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Quality Evaluation and Kinetics of Dependency of Apparent Viscosity of Whole Wheat- Water Yam Flour Mixture on Temperature in Relation to The Cooked Paste

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ABSTRACT

In the past, cooked paste commonly called fu-fu from whole wheat flour was well acceptable by African indigenes due to its light weight, fibre composition and other nutrients. However, it is a carbohydrate rich food and contains gluten not acceptable by some individuals' body systems. Quality evaluation and kinetics of dependency of apparent viscosity of whole wheat-water yam flour mixture on temperature in relation to the cooked paste were investigated. Composite flours (80:20-B, 60:40-C, 50:50-D, 40:60-E, 20:80-F; WYF: WMF-whole wheat meal flours) were formulated from wheat grains and water yam tubers. Samples A (water yam flour (WYF-100%)) and G-commercial whole wheat meal flour (WWF-100%) served as control. Flour samples were subjected to proximate, selected micronutrient, viscous and pasting characteristics analyses, while the cooked paste was evaluated using selected sensory attributes. Crude fat content of flours ranged from 0.19-1.80%, while crude fibre content differed significantly ($p< 0.05$) and varied between 1.08 and 4.88%. Crude protein content ranged from 2.10-4.50%, while carbohydrate by difference ranged from 61.10-80.10%. Heating temperatures for the flour dispersions ranged from 70-100oC. Sample B had the highest final viscosity among the blended samples. Apparent viscosities of the dispersions increased with increasing temperatures and displayed dilatants fluid behaviour. Sample B had the lowest value of activation energy required to obtain a suitable cooked paste among others. Overall results indicated that sample B could be consumed as an alternative cooked fu-fu to whole wheat flour fu-fu.

Keywords

Cooked paste, Flour dispersions, Heating temperatures, Pasting properties, Viscosity.

Introduction

Cooked paste known as Fu-Fu is prepared by boiling flour in water with strong agitation to obtain desired gelatinized product. This pasty product is meant to be swallowed after moulding and inserting into suitable soup. In Africa generally, Fu-Fu is a staple food. The flour utilized for the paste preparation could be from roots, tubers and cereals such as cassava, yam, cocoyam, wheat, maize, sorghum, millet, rice and hungry rice, among others. In the past, cooked paste from wheat grains was well acceptable by African indigenes. However, there was the need for product diversification for the purpose of enhancement in food and nutrient security. Wheat is used throughout the world as food for man. It could be processed into flour, from which a great variety of baked or cooked products can be made [1]. Mepba *et al*. [2] reported 0.46% ash, 12.86% crude protein, 1.40% crude fat, 11.31% moisture, 0.82% crude fibre and 73.15% total carbohydrate contents for wheat flour in Nigeria. Fernandez *et al*. [3] also obtained 11.94% moisture, 11.60% protein, 3.67% fat, 0.55% ash and 1.80% Crude fibre contents for wheat flour bought from a local market in Hermosillo, Mexico.

Moreover, water yam (*Dioscorea alata*) is one of the yam species even though consumed in most localities globally is not yet fully utilized and developed [4]. This yam has a higher multiplication ratio and tuber yield as well as better storability to preferred indigenous species [5]. Generally, *D. alata* was noted to contain less sugar and has extended shelf-life by Romain and Raemackers [6], which assisted in its' availability in periods of scarcity. It is also known for high nutritional contents, such as crude protein (7.40%), starch (75.0-84.0%) and vitamin C (13.0-24.70 mg/100g) as recorded by Osagie [7]. In addition, sticky, rubbery, firm or thick texture and spread-ability of cooked paste from flour dispersions could be measured in terms of viscosity or consistency index which is a rheological property [8]; and an important parameter for evaluation of the final flour products in addition to physicochemical properties. Measurement of viscosity of flour dispersions utilized as cooked paste is necessary to determine appropriate cooking time and pasting temperature for paste that could be acceptable by the consumers. Gelatinization temperature values as indicated by previous research reports depend on amylose and amylopectin ratio of the starch-flour composition [9]. Amylose molecules with high linearity and interaction during hydrogen bonding would tend to provide high gel strength for the cooked flour dispersion, while amylopectin molecules with complex structures may provide high viscous cooked paste. However, all these properties depend on the source of flour and limited information is still available in the area of Fu-Fu preparation.

Materials and Methods

Fresh mature white water yam tubers (*Discorea alata*) were purchased from a local market in Abakaliki, Ebonyi State, Nigeria, while wheat grains and commercial whole wheat meal flour (Dangote Flour Mills Ltd, Nigeria) were purchased from 'Ogige' market in Nsukka town, Enugu State. Other materials used include; kitchen knives, plastic baskets, pre-treatment chemicals, among others, and all were purchased from the later market.

Experimental design

Experiment was designed based on a completely randomized design [10].

Preparation of water yam and wheat meal flour samples

Water yam tuber *(D. alata)* was washed thoroughly in potable water and allowed to drain in a plastic basket for 10 minutes, and then peeled. The peeled tubers were manually sliced to average of 2 mm thickness into pellets with a stainless-steel kitchen knife and weighed (5 kg). The sliced yam was soaked into a 0.12% solution of sodium meta-bisulphate for 10 minutes [11] and drained completely. The yam pellets (5 kg) were dried in a hot air oven at 105^{o}C for four (4) hours to constant moisture content of 6%-w. b, cooled, milled, sieved (1 mm mesh-size) and packaged in air tight container for further use at laboratory temperature (28.0^{o}C). Wheat grains were thoroughly sorted to remove bad and non-wheat grains including other dirt particles. The sorted grains (5 kg) were soaked in enough clean water for 5 minutes, washed, drained and spread on flat stainless-steel trays for drying inside a hot air oven (at 105^{o}C for 6 hours for moisture content of 8%-w. b). The dried wheat grains were milled using plate mill, sieved (1 mm mesh-size) to obtain uniform particle size and the flour packaged using polythene bag.

Formulation of the flour composite

Water yam and whole wheat meal flours were blended in the ratios of 80:20-B, 60:40-C, 50:50-D, 40:60-E and 20:80-F; water yam and wheat flour blends (after preliminary investigation on formulations and cooking). Commercial whole wheat flour (100%-WWF) and water yam flour (100%-WYF) served as control.

Analytical methods

Proximate composition of the flour samples

Moisture, ash, crude fibre, fat and protein contents of samples were determined using standard method of AOAC (2010). Total carbohydrate was obtained by difference.

Determination of vitamins B_1 and C

Method described by AOAC (2010) was used for Vitamins B_1 and C for Vitamin B_1 (Thiamine), five (5) grammes of each sample was homogenized in 5N ethanolic sodium hydroxide solution and the mixture filtered and made up to 100 ml with extract solution. Ten millilitres (ml) of the filtrate diluted was dispensed into conical flask and 10 ml of potassium dichromate solution was added. The resultant solution was allowed to stand for 15 minutes at room temperature (28.0 ± 2.0^{o}C) for colour development. Thereafter, absorbance of the sample was measured at 360 nm from spectrophotometer against a blank and standard Vitamin B1. The B1 was calculated as follows (equation 1):

$$B1\left(\frac{mg}{100g}\right) = 100/w \times au/as \times c \times d \qquad \text{equation 1}$$

Where, w= weight of sample; au= absorbance of the sample solution; as= absorbance of the standard solution; c= concentration of the standard solution; d= dilution factor

Vitamin C (Ascorbic acid) was determined by titration method described in AOAC (2010). About 15 g of trichloro-acetic acid was dissolved in 40 ml acetic acid and 200 ml of distilled water. This was diluted to 500 ml and 60 ml of the solution was added to 5 g of each sample. Mixture obtained was homogenized and filtered under suction. The filtrate was poured into 250 ml volumetric flask and made up to the mark with distilled water. A 10 ml of the resulting solution was pipetted into 250 ml conical flask and titrated against the standard indophenol's solution. Titre value was recorded and vitamin C calculated as follows (equation 2):

$$Vitamin\ C\left(\frac{mg}{100g} of\ sample\right) = 20k$$

Where;

$$k = titre\ value \times 3.60 \times 25 \frac{1}{weight\ of\ sample} \qquad \text{equation 2}$$

Determination of Iron contents of flour samples

Iron was determined using the method of AOAC [12].

Functional properties

Bulk density

The bulk density (Equation 3) was determined by the method of Onwuka [13]. A 10 ml capacity graduated measuring cylinder was weighed and gently filled with the sample followed by gently tapping the bottom until there was no further diminution of the sample level after filling to the 10ml mark. The bulk density was calculated as (equation 3):

$$ulk\ density\ (\frac{g}{ml}) = \frac{weight\ of\ sample}{volume\ of\ sample} \qquad \text{equation 3}$$

Water absorption capacity

Water absorption capacity was determined the method of Onwuka [13]. A 1 g of sample was weighed into 15 ml centrifuge tube and suspended with 10 ml of distilled water. The tube with the mixture was shaken on a platform tube rocker for 1 minute at room temperature. The sample was allowed to stand for 30 minutes and centrifuged at 1200 x g for 30 minutes. The volume of free water was read directly from the tube. Water absorption capacity was calculated as shown (equation 4):

$$WAC(\%) = amount\ of\ water\ added - free\ water \times density\ of\ water \times 100 \frac{1}{weight\ of\ sample}$$

Gelatinization temperature

Onwuka [13] method was also used for determination of gelatinization temperature. A suspension containing 10% of the flour sample was prepared with a test tube. The aqueous suspension was heated in a boiling water bath with continuous stirring. Gelatinization temperature was determined and recorded 30 seconds after gelatinization was visually observed.

Apparent viscosity measurement of the flour dispersions

Viscosity (equation 5) measurements was carried out at room temperature (28°C ± 0.5) using a Brookfield Viscometer (Model RVTDV II, Brookfield Engineering Laboratories, Inc., Stoughton, MA, USA). Spindle number two (2) was used for the measurement. Viscometer probe bearing the spindle was immersed in a beaker (250ml) containing 200ml of the sample dispersion and was arranged to shear the dispersed sample at the spindle rotational speed of 60rpm. The concentration of sample was 20% (w/v) and heating stress was employed on each sample at varying temperatures of 70, 75, 80, 85, 90, 95 and 100°C, respectively. Triplicate measurements were made in each treatment.

$$Apparent\ viscosity\ (\mu a) = \frac{shear\ stress\ (\tau)}{shear\ rate\ (\gamma)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots..equation\ 5$$

Determination of pasting properties of flour samples

Pasting properties of flours were determined using Rapid Visco Analyser (RVA) series 4 (New Scientific P.V.T Ltd, Australia) with the aid of Thermocline for windows version 1.1 software, 1996). The 12 minutes profile was used and time-temperature regime used was an ideal temperature of 50°C for 1 minute. Samples were heated from 50-95°C in 3 minutes 45 seconds period, held at 95°C for 2 minutes 10 seconds, then cooled to 50°C over a 3 minutes 45 seconds period followed by a period of 2 minutes when temperature was held at 50°C (Newport Scientific, 1996).

Microbial analysis (Total viable and mould counts) of the flour samples

Total viable count of each sample was determined using method described in Prescott *et al*. [14]. One gram (1 g) of the sample and 9 ml of ringer solution were used to make serial dilutions up to 10^{-3}. The diluted sample was pipetted into a marked Petri dish. 15 ml of prepared nutrient agar solution was added; the solution was swirled to mix and incubated at the temperature of 37°C [15] for 24 hours. After incubation, the number of colonies was counted and represented as colony forming unit per gram (cfu/g).

Mould count determination for the samples was done according to the method described by Prescott *et al.* [14]. The media used was Sabouraud dextrose agar. 15 ml of Sabouraud dextrose agar solution was added to one (1) gram of sample in the Petri dish. It was thoroughly mixed and allowed to set before incubating at temperature of 37°C for 48 hours. After incubation, the number of colonies was counted and represented as colony forming unit per gram.

Sensory evaluation

Cooked paste from the mixed flours with control; and okra soup were prepared and used to carry out sensory testing comprising 20 untrained panellists selected from final year students of the Department of Food Science and Technology. The 9-point Hedonic scale was used where 9 represent 'liked extremely' and 1 stands for 'disliked extremely' [10]. Sensory attributes evaluated for the cooked paste include; colour, finger feel, flavour, swallow-ability, spread-ability, mould-ability and overall acceptability. Flat ceramic plates and bowls were used to serve the panellists and potable bottled water was kept for the judges to rinse mouths in between testing.

Data analysis

Data collected were subjected to a one-way analysis of variance as described by Obi [16] and Means were separated using least significant difference. The SPSS (Statistical product solution services) software package version 20.0 was used. Significance was accepted at $p<0.05$.

Results and Discussion

Proximate composition of the control and blended flour samples

Figure 1 shows the proximate composition of the blended flour samples and the control. Moisture contents of the composite flours varied between 6.15 and 9.07%. This highlights the level of dryness of the samples and has implications on the keeping quality of the flours. Hence, values obtained fell within the range allowed for flours (<10%) according to SON [17]. Ash content differed significantly ($p<0.05$) and ranged from 0.5-2.5% among the blends. This indicates that blended flours were fair sources of some of the minerals. However, sample B (2.5%) has higher amount of ash than other blends. Enwere [11] also reported ash content range of 0.7-2.1% for specie of water yam studied in Nigeria. Crude fat content of composite flours ranged from 0.79-1.05%, while that of water yam flour was 0.17%. The low-fat contents of the flour blends could be an advantage to prevention of rancidity in the flours during storage and availability of cooked paste with low fat composition suitable for obese and diabetes Miletus Type 2 individuals. Enwere [11] reported a range of 0.1- 0.3% fat content for species of water yam studied.

There were significant ($p<0.05$) differences in crude protein composition of the mixed flours that varied between 2.1 and 3.6% for samples with more water yam flour inclusion. Protein content within 4.30-11.95% was obtained for water yam in earlier studies of Baah *etal*. [9] and Lebot et *al*. [18], while Enwere [11] reported 1.1 to 2.8% for the species verified. Findings of Woolfe (1987) on potatoes suggested that variations could be due to genetic composition of the varieties and environmental conditions. Fibre contents of the blended flours differed significantly ($p<0.05$) and ranged from 2.10-3.88% for samples that had higher amount of water yam flour inclusion than whole wheat meal flour. Sample D has highest crude fibre content (3.88%) among all the flour mixtures. Regular consumption of dietary fibre has been known to prevent colon cancer as it acts as roughages and increases feacal bulk and lowers plasma cholesterol, among others [19]. Hence,

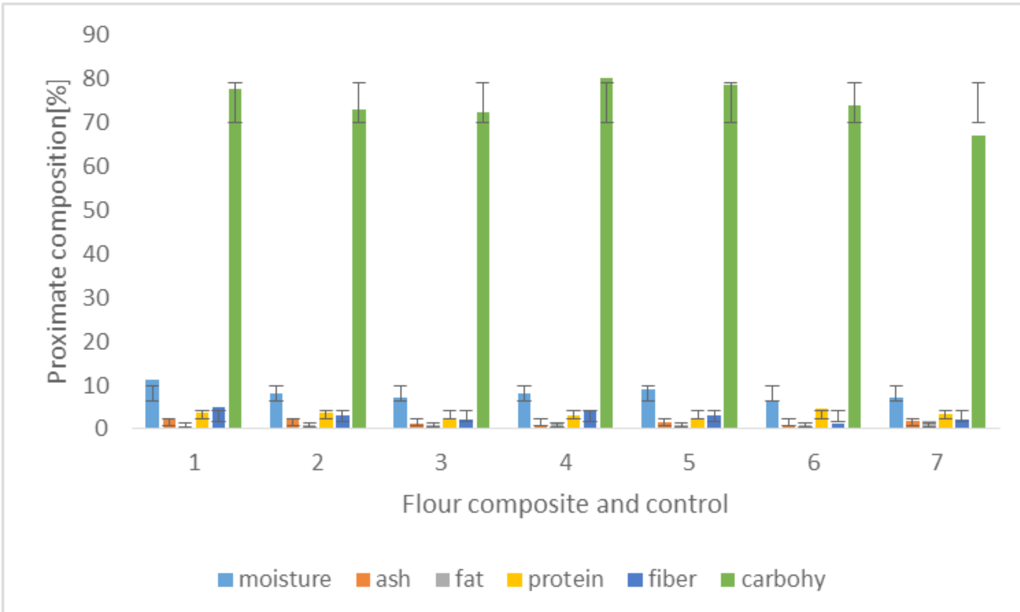

Figure 1: Proximate composition of water yam-wheat composite flours.

Key: A [1]-100% water yam flour; (B [2]-80:20, C [3]-60:40, D [4[-50:50, E [5]-40:60, F [6]-20:80 Water yam flour: Whole wheat meal flour, respectively), G [7]-100% commercial whole wheat meal flour.

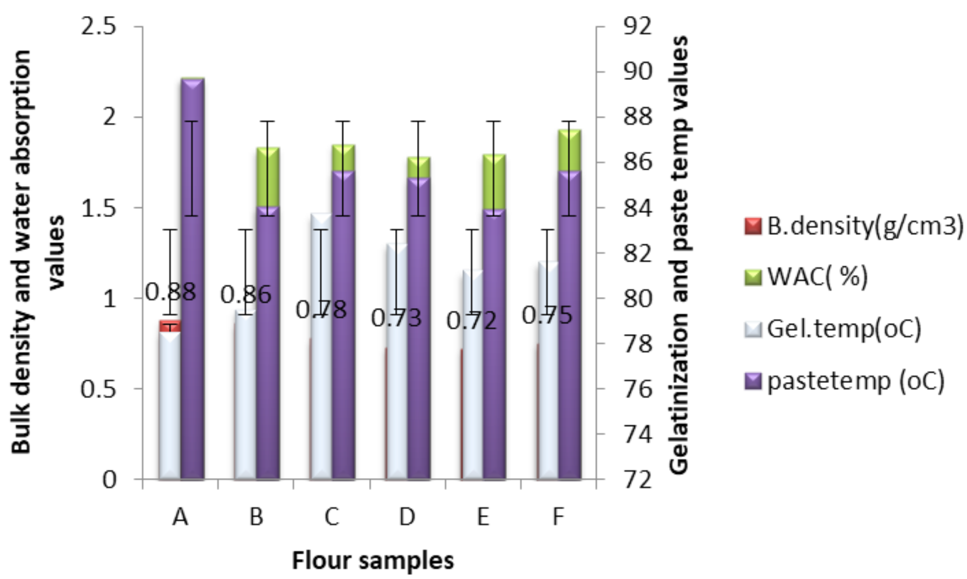

Figure 2: Selected functional properties of water yam-wheat meal composite flours.

Key: A-100% water yam flour; (B-80:20, C-60:40, D-50:50, E-40:60, F-20:80; Water yam flour: Whole wheat meal flour, respectively) this blend might give rise to cooked paste that would benefit the health of the aged (70 years and above) than other end-users.

Values for total carbohydrates of the flour blends ranged from 72.0-80.0%. Carbohydrate composition of all samples were significantly ($p<0.05$) higher than all other nutrients analyzed for the samples. Flour contains high proportion of starch, which is a form of complex carbohydrate and tuber crops such as yams are quite rich in starch, accounting for 60-89% [20]. Similarly, Baah et *al*. [9] reported 78.30% for starch on water yam species from Nigeria. Therefore, blending of water yam flour with carbohydrate content of 77.70% and whole wheat meal flour has given rise to high carbohydrate composition for all the mixtures. Sample D with equal flour blends has 80.0% carbohydrate composition. This is of an advantage to the final cooked paste because starch is a dominant factor in determining the physicochemical, rheological and textural properties of yam products [9].

Functional properties of the flour mixtures and control

Figure 2 shows functional properties of the flour samples. Bulk density of the composite flours varied between 0.72 and 0.86%. Hence, there were no significant ($p>0.05$) differences in this property among all samples and indicated that all could have similar packaging characteristics [21]. Bulk density is an indication of the porosity of the blended flour samples. Water absorption capacity of the samples ranged from 1.78-1.85%, while that of water yam flour (control) was 2.10%. Water absorption capacity represents the potential of a product to associate with water under conditions where water is limited [22]. There were no significant ($p>0.05$) differences in water absorption capacity among all the composite flours. This might indicate that all the flour blends interacted similarly with water during testing. Water absorption capacity can be used to evaluate physicochemical properties of carbohydrates in product development involving soups, baked products, among others [23].

Gelatinization temperature in all the flour blends had significant ($p<0.05$) differences as presented in Figure 2 (79.50-83.7^{o}C) and indicated effect of heat on the flour dispersions. Gelatinization as a chemical reaction and transition phase is a process that breaks down the intermolecular bonds of starch molecules in the presence of water and heat [24]. When starch is heated in the presence of excess water it undergoes this transition phase and there is a characteristic temperature range for gelatinization corresponding to each starch type. It occurs when water diffuses into the granule, which then swells due to hydration of the amorphous phase causing loss of crystallinity and molecular order. The more the molecules are ordered the higher the temperature of gelatinization. Sample C (60:40) had highest value of gelatinization temperature (83.70^{o}C) among others. However, addition of graded levels of whole wheat meal to water yam flour gave rise to increase in temperature of gelatinization.

The pasting temperature of samples B and E values were similar, approximately 84.0^{o}C, while gelatinization temperatures relatively differed (Figures 2 and 4). The difference could be due to less inclusion of water yam flour than whole wheat meal flour used during study period that might have higher fibre and other components more than commercial sample. Research findings of Baah *et al*. [9] on *D. alata* varieties indicated that high dietary fibre and other components could be a challenge to potential of their starch granules to swell freely and form stable viscous paste. From physical examination of the wheat meal flour utilized during study period, it was observed that a difference existed in colour that was deep-dark brown with more rough texture as determined by finger-feel than commercial wheat meal flour.

Selected micronutrients of the composite flours

Values for selected micronutrients are displayed in Figure 3 and ranged from 3.40-3.90 mg/100g for vitamin C; 0.33-0.50 mg/100g for B1 and 1.22-1.50 mg/100g for Iron, among all blended samples. Results showed that the flour blends were fair sources of vitamin C and iron but a poor source of vitamin B1. Vitamin C is known as a strong antioxidant capable of protecting the body system even though is very heat labile, while Iron is required for the proper functioning of the human blood. There were no significant ($p<0.05$) differences in B1 composition of all the blended samples. The B and D samples had higher amount of vitamin C, an antioxidant than other composite flours.

Effect of temperature changes on apparent viscosity of flour dispersions

Figure 4 shows effect of temperature changes (70, 75, 80, 85, 90, 95 and 100^{o}C) on apparent viscosity of the sample dispersions (20% w/v). Values obtained varied between 230.20 and 559.10 mPa.s for all flour blends, while water yam flour dispersion recorded 625.20mPa.s. Viscosity is simply resistance to flow by any given fluid or as regarded industrially; consistency of a food product at any given condition. However, apparent viscosity represents viscosity of a Newtonian fluid that shows resistance to flow at the chosen rate of shear. Values displayed in Figure 3 indicated that as the heating temperature was increased, apparent viscosity increased which were characteristics of shear thickening or dilatants fluids. This could be that at the operational shear rate (60 rpm), water was squeezed out between starch molecules in such a way as to encourage more strong interactions between solid-solid and solid-solvent particles. Sample B (80:20) had higher increasing viscosities (497.20-559.10 mPa.s.) as the temperature increased among the blended flours. Viscosity of a starch-flour dispersion primarily depends on the extent of gelatinization of the dispersion, while pasting temperature practically represents that at which viscosities increase by at least 24 mPa.s over 20 seconds period. It is an indicator to the temperature required to cook flour dispersions beyond gelatinization point. However, research findings of Baah *et al*. [9] on *D. alata* varieties indicated that high dietary fibre and other components could cause reduction to potential of starch granules to swell freely and form stable viscous paste. Nevertheless, relatively well-cooked paste is determined between suitable time of cooking, gelatinization and pasting temperatures in addition to sensory attributes [25].

Pasting properties of flour dispersions

Figure 5 shows pasting characteristics of flour dispersions. The

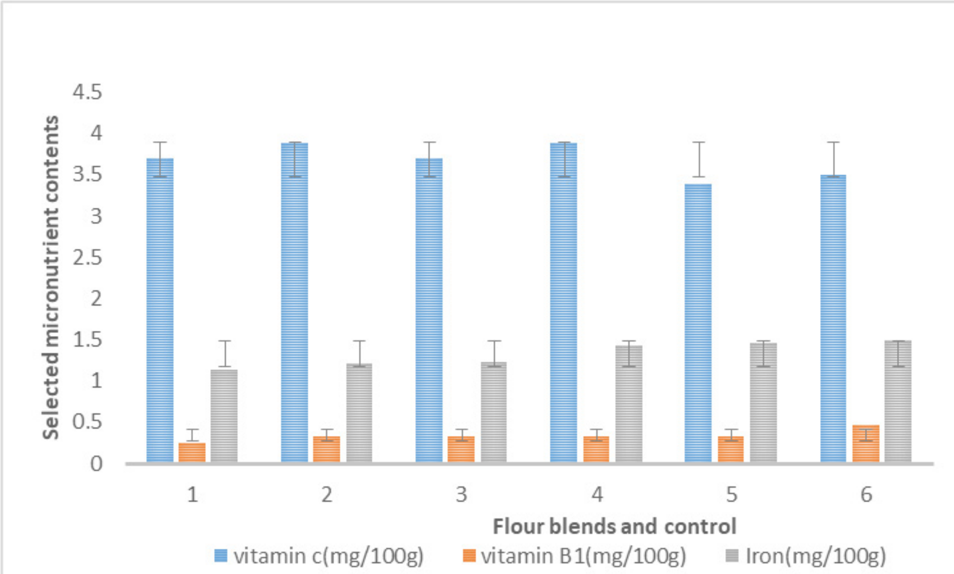

Figure 3: Selected micronutrient composition of the composite flours.

Key: A [1]-100% water yam flour; B [2]-80:20, C [3]-60:40, D [4]-50:50, E [5]-40:60, F [6]-20:80 (Water yam flour: Whole wheat meal flour, respectively)

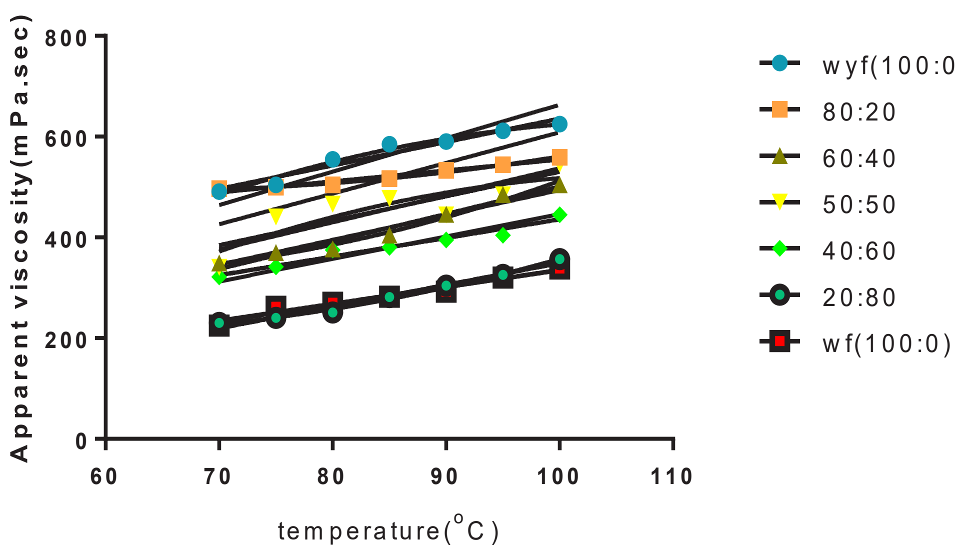

Figure 4: Changes in apparent viscosities of flour dispersions (20%w/v) with increasing temperature.

WYF-water yam flour; WWF-commercial whole wheat meal flour

Key: A-100% water yam flour; (B-80:20, C-60:40, D-50:50, E-40:60, F-20:80 Water yam flour: Whole wheat meal flour, respectively), G-100% commercial whole wheat meal flour.

properties are relevant in determining product performance and have effect on sensory properties of the food products in which yams are incorporated. Peak viscosity of the composite flours varied between 991.50 and 1075.00 RVU and showed that blending had effect on the flour samples. Viscosity is an indicator of the ability of the starch granules from the flour to swell freely before their physical breakdown. Samples B and E had higher values for peak viscosity indicating the ability of their starch-dispersions to swell freely and develop maximum viscosity at the onset of heating the flour dispersions. However, values obtained were higher than that for *D. alata* varieties from those recorded by Wireko-Manu *et al*. [26].

Trough viscosity ranged from 717.00-856.00 RVU for all the blended flours. It is the minimum viscosity value in the constant temperature phase of the Rapid Visco-Analyzer and measures the potential of a paste to withstand breakdown during cooling [27]. Sample B had lowest values, while C had the highest value among all blended samples. Values of breakdown viscosity for all blends also varied between 141.50 and 363.00 RVU. This pasting behaviour is used to determine the ability of flour dispersion to withstand heating and shear stress during cooking. Hence, it is an index of the stability of starch. Higher breakdown viscosity values show lower ability of sample to withstand heating and shear stress during cooking [28]. Therefore, sample B had lower ability to form stable dough during cooking than other blends while C had higher potential.

Final viscosity of the composite flours ranged from 1220.50-1454.50 RVU. This is a change in viscosity after cooling the cooked paste and one of the most common parameters used to define quality of a particular starch-based sample. It indicates the ability of the dispersion to form a viscous paste or gel after cooling cooked paste, as well as the resistance of the paste to shear force during stirring [29,30]. Sample B has the highest value among all blended samples. Setback viscosity value also ranged from 482.50-737.50 RVU. It is the recovery of the viscosity of the heated starch-flour suspension during cooling [31]. Starches with high setback viscosity would tend to have stiffer pastes, but are susceptible to weeping when used as filling in frozen product application [32]. The blends had higher setback values than water yam flour. Generally, the tendency of yam starch pastes to retrograde could be a limiting factor for its use in food industries. The lower setback observed for water yam flour samples in this study suggests that its flour is relatively more stable when cooked and will have a lower tendency to undergo re-progradation during freeze and thaw cycles than wheat flour. Sample C cooked paste had lower setback value than other blends.

Pasting temperature values ranged from 83.95-85.60°C for the flour blends that were cooked within 5.0 to 5.33 minutes, while water yam flour was cooked within 7.00 minutes. Water yam flour had also highest pasting temperature (89.7°C) and underscores the reports from previous findings that water yam starch was made up of mainly amylose [26,32]. There were no significant ($p>0.05$) differences among blended samples in the peak time. Hence, blending in the present study has an advantage of saving time of cooking for all the flour blends.

Dependency of apparent viscosity on temperature

Effect of temperature on apparent viscosity of all flour dispersions was modeled using Arrhenius type of equation (Equation 6) since gelatinization is a type of chemical reaction that takes place as viscosity of flour dispersions changes with temperature/heating stress [34].

$$K = Ao\, e^{-Ea/RT} \qquad 6$$

K represents apparent viscosity at the heating stress and shear rate; A_o (consistency factor) is a constant, an important rheological parameter for non-Newtonian fluids (Pas^n). Ea is the flow activation energy (J/mol), R is the universal gas constant (J/mol/K), and T is the absolute temperature in Kelvin, K. In Arrhenius equation, A_o, stands for total number of collisions that may or may not lead to reaction per second, while $e^{-Ea/RT}$ represents probability that any given collision may result to a reaction. Increasing the temperature or decreasing the energy of activation will result to increase in the rate of reaction. Similar description on effect of temperature on apparent viscosity at constant shear rate based on Arrhenius equation was given by Rao [35]. Values obtained for the Ao that represented pre-exponential factor in Table 1 for all the flours equaled 1.007 and could indicate that the flour dispersions had similar reaction frequency factor. Hence, similar collisions existed for the sample particle interactions during gelatinization process.

However, minimum energy of activation required for gelatinization to take place increased with more addition of water yam flour into the blend. Sample B had lowest minimum activation energy required for gelatinization to take place among blended samples and the Ea increased with more inclusion of water yam flour. Among the blends with less inclusion of water yam flour, sample E (40:60) has the lowest minimum E_a. Activation energy is the minimum energy required for reaction to take place in a system. The coefficient of determinant, R^2, for the various regression

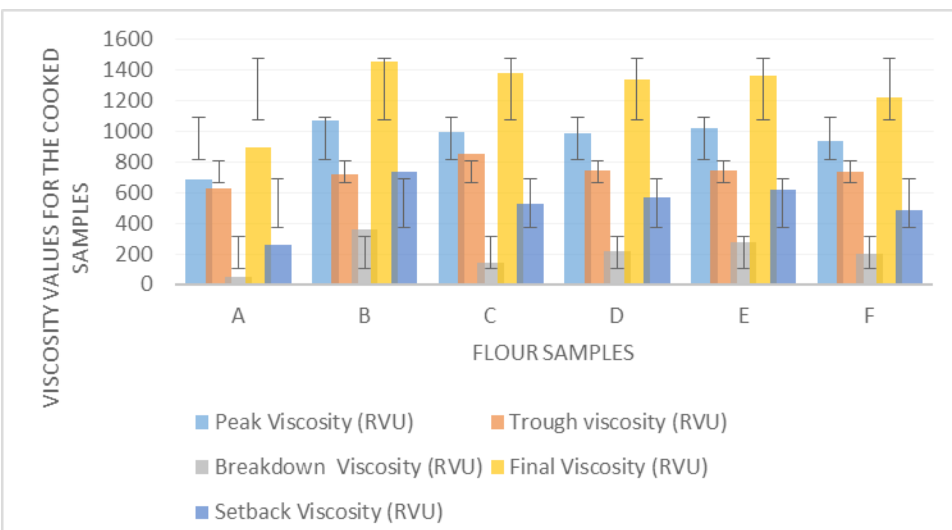

Figure 5: Pasting characteristics of flour samples during cooking.

Key: A-100% water yam flour; (B-80:20, C-60:40, D-50:50, E-40:60, F-20:80; Water yam flour: Whole wheat meal flour, respectively), G-100% commercial whole wheat meal flour models of plotting log apparent viscosity against log of reciprocal of temperature/heating stress (from Arrhenius-type equation 6), indicated good fit for the relationship that existed between apparent viscosities (mPa.s) and temperature (°C)- (Table 1). Results in Table 1 should also be correlated with Figure 6 in terms of the values of the slope that equaled to, $-E_a/R$, as either more of water yam flour is increased or decreased in the mixture. From Table 1 and Figure 6, one could deduce that in terms of saving energy cost, samples B and E were better among other blended flour samples.

Table 1: Parameters of Arrhenius-type equation for apparent viscosity dependency on temperature for the starch-flour dispersions (20% w/v).

Samples WYF: WMF	A_0	$-E_a$ (KJ/mole	Coefficient of fit (R^2)
A (100%)	1.007	2.75	0.95
B (80:20)	1.007	2.08	0.94
C (60:40)	1.007	4.89	0.96
D (50:50)	1.007	6.13	0.74
E (40:60)	1.007	4.81	0.97
F (20:80)	1.007	7.85	0.92
G (100%WWF)	1.007	9.06	0.94

WYF-water yam flour; WMF-whole wheat meal flour; WWF-commercial whole wheat meal flour; A0 (Reaction/Cooking frequency factor); Ea (activation energy).

Total viable and mould counts of the flour samples

The total viable and mould counts of the flour blends are presented in Table 2. The values ranged from 2.02×10^2 -2.72×10^2 and 1.10 $\times10^2$ - 2.00×10^2 CFU/g, respectively, for all blended samples. All the values were within acceptable limit ($<10^5$) according to Anonymous [36]. Consequently, the flour samples were processed under hygienic conditions and safe for human consumption [37].

Table 2: Total viable and mould counts of the flour samples.

Flour blends (WYF:WF)	Total viable counts (CFU/g)	Mould Counts (CFU/g)
A (100:00)	2.52×10^2	1.9×10^2
B (80:10)	2.21×10^2	1.1×10^2
C (60:20)	2.41×10^2	1.5×10^2
D 50:50)	2.4×10^2	2.2×10^2
E (40:60)	2.02×10^2	1.0×10^2
F (20:80)	2.72×10^2	2.0×10^2
G (100:00)	2.63×10^2	$1.1x10^2$

Key: A-100% water yam flour; (B-80:20, C-60:40, D-50:50, E-40:60, F-20:80 Water yam flour: Whole wheat meal flour, respectively), G-100% commercial whole wheat meal flour.

Sensory scores of the cooked pastes

Scores for the sensory attributes of cooked pastes are shown in Table 3. Sample B (80:20) cooked paste had higher scores (6.70-7.00) in attributes such as colour, flavour, mould-ability, swallow-ability than others but no significant (p>0.05) difference existed between it and sample D in the scores for finger feel and spread-ability. Also, there were no significant (p>0.05) differences in the overall acceptability of samples B, C and D.

Conclusion

The study showed that in proximate composition, sample B (80:20) had higher amount of ash than others but all the samples

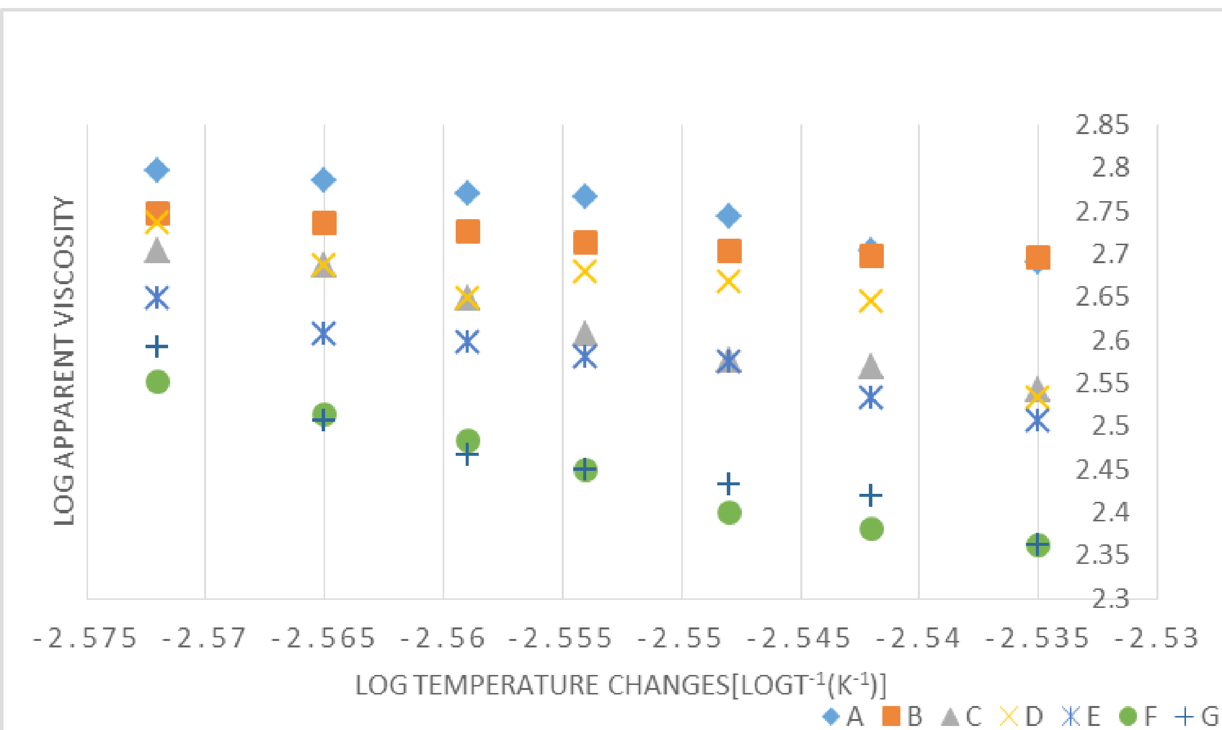

Figure 6: Effect of temperature on apparent viscosity of all flour dispersions (20% (w/v)) based on Arrhenius-type equation.

Key: A-100% water yam flour; (B-80:20, C-60:40, D-50:50, E-40:60, F-20:80; Water yam flour: Whole wheat meal flour, respectively), G-100% commercial whole wheat meal flour.

Table 3: Sensory scores of the cooked paste.

Samples (WYF:WMF)	Colour	Flavour	Finger feel	Spread-ability	Mould-ability	Swallow- ability	Overall acceptability
A (100:00)	$5.66^c \pm 2.0$	$7.0^a \pm 2.0$	$6.51^a \pm 1.1$	$6.20^a \pm 1.5$	$5.90^b \pm 0{,}1$	$6.65^b \pm 2.0$	$6.30^a \pm 2.1$
B (80:20)	$6.71^b \pm 1.0$	$6.75^b \pm 1.0$	$6.25^a \pm 1.3$	$6.70^a \pm 1.1$	$5.90^b \pm 1.0$	$7.00^a \pm 2.0$	$6.39^a \pm 2.1$
C (60:40)	$5.7^c \pm 1.1$	$6.05^b \pm 2.1$	$5.81^b \pm 2.2$	$5.55^b \pm 1.9$	$5.35^b \pm 2.0$	$6.35^b \pm 1.8$	$6.55^a \pm 1.6$
D (50:50)	$6.35^b \pm 2.2$	$6.40^b \pm 1.1$	$6.25^a \pm 1.0$	$6.70^a \pm 1.5$	$5.35^b \pm 0.3$	$6.35^b \pm 1.8$	$6.55^a \pm 1.6$
E (40:60)	$6.75^b \pm 1.3$	$6.25^b \pm 1.2$	$5.45^b \pm 2.0$	$5.45^b \pm 2.3$	$4.08^b \pm 2.0$	$5.85^c \pm 2.4$	$5.80^b \pm 2.4$
F (20:80)	$4.65^d \pm 2.0$	$5.35^c \pm 1.0$	$5.75^b \pm 2.0$	$5.90^b \pm 2.1$	$5.41^b \pm 3.2$	$5.80^c \pm 1.9$	$5.35^b \pm 2.0$
G (100:00)	$7.10^a \pm 2.4$	$6.51^b \pm 2.2$	$5.55^b \pm 3.1$	$5.23^b \pm 2.6$	$5.10^b \pm 3.1$	$5.30^c \pm 2.5$	$5.30^b \pm 25$

Values on the table are means ± SD of triplicate readings. Means with different superscripts in the same column are significantly different ($p< 0.05$). WYF=Water yam flour; WMF= Whole wheat meal flour.

had low fat content, while sample D (50:50) had higher crude fibre content than others. There were no significant ($p>0.05$) differences in the bulk density of composite flours but incorporation of more whole wheat meal flour led to higher gelatinization temperatures that were above that of water yam flour. All the flour samples were fair sources of vitamin C and Iron. Sample B had the highest final viscosity among the blended samples, while no significant ($p>0.05$) differences existed in the peak time. It had also lowest pasting temperature with sample E among the blended samples. All the flour dispersions displayed dilatant fluid characteristics during heating. However, sample B had lowest activation energy (E_a) value required for a suitable cooked paste. It had also gelatinization and pasting temperatures of 79.50 and 84.05°C, respectively; with cooking time of 5.33 minutes. Sample B scored higher (6.70-7.00) in sensory attributes such as flavour, mould-ability and swallow-ability than other samples but no significant ($p>0.05$) differences were observed for samples B and D in finger feel and spread-ability. Overall results indicated that sample B could be consumed as an alternative to whole wheat flour for a nutritional cooked paste than others.

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