting bowl, after which the supernatant was discarded. The starch slurry was then oven dried using a hot air oven (Uniscope, SM9053, England) at 50°C for 24 h. The starch flakes were milled using laboratory milling machine (sieve size 500 µm aperture) to get native starch flour (Figure 1). The native starch yield was expressed in percentage dry weight of native starch per weight sample used. The native starch obtained was divided into two portions: the first lot was stored in a labelled Ziploc bag and kept in an air tight jar till the time of usage while the second lot was modified according to the method documented by Atichokudomchai and Varavinit (2003).

Starch modification using acid

The starch modification of the native starch sample was done using method documented by Atichokudomchai and Varavinit (2003). Acid hydrolysis of the native starch was carried out by suspending 200 g (dry basis) of native starch in 400 mL of 6% (w/v) HCl solution at 27 ± 2°C for 1 h without stirring. After hydrolysis, the suspension was neutralized with 10% (w/v) sodium hydroxide solution to terminate the reaction. The slurry was washed three times with distilled water, dried in a hot air oven at 45°C for 24 h and then milled using laboratory milling machine (sieve size 500 µm aperture) to get acid modified starch flour. The acid modified starch was kept in a labelled Ziploc bags and kept in an air tight jar till the time of usage. The yield of acid hydrolyzed starch was expressed on dry basis as percentage dry weight of recovered starch per dry weight of native starch.

Physico-chemical properties determination

The physiochemical properties such as bulk density, amylose and amylopectin ratio, flow property and its least gelation concentration was carried out on both the native and modified starches using standard procedure.

Moisture content

The moisture content determination was carried out using AOAC (2005). The sample (3 g) was placed in moisture cans of known weight and dried in a hot air oven at 105 ± 1°C for 6 h, cooled in a desiccator and subsequently re-weighed. The moisture content was determined using Equation 1 below:

$$M.C_{db} = \frac{W_1 - W_2}{W_2} \times 100 \quad (1)$$

Where: W_1 = weight of the starch powder before drying (g); W_2 = weight of the starch powder after drying (g); M.C db = moisture content on dry basis (%).

Packed bulk density

The bulk density was determined according to the method documented by Okezi and Bello (1988). A 10-mL graduated

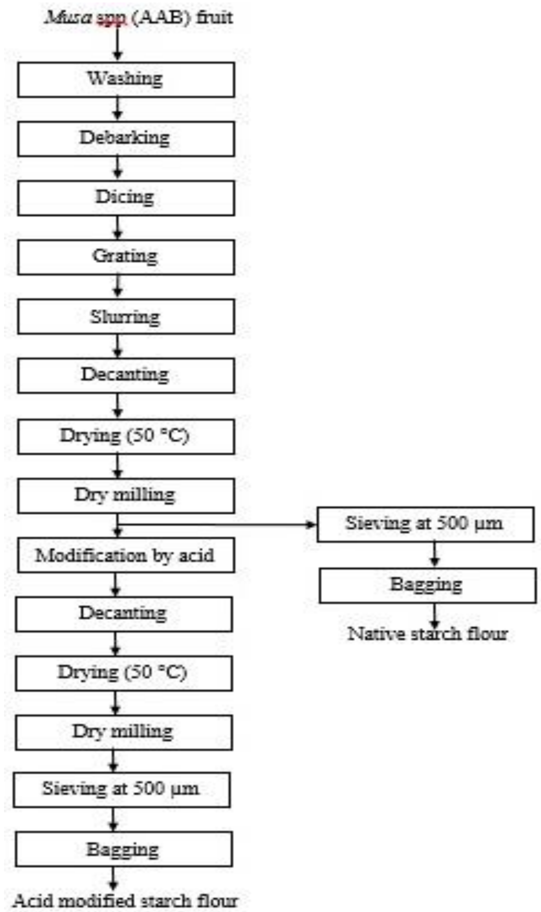

Figure 1. A schematic diagram showing extraction of *Musa* spp (ABB) native and acid modified starch. Source: Gbadamosi and Oladeji (2013).

cylinder was gently filled with a known weight of the sample and the bottom of the cylinder was gently tapped several times on a laboratory work bench until there was no further diminution of the sample level after filling to the 10-ml mark of the cylinder. Bulk density then was calculated using Equation 2.

$$BD = \frac{m}{v} \quad (2)$$

Where: BD = bulk density (g/mL); m = weight of sample (g); v = volume occupied by sample (mL).

Loose bulk density

The method documented by Yusuf (2004) was used for the determination of the loose bulk density. A 10-mL graduated cylinder was gently filled with the starch sample. This was not tapped. The volume occupied was recorded. The loose bulk density was then calculated using Equation 2.

Gelation and least gelation concentration

Least gelation concentration was determined by the method documented by Coffman and Garcia (1977). The flour suspension (10 ml) in distilled water (2-20%) was transferred into test-tube, heated in a boiling water-bath for 1 h and cooled. The sample in test-tube was further cooled for 2 h at 4°C and the least gelation concentration (LGC) was taken as concentration when the sample from the inverted test tube did not fall or slip.

Determination of density ratio and porosity

The density ratio (D_r) and porosity of the sample flours were determined using Equations 3 and 4 (Mohsenin, 1986):

$$D_r = \left(\frac{\rho_B}{\rho_T}\right) \times 100 \quad (3)$$

$$P = \left(1 - \left(\frac{\rho_B}{\rho_T}\right)\right) \times 100 \quad (4)$$

Where:
D_r = bulk ratio; P = porosity (%); ρ_B = packed bulk density of the sample (g/mL); ρ_T = tapped density of the sample (g/mL).

Flowability properties

Flowability as a function of compression and compaction of the samples was determined from packed bulk and loose bulk densities data. The Hausner ratio and Carr index of the flour samples were determined using Equations 5 and 6, respectively. The values of Hausner ratio and Carr index were used to classify the flour samples compression, compaction and flowability as excellent, good, fair, or poor (Paksoy and Aydin, 2004).

$$HR = \frac{\rho_\infty}{\rho_0} \quad (5)$$

$$C.I = \frac{\rho_B - \rho_b}{\rho_b} \times 100 \quad (6)$$

Where:
HR = Hausner ratio; ρ_∞= Asymptotic constant density after certain amount of taps; ρ_0 = Initial bulk density; C.I = Carr Index; ρ_B = Packed bulk density, g/mL and ρ_b= Loose bulk density, g/mL.

Amylose and amylopectin contents

The amylose content was determined using method documented by Thomas et al. (2013). Sample (100 mg) was measured into 100-mL standard flask, 1.0 mL of ethanol (95%) and 9.0 mL of 1.0 M NaOH was added, and the mixture was heated on a boiling water-bath for 10 min to gelatinize the starch. The gelatinized starch solution (5.0 mL) was subsequently transferred to a 100-mL standard flask; further, 1.0 mL of 1.0 M acetic acid and 2.0 mL of stock iodine solution were added to it and the volume was made up to the mark with distilled water. The content was thoroughly vortex and allowed to settle for 20 min. The resultant colour was allowed to develop and the absorbance read at 620 nm using a UV-Spectrophotometer (Model - 752S). The amylose content was then calculated from the standard curve of potato amylose, expressed in percentage. The amylopectin content was obtained by subtracting the value of amylose content determined from 100.

$$APC = 100 - AC \quad (7)$$

Where: APC = Amylopectin content (%) and AC = Amylose content (%).

Thermal properties

The thermal properties of the starch flour samples were measured using a KD2 Pro Thermal Properties Analyser (Decagon Devices Inc., Pullman, WA), a portable field and laboratory equipment that use the transient line heat source method. The 30-mm long, 1.28-mm diameter, and 6-mm spacing dual needle SH-1 sensor measures the onset temperature, peak temperature, end temperature, gelatinization enthalpy, and specific heat capacity (heat capacity). An interval of 5 min was provided between each reading.

Thermal diffusivities of the flour samples were thereafter determined from the temperature - time data of the samples generated by the DSC using Equation 8 according to Leniger and Beverloowere (Man et al., 2013) and then employed to determine thermal diffusivity which was calculated using Equation 8 given by Leniger and Beverloowere

$$-\log\frac{T_{max}-T_i}{T_{max}-T}=\frac{1}{2.303}\left[\frac{5.78}{R}+\frac{\pi^2}{L^2}\right]\alpha t \quad (8)$$

Where: T_{max} = Maximum processing starch flour temperature (K); T_i = Initial starch flour temperature (K); T = Starch flour temperature at any time (K); R = Radius of the crucible (m); L = Length of the starch flour in the crucible (m); t = time (s); and α = thermal diffusivity (m^2/s).

Thermal conductivity was calculated mathematically using Equation 9

$$k=\rho\alpha C_P \quad (9)$$

Where: α = thermal diffusivity (m^2/s); k = thermal conductivity (w/m°C); C_P= specific heat capacity (J/(gK)) and ρ= density (g/mL).

Coefficient of friction of the starch flour

The coefficient of friction of starch flour sample was determined using the method documented by Bahnasawy (2007). The coefficient of friction was tested against plywood, stainless steel, galvanized steel and glass surfaces. A bottomless cylinder of 5 cm diameter and 10 cm height was filled with the starch sample and placed over the different surfaces which were in turn placed on an inclined plain system. The surfaces were gently raised using a jack and the angle at which the powder motion began as the plain inclined was read off with a calibrated protractor in degrees. The coefficient of friction was calculated using Equation 10.

$$\mu=tan\alpha \quad (10)$$

Where: μ = coefficient of friction and α = angle, in degrees.

Angle of repose

The method documented by Garnayak et al. (2008) was used in determination of angle of repose. A bottomless cylinder of 5 cm diameter and 10 cm height was placed over a plain surface and the starch flour sample was placed in the cylinder. The cylinder was raised slowly allowing the sample to flow down and form a natural slope. The angle of repose was calculated using Equation 11.

$$\theta=\tan^{-1}\left(\frac{2h}{D}\right)$$

Where: θ = angle of repose (°); h = height (cm) and D = diameter (cm).

Statistical analysis

The data obtained were analyzed descriptively and inferentially using Turkey's post test procedures of GraphPad Prism version 4.00 for Windows.

RESULTS AND DISCUSSION

The yield of native and modified starch flour samples were 45.3 and 93.43%, respectively. The values obtained were higher than 40.9% reported by Tribess et al. (2009) for native *Musa* spp (ABB) starch but lower than 58.5% documented by Suntharalingam and Ravindran (1993). The difference in the yield values could be attributed to difference in variety or specie and geographical location as reported by Ravi and Mustaffa (2013).

Ambigaipalan et al. (2011) reported that the yield of starches from faba bean (32.94 - 36.34%), black bean (27.53 - 29.89%) and pinto bean (27.41 - 31.16%) varied. Akanbi et al. (2009) also reported 14.26% for bread fruit starch. The value obtained from *Musa* spp (ABB) was higher than legume starches reported by authors because legumes have less starch content compared to cereals, tubers and starchy berries. This result indicates that *Musa* spp (ABB) can serve as an alternative source of starch in the food industry and other allied industries.

The physico-chemical properties such as moisture, bulk density, gelation and least gelation concentration, porosity, density ratio, and flow properties of native and modified *Musa* spp (ABB) starch are presented in Table 1.

The moisture content values were 2.07 and 1.35% (d.b) for native and modified starches, respectively. The values obtained compared favorably with 2.85% of commercial potato starch with no significant difference ($p \leq 0.05$). Flour is considered shelf stable if its moisture content is below 11% (Gbadamosi et al., 2012). Hence, the shelf stability of the starch flour investigated could be considered shelf stable for moisture related deterioration.

The bulk densities of native and modified Musa spp starch flour were 0.65 and 0.63 g/mL (loose) and 0.84 and 0.85 g/mL (packed), respectively. The values obtained compared favourably with 0.51 and 0.66 g/ml (commercial potato starch) for loose and packed densities, respectively. Acid hydrolysis of the *Musa* spp starch resulted in increased packed bulk density. There is no significant difference ($p \leq 0.05$) between native and modified starch bulk density values but there is significant difference when compared with the value of commercial potato starch. The values obtained compared favourably with 0.64, 0.68 and 0.68 g/mL for cassava starch, cocoyam and breadfruit flours, respectively (Gbadamosi and Oladeji, 2013).

The bulk density either loose or packed, measures quantity of material that can be packed within a pre-specified packing space (Gbadamosi and Oladeji, 2013). It depends on the combined effect of interrelated factors

Table 1. Physico-chemical properties of *Musa* spp. starch.

Parameters	Native starch	Modified starch	Potato starch
Loose bulk density (g/mL)	0.65±0.03[a]	0.63±0.01[a]	0.51±0.03[b]
Packed bulk density (g/mL)	0.84±0.06[a]	0.85±0.03[a]	0.66±0.04[b]
Carr index (%)	29.11±4.03[a]	35.78±5.53[a]	30.61±7.36[a]
Hausner ratio	1.29±0.03[a]	1.36±0.05[a]	1.31±0.07[a]
Density ratio (%)	77.26±2.36[a]	74.25±2.75[a]	76.53±4.21[a]
Porosity (%)	22.73±2.36[a]	25.74±2.75[a]	23.47±4.21[a]
Angle of repose (°)	31.6±3.31[b]	31.91±1.99[b]	39.78±1.74[a]
Moisture content (%)	2.07±0.19[a]	1.35±1.35[a]	2.85±0.07[a]
Compressibility	Fair	Very good	Good
Flowability	Free flowing	Free flowing	Free flowing

Values are mean ± standard deviation in triplicate. Mean values within each row bearing different superscript roman letter are significantly different (p≤0.05).

Table 2. Pearson Correlation Matrix between properties of *Musa* spp. and potato starch flours.

Variables	LBD	PBD	C. I	H.. R	D. R	P	A. R	AMY	APEC	M. C	LGC
LBD	1	0.9856	0.1922	0.2558	-0.1748	0.1736	-0.9968	0.9935	-0.9935	-0.8192	-0.6068
PBD	0.9956	1	0.3554	0.4156	-0.3388	0.3377	-0.9960	0.9984	-0.9984	-0.9044	-0.7325
C. I	0.1922	0.3554	1	0.9979	-0.9998	0.9998	-0.2702	0.3027	-0.3027	-0.7202	-0.8966
H. R	0.2558	0.4156	0.9979	1	-0.9966	0.9965	-0.3325	0.3642	-0.3642	-0.7640	-0.9236
D. R	-0.1748	-0.3388	-0.9998	-0.9966	1	-1.0000	0.2532	-0.2858	0.2858	0.7079	0.8887
P	0.1736	0.3377	0.9998	0.9965	-1.0000	1	-0.2520	0.2847	-0.2847	-0.7070	-0.8881
A. R	-0.9968	-0.9960	-0.2702	-0.3325	0.2532	-0.2520	1	-0.9994	0.9994	0.8625	0.6686
AMY	0.9935	0.9984	0.3027	0.3642	-0.2858	0.2847	-0.9994	1	-1.0000	-0.8792	-0.6934
APEC	-0.9935	-0.9984	-0.3027	-0.3642	0.2858	-0.2847	0.9994	-1.0000	1	0.8792	0.6934
M. C	-0.8192	-0.9044	-0.7202	-0.7640	0.7079	-0.7070	0.8625	-0.8792	0.8792	1	0.9530
LGC	-0.6068	-0.7325	-0.8966	-0.9236	0.8887	-0.8881	0.6686	-0.6934	0.6934	0.9530	1

such as the intensity of attractive inter-particle forces, particle size and number of contact points (Gbadamosi and Oladeji, 2013). Bulk density plays essential role in dispersion rate of food powder, which is related to starch reconstitution.

The angle of repose values were 31.6, 31.91 and 39.78° for the native, modified and commercial potato starch flour samples, respectively (Table 1). The angle of repose is an indication of the flow rate of the starch powder extracted. It correlates with the values for loose bulk density, packed bulk density and the moisture content as seen in Table 2. According to Carr (1965, 1970) and Raymus (1985), angle of repose below 30° indicated good flowability, 30° - 45° some cohesiveness, 45° - 55° true cohesiveness and above 55° sluggish or very high cohesiveness and very limited flowability. To this end, the native and modified starches of *Musa* spp (ABB) and that of potato starch exhibited some cohesiveness. Since there are about eight different methods of measuring the angle of repose which give somewhat different values, the published values of angles of repose are seldom comparable (Gbadamosi and Oladeji, 2013).

Using the Pearson correlation matrix (Table 2), loose bulk density correlates significantly (p≤0.05) to packed bulk density (0.9856), angle of repose (-0.9968), amylose (0.9935), amylopectin (-0.9935) and moisture content (0.8.19) as shown in Table 2. Packed density on the other hand, exhibit significant (p<0.01) correlation with loose bulk density (0.9858), angle of repose (-0.9960), amylose (0.9984), amylopectin (-0.9984), moisture content (-0.9044) and least gelation concentration (-0.7325).

The density ratio of native and modified starch samples were 0.77 and 0.74% respectively. These values compared favourably with that of commercial potato starch which had a density ratio of 0.76% (Table 1). Paksoy and Aydin (2004), reported similar values of density ration at 0.73, 0.76, and 0.79% for breadfruit starch flour, *Musa* spp starch flour and wheat starch flour, respectively.

The porosity values of native and modified starch samples were 22.73 and 25.74% respectively with no significant difference (p ≤ 0.5). The porosity values

Table 3. Gelation and least gelation of *Musa* spp and potato starch flours.

Concentration	Native starch	Modified starch	Potato starch
2	--	-+	--
4	-+	-+	-+
6	-+	-+	-+
8	-+	++	-+
10	-+	++	-+
12	-+	++	-+
14	++	++	-+
16	++	++	-+
18	++	++	++
20	++	++	++
LGC	14%	8%	16%

-- No gelation, -+viscous, ++full gelation, LGC least gelation concentration.

Table 4. Starch characterization of *Musa* spp. starch flour.

Parameter (%)	Sample		
	Native starch	Modified starch	Potato starch
Amylose	31.27±0.17[a]	33.26±0.04[a]	29.77±0.11[a]
Amylopectin	68.73±0.17[a]	66.74±0.04[a]	70.23±0.11[a]
Amylose/amylopectin	0.45±0.01[a]	0.50±0.01[a]	0.42±0.01[a]

Values reported are means ± standard deviation in triplicate. Mean values within each row bearing a different superscript roman letter are significantly (p≤0.05) different

obtained compared favourably with 23.47% of commercial potato starch flour. The values obtained also compared favourably with 24.1 and 23.8% for mug bean and sorghum starch powders, respectively (Gupta and Das, 1997; Altuntas and Yildiz, 2007). Porosity measures the percentage of voids of an unconsolidated mass of materials often needed in air and heat flow studies as well as other application. The Pearson correlation matrix showed significant correlation between porosity and Carr index (-0.9998), Hausner ratio (-0.9966) and least gelation concentration (-0.8881) (Table 2).

Carr index and Hausner ratio for the native and modified starch flour samples were 29.11 and 1.29; 35.78 and 1.36, respectively (Table 1). The values compared favourably with 35.78 and 1.31 for commercial potato starch. The Carr index and Hausner ratio indicate the flow properties of flour samples. Using Carr index assessment, the native starch showed fair compactness and compressibility but poor flowability, while modified starch sample indicated higher compressibility but poor flow properties and potato starch indicated a fair level of compressiveness but a poor flow property (Table 1). As reported by Falade and Ayetigbo (2014), most hydrocollides are known to have good compressibility but very poor flow ability properties when it is based on their Carr index. When Hausner ratio and angle of repose are used as flow property index, it was seen that the starch samples were free flowing and compressible. Acid hydrolysis did not improve the flowability of modified starch but improved the compressibility. Similar trends were reported by Olorunsola et al. (2011) for native and acid hydrolyzed sweet potato starch.

The Carr index provides an indirect measure of material fluidity, and the higher its value, the more cohesive the substance (Riley et al., 2008). Hausner ratio correlated significantly with Carr index (0.998), porosity (0.997) and least gelation concentration (-0.9236).

The gelation and least gelation concentration of the native and modified starch samples were shown in Table 3. The least gelation concentration of native and modified starch samples occurred at 14 and 8% (w/v), respectively whereas the acid modification of the starch resulted in the intermolecular repulsion to occur in the starch-gel accounting for its lower gelation concentration. The least gelation concentration result obtained for the modified starch is consistent with the report by Oladebeye et al. (2014), which suggest the rapid tendency of starch granules to swell at an elevated temperature within a short time. The low gelation concentration of the modified starch enhances its application as a bulking agent in food formulations such as chocolate and confectioneries. It is used as an index of gelation capacity.

The result for the amylose and amylopectin content and amylose- amylopectin ratio of the starches are presented in Table 4. The result indicates that the amylose content of the samples ranged between 29.77 - 33.26% which

Table 5. Thermal properties of *Musa* spp. starch flour using differential scanning calorimetry (DSC)

Parameter	Native starch	Modified starch	Potato starch
Onset Temperature, TO	92.8°C	79.3°C	72.7°C
Peak Temperature, TP	109.5°C	121.2°C	106.4°C
End Temperature, TE	114.2°C	122.8°C	106.2°C
Enthalpy, H	56.75 J/g	81.25 J/g	278.6 J/g
Temperature Range	21.4°C	43.5°C	35.5°C
Specific Heat Capacity, C_P	14.24 J(gK)	20.28 J(gK)	10.95 J(gK)
Thermal conductivity, k	0.5 w/m°C	0.705 w/m°C	0.305 w/m°C
Thermal diffusivity, α	0.09 m^2/s	0.094 m^2/s	0.095 m^2/s
Density, ρ	0.84 g/mL	0.85 g/mL	0.66 g/mL

falls within the values (24.41 to 36.87%) reported for different *Musa* cultivars (Mustaffa, 2013). The high amylose content of the modified starch indicates high amylose-amylopectin ratio and hence, slowly digestible. The amylopectin content range from 66.74 to 70.23% (Table 4), with the potato starch having the highest amylopectin content. The amylose content values were within the reported range of 24.41 - 36.87% for various *Musa* spp cultivars (Mustaffa, 2013).

Amylose-amylopectin ratio for the native and modified starch samples and commercial potato starch sample were 0.45, 0.5 and 0.42%, respectively. The lower the amylose-amylopectin content range, the lower the glycemic index of the starch making it ideally consumable by diabetic patients. It is also an indication that hydrolysis of the starch is slow showing that the starch is a slowly digestible resistant starch (Jenkins et al., 1981). Amylose plays an important role in the starch internal structure and its digestibility is readily present in the amorphous region during modification. This region can be easily assessed than the amylopectin side chains, thus the amylose content is subject to change during modification (Man et al., 2013). The structural difference between amylose and amylopectin is said to be the backbone of starch during utilization. Starch with high amylose content tend to show a high degree of flakiness, however food materials prepared with starch that has a low amylose content becomes hard sticky and hard to chew (Karmakar et al., 2014). The amylose content of starch is an important characteristic that affects its functionality.

The onset temperature, peak temperature, end temperature, gelatinization enthalpy, temperature range, specific heat capacity and density of native and modified starch flour samples were 92.8°C, 109.5°C, 114.2°C, 56.75 J/g, 21.4°C, 14.24 J/(gK) and 0.84 g/mL; and79.3°C,121.2°C, 122.8°C, 81.25 J/g, 43.5°C, 20.28 J/(gK), and 0.85 g/mL, respectively (Table 5). The values obtained compared favourably with commercial potato starch values of 72.7°C, 106.4°C, 106.2°C, 278.6 J/g, 33.5°C, 10.95 J/(gK) and 0.66 g/mL for its onset temperature, peak temperature, end temperature, gelation enthalpy, temperature range, specific heat capacity and density, respectively. As shown in Table 5, the gelatinization enthalpy (ΔH) for the potato starch is greater than that of native starch and modified starch, with native starch having the least enthalpy value. Singh et al. (2009), in their report, related gelatinization enthalpy to degree of crystallization. Starch with high gelatinization enthalpy possess higher degree of crystallization and hence, low swelling power. The variation in ΔH in starches as result of modification and starch type may be due to differences in quantity of longer chain amylopectin (Singh et al., 2003). The high gelation temperature range value of the modified starch indicates the presence of crystallite of difference stability within the crystalline region of the starch granule (Hoover et al., 1997). Density of the samples which is a function of mass and volume differed significantly between native and modified starch and potato starch. Native and modified starches had significantly similar densities.

The static coefficient of friction of dried starch samples was determined against glass, wood, galvanized steel and stainless steel. The coefficient of static friction for native and modified *Musa* spp (ABB) starch samples against glass, wood, galvanized steel and stainless steel were 0.46 and 0.40°; 0.41 and 0.48°; 0.36 and 0.45°; and 0.40 and 0.45° respectively (Table 5). This compares favourably with commercial potato starch sample which had 0.51, 0.66, 0.61, and 0.57° for glass, wood, galvanized steel and stainless steel respectively (Table 6). The values obtained for coefficient of static friction are similar to those documented by Carman (1996) for glass (0.40 - 0.45°), wood (0.40 - 0.50°), and galvanised steel (0.4 - 0.5°). No significant difference ($p \leq 0.5$) was observed among the starch samples. Each sample was statistically different from the other as shown in Table 5. The static co-efficient of friction data is helpful in designing storage facilities and other bulk handling devices such as impelling unit and augers.

Conclusion

This study investigated some engineering and

Table 6. Coefficient of friction.

Sample	Glass (°)	Wood (°)	G. Steel (°)	S. Steel (°)
Native starch	0.46±0.03[ab]	0.41±0.05[c]	0.36±0.03[b]	0.40±0.06[b]
Modified starch	0.40±0.02[b]	0.48±0.04[b]	0.45±0.02[b]	0.45±0.02[b]
Potato starch	0.51±0.07[a]	0.66±0.03[a]	0.61±0.09[a]	0.57±0.03[a]

G. steel – galvanized steel, S. Steel – stainless steel. Mean values within each row bearing different superscript letter are significantly different (p<0.05).

physiochemical properties of *Musa* spp (ABB) starch flour samples in relation to its bulk handling. The study therefore provides engineering data in relation to process design, control and bulk handling needed by PLC logic controllers obtained from sensors that detect, measure and interprets these data with a view to extending the usage of *Musa* spp (ABB) starch samples in food process industry.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Effects of freezing as a post-harvest storage technique on quality of Friesian crossbred cattle milk

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Twenty-five raw milk samples from Friesian crossbred dairy cows were analyzed for milk fat, protein and lactose using an ultrasonic milk analyzer. The samples were then subjected to two different freezing protocols; single freezing and multiple freezing, after which parameters were reanalyzed after freezing and thawing at different freezing times (24, 48, and 72 h). Paired t-test was used to compare the effect of freezing type while the differences in milk constituents with freezing time were analyzed using ANOVA. Linear regression analysis was also performed to study correlations between freezing duration and any change in cattle milk's macronutrient content. The results indicated that milk fat, protein and lactose content decreased significantly with freezing time. However, the decrease was more in multiple frozen samples than single frozen samples. The most decreased macronutrients were lactose (14.1%) in single freezing and fat (25.5%) in multiple freezing. Analysis of the interaction between freezing type and freezing time showed that freezing time significantly affected all the parameters while freezing type (p=0.03) and its interaction with freezing time (p=0.02) affected only the fat content. In conclusion, it should be noted that cattle milk samples frozen at -20°C leads to a significant decrease in fat, protein, and lactose content. The loss of constituents was much more pronounced when samples were frozen, thawed, and refrozen (multiple freezing) than when samples were thawed only once (single freezing).

Key words: Single freezing, multiple freezing, macronutrients, dairy cattle.

INTRODUCTION

Milk and other animal-source foods are concentrated dietary sources of macro- and micronutrients such as proteins, carbohydrate, calcium, phosphorus and vitamin B2, B12. Milk is an incredibly important form of animal-source food since it is intended for nurturing the young, a population group at high risk for nutritional deficiencies. Worldwide, nearly 229.2 million children below five years were affected by malnutrition by 2019, with 144 million stunted, 47 million wasted, and 38.2 million overweight (UNICEF/WHO/World Bank Group, 2020). In Kenya, under-nutrition affects nearly one third of children (KNBS, 2015). This under-nutrition increases disease risk, restricts cognitive development, and impedes human capital accumulation. Human milk has been and still is

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the best source of nutrition that is uniquely suited not only for term and preterm infants (Victora et al., 2016) but also for very low birth weight (VLBW) infants (Arslanoglu et al., 2019), conferring both short- and long-term health benefits. It is recommended that the delivery of this milk to the infant be through breastfeeding. However, sometimes breastfeeding may not be possible due to mother and infant contraindications (Szajewska et al., 2016).

Usually, in such cases, in developed countries, human milk bank for hospitalized babies has been considered as the first choice. However, the emergence of immune debilitating diseases like HIV/AIDS and the development of infant formulas have highly affected the human milk bank's popularity (Leaf and Winterson, 2009). Conversely, in developing countries, where milk banks and infant formulas are not easily accessible, one way to foster infants' nutritional status is by increasing their consumption of livestock-derived foods (LDF), especially milk. Milk produced by domestic animals is not only consumed by infants but also by other age groups.

In Kenya, dairy cattle produce more than 56% of the country's overall milk production (Odero-Waitituh, 2017). This makes cattle milk the most common and readily available milk source for infant supplementation and household consumption (Muriuki, 2011). Over 70% of this milk is marketed raw through informal markets (Muriuki, 2011). Therefore, this milk has a shortened shelf life, usually between three to five days (Ajmal et al., 2018). To preserve the nutritional value, avoid spoilage and increase this milk's shelf life, players along the milk value chain have considered freezing as a good solution due to its greater storability and convenience (Pollack, 2001). However, many consumers tend to freeze the milk in bulk, thaw, and then refreeze the remaining aliquot of milk. Bulk milk storage contrasts with previous studies' recommendations that milk should be stored in small amounts that are consumable within one feeding (Alinovi et al., 2020). Further, many previous studies on effect of freezing on quality have been on human milk (Abranches et al., 2014; García-Lara et al., 2012), with very few studies on the effect of freezing on cattle milk's macronutrients content (Weese et al., 1969). As such, there is a need to assess the impact of freezing and refreezing thawed milk, as a post-harvest storage technique, on cattle milk's nutritional composition. Therefore, this study seeks to evaluate the effects of freezing (type and time) on the cattle milk composition.

MATERIALS AND METHODS

Experimental animals

The experiment was approved by the Faculty of Veterinary Medicine, University of Nairobi's Institutional Animal Care and Use Committee (IACUC), Reference number: FVM BAUEC/2020/268. The experiment was conducted at the University of Nairobi Veterinary farm. The farm lies between latitudes 1° 14' S and 33° 4' S and longitudes 36° 42' E and 36° 3' E. Twenty-five Friesian crossbred dairy animals (350 ±50 kg body weight) were randomly selected from the farm herd for use in this study.

Milk sampling

The samples were collected in morning milking (6 am) prior to feeding. Milk samples were collected aseptically and placed in labeled sterile 50 ml polypropylene centrifuge tubes. Samples were immediately placed in ice cooled container and transported to the laboratory for analysis. Twenty-five 50 ml samples of fresh milk from each cow were analyzed for milk composition parameters on the day of collection, 0 h, then divided into four portions of 10 ml aliquots. The samples were then allocated either into single freezing or multiple freezing protocol (freezing type). For single freezing, milk composition was determined on three aliquots of each sample in the following order: (i) after 24 h (aliquot 1), (ii) after 48 h (aliquot 2), and (iii) after 72 h (aliquot 3). All aliquots were discarded after taking measurements at each time point. Determination of milk composition for the multiple freezing was done on the fourth aliquot for each sample, after 24, 48 and 72 h. Following each of the measurements, in the latter experiment, the samples were refrozen and then thawed for the next measurements before being discarded after analysis at 72 h. All samples were frozen at -20 ± 1°C (Kamelska et al., 2012; Pietrzak-Fiećko and Kamelska-Sadowska, 2020) in a DW-40W380 Haier Deep Freezer (Haier Medical Laboratory Products. Co., Ltd. Qingado, China). Prior to the analysis, samples were left to thaw at room temperature for 45-60 min and homogenized by shaking for 30 s (Figure 1).

Milk parameter measurement and Statistical analysis

Milk fat, protein, and lactose, for all the samples, were determined using an automatic ultrasonic milk analyzer (Lactoscan MCC, SLP 60, V60), calibrated for cattle milk. Statistical analysis was performed on the various milk nutritional parameters using SPSS version 25 SPSS Inc, Chicago, Ill). Paired t-test was used to compare macronutrient concentrations of single freezing and multiple freezing experiments. In addition, analysis of variance (ANOVA) was used to assess for differences in milk constituents from fresh milk and over previously frozen milk at different times. The means were then compared using the Bonferroni posthoc test. Variables were expressed as percent mean ± SE. A p-value of $p \leq 0.05$ was considered significant. The linear model described below was fitted to study correlations between freezing duration and any change in cattle milk's macronutrient content:

$$Y = a + X\beta$$

where Y is the predicted change in individual milk parameter content, the dependent variable, depending on the duration of freezing (hours), X, the vector of the independent variable, a is the intercept, a constant, and β is the regression slope

RESULTS

The milk fat, protein, and lactose contents significantly decreased with an increase in duration of freezing, from 0 to 72 h, for single freezing ($p<0.05$) and multiple freezing ($p<0.001$) (Table 1). Additionally, the decline in all the parameters had a significant correlation with the freezing duration (Figure 2). When samples for single and multiple freezing experiments were compared at different times, it

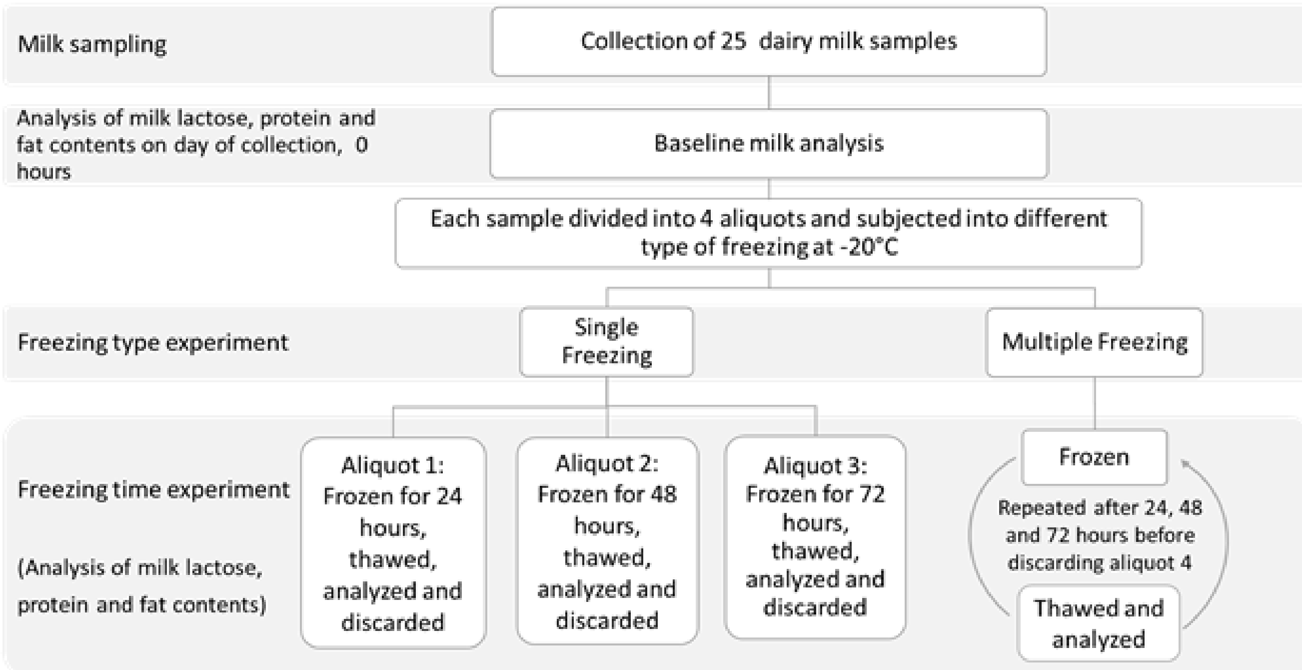

Figure 1. The scheme of sample analysis.

Table 1. Effects of type of freezing on milk composition of Friesian crossbred dairy cattle.

Freezing type	Parameter	Freezing time (hours)				P-value
		0	24	48	72	
Single	Fat (%)	3.81±0.12[a]	3.59±0.10[a]	3.4±0.11[a]	3.39±0.10[a]	0.042
	Protein (%)	2.03±0.04[b]	1.92±0.05[ab]	1.83±0.05[a]	1.81±0.05[a]	0.005
	Lactose (%)	2.13±0.06[b]	1.96±0.05[ab]	1.85±0.06[a]	1.83±0.06[a]	0.002
Multiple	Fat (%)	3.81±0.12[c]	3.59±0.10[bc]	3.29±0.10[b]	2.84±0.13[a]	<0.001
	Protein (%)	2.03±0.04[b]	1.92±0.05[ab]	1.77±0.05[a]	1.76±0.05[a]	<0.001
	Lactose (%)	2.13±0.06[b]	1.96±0.05[ab]	1.77±0.07[a]	1.76±0.06[a]	<0.001

Data for freezing time is presented as mean ± SE, abMean with different superscripts within a row are significantly different (P<0.05)

was observed that most milk parameters were lowest for multiple freezing at 48 and 72 h. Assessment of the magnitude of parameter decline between the fresh milk and the milk parameters at 72 h revealed that all the parameters decreased with a higher magnitude for multiple freezing than single freezing. Specifically, lactose, 14.1%, and fat content, 25.5%, were the parameters that decreased the most during both single and multiple freezing. Analysis of the interaction between freezing type and freezing time showed that freezing time had a significant effect on all the parameters while freezing type (p=0.03) and its interaction with freezing time (p=0.02) affected only the fat content (Table 2).

DISCUSSION

Milk is of nutritional value to both young and adults because of its complex constituent's mixture of fats, proteins, carbohydrates, minerals, vitamins, and other miscellaneous constituents dispersed in water (chloride, sodium, and urea). Although milk composition is unique for each species, the presence of the same nutrients renders milk from different species substitutable, e.g., bovine milk has been used to feed infants where human milk is not available. The milk water content is approximately 88% for both bovine and human milk while milk fat, lactose and protein is content is 3.9 and 4.1%,

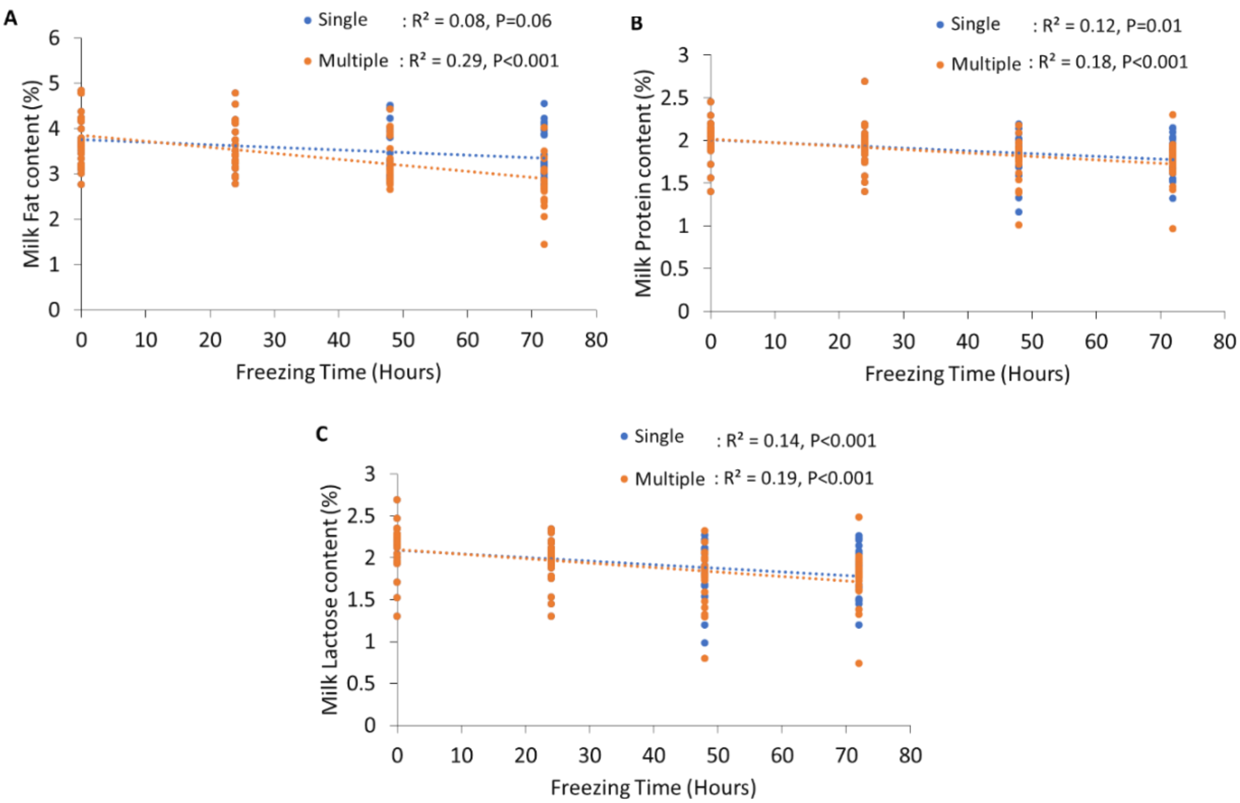

Figure 2. Correlation between duration of freezing (hours) and the changes in milk parameter content. Graph A is for Milk Fat, B is for Milk Protein, and C is for Milk Lactose.

Table 2. Interaction effect of freezing time and freezing types on milk composition of Friesian crossbred dairy cows.

Parameter	Time (hours)				P-Value		
	0	24	48	72	T	F	TXF
Fat (%)	3.81^{c}	3.59^{bc}	3.34^{ab}	3.14^{a}	<0. 001	0.03	0.02
Protein (%)	2.03^{b}	1.92^{b}	1.80^{a}	1.79^{a}	<0. 001	0.40	0.88
Lactose (%)	2.13^{c}	1.96^{b}	1.81^{ab}	1.80^{a}	<0. 001	0.40	0.86

T- freezing time, F- freezing type, TXF- Time and freezing type interactions, ^{abc}Mean with different superscripts within a row are significantly different (P<0.05).

4.5 and 7%, and 3.3 and 1.3% respectively (Haug et al., 2007; Martin et al., 2016). While the species influences the milk composition (Roessler et al., 2019), other factors like storage time and type (freezing or refrigeration) may affect the nutrient content.

Despite freezing fresh milk being a possible way of storing milk for a required duration, such an approach may have a deteriorating impact on product stability in terms of quality. Abranches et al. (2014), assessed the freezing and thawing effects on fat, protein, and lactose levels of natural human milk administered by gavage and continuous infusion. In the aforementioned study, there was a decrease in levels of milk parameters with increased freezing time. Similar results were observed in studies done by Weese et al. (1969) on effect of freezing and length of storage on dairy milk properties. The above studies demonstrated that refrigeration, freezing, and thawing lower macronutrient concentrations in human milk.

Previous studies have reported chemical and physical alteration of milk components during freezing and thawing (Abranches et al., 2014; García-Lara et al., 2012; Weese et al., 1969). In this study, milk fat decreased significantly with an increase in freezing time for single and multiple freezing experiments. However, this decline with freezing duration was more pronounced in the multiple freezing experiments. These results were in congruence with other previous studies that reported depressed milk fat after cattle milk was stored at -26°C (Weese et al., 1969), goat milk frozen for 80 days at between −16 to −20°C (Yu et al., 2021), sheep milk frozen at -15 or -25°C (Zhang et al., 2006), and human milk samples frozen at -20°C (Abranches et al., 2014). Similar results were also reported in cattle milk where milk was refrigerated at 4°C (Rico et al., 2014; Zajác et al., 2015). Two hypotheses have been previously put forward to explain this result. First, when milk is stored at -20°C, the lipase activity goes on, albeit at a lower rate (Goff and Sahagian, 1996). Second, repeated thawing and freezing alters the fat globule by disrupting the globule membrane, increasing the substrate's accessibility to the depressed enzyme activity (Vieira et al., 2011). In these two theories, triglycerides in fat globules are broken down, lowering their content and increasing the content of diglycerides, monoglycerides, and free fatty acids. Since the monoglycerides, diglycerides, and free fatty acids are fats, it is expected that they could be measurable. Consequently, no significant differences were expected in the quantification of fat. It is theorized that the freezing and thawing circles could have facilitated further degradation of these molecules, therefore making them unmeasurable. However, this could not be confirmed as the equipment used could not determine the concentration of individual fat molecules in milk.

Similarly, milk protein and lactose had an apparent consistent decrease after freezing and thawing. This is in agreement with a study by Weese et al. (1969), who reported decreased fat, protein, and lactose in cattle milk. The decrease in milk constituents was attributed to coagulation and degradation when frozen milk is thawed. Specifically, the protein decrease was in agreement with a previous study by Păduraru et al. (2019) on the influence of refrigeration or freezing on human milk macronutrients. Another study by Vieira et al. (2011) reported up to 13.6% decrease in protein content when human milk was frozen and thawed. Several reasons have been put forward to explain the protein reduction. First, studies have suggested that milk protein flocculate and precipitate upon thawing after freezing (Babcock et al., 1949). In this study, flocculation was avoided by completely homogenizing the milk samples after thawing before taking the measurements. Secondly, during cold storage, casein micelles tend to lose their stability (Goff and Sahagian, 1996) because of physical aggregation after rejection from growing ice crystals and weakening of hydrophobic interactions between casein molecules within the micellar structure (Archer et al., 2017). Other studies have shown that, due to its crystallization ability during frozen storage, lactose is also an influential factor for casein destabilization. Goff and Sahagian (1996) reported that casein micelle destabilization could occur with as low as 40% lactose crystallization.

Conclusion

We conclude that despite freezing being a widely used storage technique, there is a significant decrease in fat, protein, and lactose content. This decrease in constituents was more pronounced when samples were frozen, thawed, and refrozen (multiple freezing) than when samples were thawed only once (single freezing).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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