

## Effect of pre-treatments on the chemical, functional and storage properties of breadfruit (*Artocarpus altilis*) flour

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### Abstract

Breadfruit pieces were subjected to two different pre-treatments, microwave radiation (2450 Hz) for 40 seconds and steeping in sodium acetate buffer solution pH 3 for 30 minutes, during the production of breadfruit flour as means of stabilizing breadfruit flour quality during storage. The two flour samples with untreated sample (control) were subjected to chemical and functional analyses; the three flour samples were packaged in high density polyethylene and stored for 14 weeks with the following analysis carried out fortnightly; sugar content, swelling power, moisture content, water and oil absorption capacities. Pasting analysis was carried out at six week interval. The results indicated that the treatments did not have any significant effect ( $p \leq 0.05$ ) on the chemical composition of the flour; the control breadfruit sample contained 6.01% moisture, 5.21% protein, 1.92% fat, 2.67% ash, 5.95% fibre and 4.10% sugar. The treatment had significant effect on the functional properties of breadfruit flour ( $p \leq 0.05$ ). The swelling power and water absorption capacity of the control sample, microwave treated sample and sodium acetate buffer pH 3 treated sample were 5.13 g/g and 4.60 ml/g; 5.96 g/g and 4.50 ml/g; 4.84 g/g and 4.20 ml/g respectively. The two treatments especially microwave radiation caused minimal reduction (i.e. had lower percentage reduction) in the swelling power, water absorption capacity and pasting profile of breadfruit flour during storage when compared with control sample; this is desirable in food applications. Treatment with microwave radiation was able to preserve the quality integrity of breadfruit flour during storage better than the treatment with sodium acetate buffer pH 3.

### Keywords

Breadfruit flour,  
Microwave radiation,  
Low pH,  
Storage properties

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### Introduction

Breadfruit (*Artocarpus altilis*) is a seedless, starchy tropical fruit native to the Pacific Islands (Worrell *et al.*, 2002). Breadfruit is a valuable food resource due to its high caloric content with a moderate glycemic index and significant amount of vitamins and minerals. The high carbohydrate content of the fruit makes it a potential staple that could be used to combat hunger and provide food security (Appiah *et al.*, 2011). Breadfruit is consumed unripe and cooked as a starchy staple equaling or surpassing other tropical crops like sweet potato and cassava in protein and carbohydrate contents (Worrell *et al.*, 1998). It has found limited application in food industries (Omobuwajo, 2003) majorly because of its poor post harvest quality. It is known that breadfruit quickly ripen in just 1-3 days after harvesting and can hardly be stored for five days even at that it has to be stored in cool place or under water in order to delay ripening (Ragone, 2006).

A major means of preserving the fruit is to process it into flour which can be used as the starting material for processing through reconstitution with hot or cold water to form paste or dough depending on the type of food products. Breadfruit flour has been used as part of composite flour in the production of bakery products and weaning food (Ijarotimi and Aroge, 2005; Olaoye *et al.*, 2007; Olaoye and Onilude, 2008). However, it has been reported that breadfruit flour does not store well because of certain changes which usually occur during storage, such changes affect the quality of the flour negatively and can limit its utilization for a wide range of food products. Mayaki *et al.* (2003) reported that there was a gradual hydrolysis of starch to sugar during storage of breadfruit flour leading to increase in sugar content and decrease in the swelling power, plastic viscosity and water absorption capacity of the flour during storage. This was thought to be as a result of continuous activity of amylolytic enzyme in breadfruit which was able to survive the drying temperature. Overcoming this problem will enhance

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the storage properties and utilization of the flour in food applications. Effort to take care of this problem by blanching or increasing the drying temperature did not yield a positive result (Mayaki *et al.*, 2003). Literature search revealed that there is dearth of information on the storage properties of breadfruit flour. This paper reports the use of microwave radiation and low pH treatment to stabilize the quality integrity of breadfruit flour during storage. The effect of the two treatments on the chemical and functional properties of the flour was also reported.

## Materials and Methods

### Source of Material

Matured unripe breadfruits were harvested at a local farm in Ile Ife, Osun State, Nigeria.

### Production of Breadfruit Flour Samples

For the untreated control sample, the freshly harvested matured breadfruits were washed with clean water in order to remove dirt and adhering latex, peeled with stainless kitchen knife into sodium metabisulphite solution (100ppm) in order to control browning. The core of the pulp was removed; the pulp was sliced into tiny pieces (1.5 cm x 1.5 cm x 1.5 cm) in order to facilitate drying and then dried in hot air oven (Model DHG 9030A) at 80°C for 9 hours. For the production of microwave treated breadfruit flour, the breadfruit pieces (250 g) were exposed to microwave radiation (2450 Hz) for 40seconds in a plastic container (17 cm x 12 cm x 5 cm) before drying; during this treatment the temperature of the breadfruit pieces was 46±1°C. Treatment with low pH was done by steeping the breadfruit pieces (250 g) in 500 ml sodium acetate buffer pH 3 for 30 minutes at ambient temperature (30±2°C) before drying. The dried breadfruit pieces were then milled into flour with hammer mill and then packaged in high density polyethylene with proper labeling.

### Analysis of chemical properties

Proximate analysis of the three breadfruit flour samples were determined according to the methods described by AOAC (2005), sugar content was determined according to the sulphuric acid-phenol method as described by Dubois *et al.* (1956) and pH was determined according to the method described by Onitilo *et al.* (2007) with the use of pH meter (Starter 2100 Bench pH Meter) which had been previously standardized with buffer solution of pH 4 and 9.

### Analysis of functional properties

Water absorption capacity and oil absorption

capacity were determined at ambient temperature (30±2°C) according to the methods described by Sathe *et al.* (1982); least gelation concentration, foaming capacity and bulk density were determined according to methods described by Onwuka (2005). The least gelation concentration was determined by heating the sample suspension (2 – 20%) for 1 hour in boiling water (100°C) followed by cooling for 2 hours at 4°C. The swelling power at 60°C was determined according to the method described by Leach *et al.* (1959).

### Storage study

The three breadfruit flour samples packaged in high density polyethylene were stored for 14 weeks under ambient condition (30±2°C) with the following analysis carried out fortnightly: sugar content, swelling power, moisture content, water and oil absorption capacities; methods aforementioned were used for the analysis. Pasting analysis was done at six week interval. The pasting properties were determined using Rapid Visco Analyser (RVA) (Model Rva-3D). 3 g of the sample was turned to slurry by mixing with 25 ml of water; this was then transferred into RVA canister and placed inside the RVA machine. The 12 minutes profile was used with sample heated from 50°C to 95°C and then cooled back to 50°C

### Statistical analysis

The difference in the experimental data was tested for statistical significance  $p \leq 0.05$  by Statistical Analysis of Variance (ANOVA) using SPSS 17.0 software package (Statistical Package for Social Scientist, Michigan, USA)

## Results and Discussion

### Chemical properties of breadfruit flour samples

The chemical properties of the three breadfruit flour samples are presented in Table 1. The moisture contents of the three samples fall below the recommended safe level (12% - 13%) for storage of cassava flour (FAO, 1992). All things being equal, this suggests that the samples would have good shelf stability. There was no significant difference ( $p \leq 0.05$ ) in the moisture contents of the three samples. The result also revealed that breadfruit flour contain appreciable amount of protein which can facilitate its use in food systems where functional property of protein is of interest. The protein contents reported for breadfruit flour samples in this work were higher than 4.76%, 4.63% and 4.54% reported for white yam flour (*D. rotundata*), cocoyam flour (Adegunwa

Table 1. Chemical composition of control and treated breadfruit flour samples

Composition	Untreated Flour (Control)	Flour Treated with Buffer pH 3	Flour Treated with Microwave Radiation
Moisture (%)	6.01 ± 0.40 <sup>a</sup>	5.95± 0.35 <sup>a</sup>	6.14± 0.20 <sup>a</sup>
Protein (%)	5.21± 0.20 <sup>a</sup>	5.35± 0.15 <sup>a</sup>	5.05± 0.05 <sup>a</sup>
Fat (%)	1.92± 0.21 <sup>a</sup>	1.98± 0.20 <sup>a</sup>	1.78± 0.10 <sup>a</sup>
Ash (%)	2.67± 0.20 <sup>a</sup>	2.78± 0.12 <sup>a</sup>	2.82± 0.30 <sup>a</sup>
Fibre (%)	5.95± 0.15 <sup>a</sup>	5.67± 0.20 <sup>a</sup>	5.60± 0.40 <sup>a</sup>
Carbohydrate (%)	78.24± 0.30 <sup>a</sup>	78.27± 0.23 <sup>a</sup>	78.61± 0.50 <sup>a</sup>
Sugar (%)	4.10± 0.10 <sup>a</sup>	4.10± 0.20 <sup>a</sup>	4.31± 0.20 <sup>a</sup>
pH	5.95± 0.02 <sup>a</sup>	5.65± 0.02 <sup>b</sup>	6.00± 0.03 <sup>a</sup>

Means of triplicate determination ± standard deviation

Values in the same row with different superscript are significantly different ( $p \leq 0.05$ )

*et al.*, 2011) and plantain flour (Abioye *et al.*, 2011) respectively. It was however lower than 12.82% and 12.45% reported for wheat flour (Arisa *et al.*, 2013) and jackfruit seed flour (Eke-Ejiofor *et al.*, 2014) respectively. The range of fibre content reported in this work was higher than 4.40% reported for plantain flour (Arisa *et al.*, 2013), 4.52% and 0.30% reported for breadnut and wheat flour respectively (Malomo *et al.*, 2011), these differences may be due to biological characteristics of the crop and the kind of sieves used during the production of the flour.

The fat contents of the three breadfruit flour samples were relatively low and this may be of advantage as relatively high fat content could be undesirable because it can lead to development of unpleasant odorous compounds during storage. The treatment appears to have no significant influence ( $p \leq 0.05$ ) on the ash content of breadfruit flour; however, sample treated with microwave radiation had the highest while control sample had the lowest. The ash content of breadfruit flour, which is indicative of the amount of mineral element in the flour, was higher than 0.61% reported for wheat flour (Malomo *et al.*, 2011) but comparable with 2.77% reported for white yam (*D. rotundata*) flour (Adegunwa *et al.*, 2011). The sugar contents of the microwave treated flour was marginally but un-significantly higher ( $p \leq 0.05$ ) than that of other two samples, this may be due to marginal dextrinization of starch during the treatment. The sugar content of breadfruit flour was higher than 1.92% reported for rice by Eke-Ejiofor *et al.* (2011). There was significant difference ( $p \leq 0.05$ ) in the pH of the three flour samples with sample treated with sodium acetate pH 3 having the lowest; this was obviously because of the treatment. These results established the fact that the two treatments did not have any significant negative effect ( $p \leq 0.05$ ) on the proximate profile of breadfruit flour and so can be adopted as pre-treatments to stabilize the quality of breadfruit flour during storage.

#### Functional properties of breadfruit flour samples

The functional properties of the breadfruit flour samples are presented in Table 2. Functional properties determine the application of food materials in food systems. The swelling power of the untreated control breadfruit flour was higher than 2.22 g/g reported for trifoliolate yam flour (Abiodun *et al.*, 2014) but lower than 13.80 g/g reported for cassava flour (Kusumayanti *et al.*, 2015). This difference may be due to variation in the chemical composition of different food materials, it is known that swelling power of flour samples is often related to their starch and protein contents (Aprianita, 2009) and the ratio of amylose and amylopectin. Treatment with microwave radiation resulted in a significant increase ( $p \leq 0.05$ ) in the swelling power of breadfruit flour. Swelling power indicate the degree of exposure of the internal structure of starch granules to action of water i.e. a measure of hydration capacity (Raules *et al.*, 1993); this may indicate that microwave treatment tend to cause slight aggregation of starch granules and subsequently increase the level of its exposure to water, thereby increasing the swelling power. This will be of advantage because high swelling capacity is an important criterion of good quality flour.

Treatment with sodium acetate buffer pH 3 seems to restrict the water absorption capacity and swelling ability of breadfruit flour even though the reduction in swelling power caused by this treatment was not significant ( $p \leq 0.05$ ) when compared with the untreated control sample. This slight reduction may be due to the reinforcement of the crystalline nature of starch granules and the associative binding forces within the starch granules by the low pH treatment. It is known that molecules that are low in pH preferably attack the amorphous region of the starch granule and disrupts it, which subsequently results in relatively higher crystallinity of starch granule and thus restrict its swelling (Khan *et al.*, 2014). Sanni *et al.* (2004) had also reported that the swelling power of starch granules reflects the extent of associative forces

Table 2. Functional properties of control and treated breadfruit flour samples

Functional Properties	Untreated Flour (Control)	Flour Treated with Buffer pH 3	Flour Treated with Microwave Radiation
Swelling Power (g/g)	5.13± 0.10 <sup>b</sup>	4.84± 0.20 <sup>b</sup>	5.96± 0.30 <sup>a</sup>
Foaming Capacity (%)	8.00± 0.40 <sup>a</sup>	5.00± 0.20 <sup>b</sup>	2.00± 0.00 <sup>c</sup>
Least Gelation Concentration (% w/v)	12.00± 0.00 <sup>a</sup>	10.00± 0.00 <sup>b</sup>	12.00± 0.00 <sup>a</sup>
Water Absorption Capacity (ml/g)	4.60± 0.20 <sup>a</sup>	4.20± 0.10 <sup>b</sup>	4.50± 0.20 <sup>ab</sup>
Oil Absorption Capacity (ml/g)	2.20± 0.10 <sup>a</sup>	1.90± 0.00 <sup>b</sup>	1.60± 0.10 <sup>c</sup>
Bulk Density (g/ml)	0.59± 0.02 <sup>b</sup>	0.61± 0.01 <sup>b</sup>	0.79± 0.03 <sup>a</sup>

Means of triplicate determination ± standard deviation

Values in the same row with different superscript are significantly different ( $p \leq 0.05$ )

within the granules: the higher the swelling power, the lower the associative forces.

Water absorption capacity is a very important functional property of flour sample in food preparation. The water absorption capacity of the untreated breadfruit flour was higher than 1.25 ml/g and 1.93 ml/g reported for plantain flour (Arisa *et al.*, 2013) and trifoliate yam flour (Abiodun *et al.*, 2014) respectively. The high water absorption capacity of breadfruit flour suggests that it will contribute positively to yield and consistency during food preparation. High water absorption capacity had been reported to improve yield and consistency, and give body to food (Osundahunsi *et al.*, 2003). There was no significant difference ( $p \leq 0.05$ ) in the water absorption capacity of untreated flour and microwave treated flour samples however treatment with low pH caused a significant reduction ( $p \leq 0.05$ ) in the water absorption capacity of breadfruit flour. This pattern of result correlates with the result of swelling power where sample treated with pH 3 had the lowest swelling power. The slight un-significant difference ( $p \leq 0.05$ ) between the water absorption capacities of control and microwave treated samples suggests that microwave only cause a slight increase in starch damage content; low water absorption capacity of flour has been attributed to starch damage (Mayaki *et al.*, 2003). Water absorption capacity of 1.25 ml/g and above is an indication of good bakery property (Giarni and Alu, 1993), the three samples of breadfruit flour in this study with water absorption capacity above 1.25 ml/g would therefore be a good starting material for bakery products.

The oil absorption capacity of untreated breadfruit flour was comparable to 2.30 ml/g of jackfruit seed flour (Odoemelam, 2005) but higher than 1.90 ml/g reported for lesser yam flour (Ukpabi, 2010). The oil absorption capacity of breadfruit flour suggests that it may find useful application in food products such as cake, soups and ground meat formulations. The

treatment also reduced the oil absorption significantly with the microwave treated sample having the lowest (1.60 ml/g). Oil absorption capacity of food materials is important because oil (fat) helps to retain flavour, improve mouthfeel and provide feeling of satiety.

The foaming capacity which is the ability of solution of a food material to produce foam after vigorous shaking, stirring or whipping, is essentially dictated by protein content. The foaming capacity of untreated breadfruit flour was higher than 2% reported for plantain flour (Mepba *et al.*, 2007) but lower than 15.33% reported for yellow water yam (*D. alata*) flour (Harijono *et al.*, 2013) The differences in the foaming capacity is as a result of different protein content and protein types in the aforementioned flour samples. Eltayeb *et al.* (2011) reported that soluble protein can reduce surface tension at interface between air bubbles and surrounded liquid. The treated breadfruit flour samples have lower foaming capacity when compared with the control sample. This reduction may be due to denaturation of protein and change in viscosity and pH as a result of treatment with microwave radiation and sodium acetate pH 3. Morr (1990) reported that foam formation and stability depend of pH, viscosity and surface tension. This suggests that treatment of breadfruit with microwave radiation and buffer pH 3 during the production of breadfruit flour may limit its utilization as foaming agents in food systems.

The bulk density of untreated breadfruit flour, 0.59 g/ml, was higher than 0.49 g/ml reported for plantain flour (Arisa *et al.*, 2013) but lower than 0.61 g/ml reported for jackfruit seed flour (Odoemelam, 2005). Treatment with microwave radiation and sodium acetate buffer pH 3 increased the bulk density to 0.79 g/ml and 0.61 g/ml respectively, this suggest that these treatments caused displacement of the internal air space within the material which resulted in the reduction of dried breadfruit pieces into finer particle during milling when compared

with untreated sample. Bulk density has implication in the packaging and transportation of food materials; high bulk density products are known to exhibit better packaging properties than those with low bulk density. High bulk density is desirable in that it offers greater packaging advantage as greater quantity may be packaged within a constant volume (Fagbemi, 1999).

The least gelation concentration is an index of gelation and it defines the lowest sample concentration at which gel remained in the inverted tube without falling. It influences the texture of food such as agidi and soup (Udensi, 2001). The least gelation concentration of the sample treated with sodium acetate buffer pH 3 was significantly different ( $p \leq 0.05$ ) from that of the other two samples. The lower the least gelation concentration the higher the ability of the flour to form stable gel (Olapade and Adetuyi, 2007). The relatively low least gelation concentration of breadfruit flour may qualify it as a gel forming agent or as an additive to other gel forming materials in food products such as pudding, soup; however, it may not be suitable for infant formulation because of the need for more dilution which would result in reduced energy and nutrient density. The result of functional properties established the fact that the two treatments improved some functional properties however the foaming capacity of the flour was negatively affected by the treatments.

#### *Storage properties of breadfruit flour samples*

Changes in the sugar content, swelling power, water absorption capacity, oil absorption capacity, and moisture content of the three breadfruit flour samples during storage are presented in Table 3. There was a gradual increase in the sugar content of control sample from 4.10% to 5.82% at the end of the storage period. This observation was consistent with the report of Mayaki *et al.* (2003) who reported an increase in the sugar content of breadfruit flour as a result of the continuous activity of starch hydrolyzing enzyme which was not completely inactivated during processing and was still active during flour storage. The breadfruit flour sample treated with sodium acetate pH 3 which initially had 4.10% sugar content before storage only slightly increased throughout the storage period to 5.39%. This result when compared with that of control sample suggests that the treatment was able to slightly restrict the activity of the amylolytic enzyme during storage; this may be due to change in the configuration of enzyme protein molecule brought about by ionization.

Even though the microwave treated breadfruit flour had the highest initial sugar content, its sugar

content was however the lowest and was significantly different ( $p \leq 0.05$ ) from the sugar contents of the other samples at the end of the storage period. This result showed that microwave radiation was able to strongly restrict the hydrolysis of starch to sugar which reflect its inhibitory effect on the amylolytic enzyme and prevent its continuous activity during storage. The effect of microwave radiation on the breadfruit amylolytic enzyme in this work was thought to be majorly of non thermal since the exposure time (40 seconds) used in this work did not allow a substantial generation of heat as reflected in the temperature ( $46 \pm 1^\circ\text{C}$ ) of breadfruit pieces treated with microwave radiation. Microwave radiation is known to have both thermal and non thermal effect on biomolecules (Porcelli *et al.*, 1997); the thermal effect is related to the heat generated by the absorption of microwave energy by the complex organic system as found in food. The non thermal effect is exhibited by the ability of microwave radiation to induce dipole oscillations in a protein's active site and thus alter its function (Alsuhaime *et al.*, 2005). Structure of enzyme can also be directly affected by the electromagnetic field of microwave radiation (Porcelli *et al.*, 1997). Microwave radiation has also been used to inactivate soybean lipoxygenase (Kermasha *et al.*, 1993), alpha-amylase in wheat flour (Aref *et al.*, 1972) and lipase enzyme in rapeseed (Ponne *et al.*, 1996). This result showed that these treatments especially microwave treatment can help reduce the degradative changes in breadfruit flour during storage.

The swelling power and water absorption capacity of the control breadfruit flour was reduced by 36.84% and 23.91% respectively during the storage. The reduction in swelling power increased with length of storage and it correlates with the increase in sugar content during storage. The reduction in swelling power might have been caused by the gradual decrease in starch concentration due to hydrolysis thus leaving reduced amount of starch to imbibe water and thereby decrease the swelling power. Also the increase in sugar content must have contributed to the reduction in swelling power through solute effect. These changes do affect negatively the performance of stored breadfruit flour in food systems and the eventual textural and organoleptic qualities of the end food products. The effect of treatment with pH 3 on the swelling capacity and water absorption capacity seems to follow that of sugar content which showed that treatment was able to restrict the activity of breadfruit amylase in hydrolyzing starch to sugar, hence the reduced decrease in the swelling power and water absorption capacity when compared with control sample. Microwave treated breadfruit flour showed a

Table 3. Change in physicochemical properties of breadfruit flour samples during storage

Sample/Storage Time (Weeks)	0	2	4	6	8	10	12	14
Sugar Content (%)								
Untreated Flour (Control)	<sup>g</sup> 4.10 <sup>b</sup>	<sup>f</sup> 4.31 <sup>a</sup>	<sup>c</sup> 4.53 <sup>a</sup>	<sup>d</sup> 4.75 <sup>a</sup>	<sup>e</sup> 5.18 <sup>a</sup>	<sup>e</sup> 5.18 <sup>a</sup>	<sup>b</sup> 5.61 <sup>a</sup>	<sup>a</sup> 5.82 <sup>a</sup>
Flour Treated with Buffer pH 3	<sup>c</sup> 4.10 <sup>b</sup>	<sup>e</sup> 4.10 <sup>b</sup>	<sup>d</sup> 4.53 <sup>a</sup>	<sup>d</sup> 4.53 <sup>b</sup>	<sup>c</sup> 4.96 <sup>b</sup>	<sup>b</sup> 5.18 <sup>a</sup>	<sup>b</sup> 5.18 <sup>b</sup>	<sup>a</sup> 5.39 <sup>b</sup>
Flour Treated with Microwave Radiation	<sup>c</sup> 4.31 <sup>a</sup>	<sup>c</sup> 4.31 <sup>a</sup>	<sup>b</sup> 4.53 <sup>a</sup>	<sup>b</sup> 4.53 <sup>b</sup>	<sup>c</sup> 4.31 <sup>c</sup>	<sup>c</sup> 4.31 <sup>b</sup>	<sup>b</sup> 4.53 <sup>c</sup>	<sup>a</sup> 4.75 <sup>c</sup>
Swelling Power (g/g)								
Untreated Flour (Control)	<sup>a</sup> 5.13 <sup>b</sup>	<sup>b</sup> 5.09 <sup>b</sup>	<sup>c</sup> 4.86 <sup>b</sup>	<sup>d</sup> 4.53 <sup>b</sup>	<sup>e</sup> 3.83 <sup>c</sup>	<sup>f</sup> 3.75 <sup>c</sup>	<sup>g</sup> 3.35 <sup>c</sup>	<sup>h</sup> 3.24 <sup>c</sup>
Flour Treated with Buffer pH 3	<sup>a</sup> 4.84 <sup>c</sup>	<sup>a</sup> 4.86 <sup>c</sup>	<sup>b</sup> 4.69 <sup>c</sup>	<sup>c</sup> 4.37 <sup>c</sup>	<sup>d</sup> 4.06 <sup>b</sup>	<sup>e</sup> 3.94 <sup>b</sup>	<sup>f</sup> 3.73 <sup>b</sup>	<sup>g</sup> 3.81 <sup>b</sup>
Flour Treated with Microwave Radiation	<sup>b</sup> 5.96 <sup>a</sup>	<sup>a</sup> 6.03 <sup>a</sup>	<sup>c</sup> 5.89 <sup>a</sup>	<sup>d</sup> 5.81 <sup>a</sup>	<sup>e</sup> 5.57 <sup>a</sup>	<sup>f</sup> 5.42 <sup>a</sup>	<sup>f</sup> 5.37 <sup>a</sup>	<sup>f</sup> 5.41 <sup>a</sup>
Water Absorption Capacity (ml/g)								
Untreated Flour (Control)	<sup>a</sup> 4.60 <sup>a</sup>	<sup>a</sup> 4.60 <sup>a</sup>	<sup>b</sup> 4.30 <sup>b</sup>	<sup>c</sup> 4.20 <sup>a</sup>	<sup>d</sup> 3.80 <sup>b</sup>	<sup>e</sup> 3.60 <sup>c</sup>	<sup>f</sup> 3.40 <sup>c</sup>	<sup>g</sup> 3.50 <sup>c</sup>
Flour Treated with Buffer pH 3	<sup>b</sup> 4.20 <sup>c</sup>	<sup>a</sup> 4.30 <sup>b</sup>	<sup>c</sup> 4.10 <sup>c</sup>	<sup>d</sup> 4.00 <sup>b</sup>	<sup>e</sup> 3.90 <sup>b</sup>	<sup>f</sup> 3.80 <sup>b</sup>	<sup>g</sup> 3.70 <sup>b</sup>	<sup>g</sup> 3.70 <sup>b</sup>
Flour Treated with Microwave Radiation	<sup>a</sup> 4.50 <sup>b</sup>	<sup>b</sup> 4.40 <sup>b</sup>	<sup>a</sup> 4.50 <sup>a</sup>	<sup>c</sup> 4.20 <sup>a</sup>	<sup>c</sup> 4.20 <sup>a</sup>	<sup>d</sup> 4.00 <sup>a</sup>	<sup>e</sup> 3.90 <sup>a</sup>	<sup>e</sup> 3.90 <sup>a</sup>
Oil Absorption Capacity (ml/g)								
Untreated Flour (Control)	<sup>c</sup> 2.20 <sup>a</sup>	<sup>d</sup> 2.30 <sup>a</sup>	<sup>b</sup> 2.70 <sup>a</sup>	<sup>a</sup> 2.80 <sup>a</sup>	<sup>a</sup> 2.80 <sup>a</sup>	<sup>c</sup> 2.40 <sup>a</sup>	<sup>f</sup> 2.10 <sup>a</sup>	<sup>g</sup> 1.80 <sup>a</sup>
Flour Treated with Buffer pH 3	<sup>d</sup> 1.90 <sup>b</sup>	<sup>e</sup> 1.80 <sup>b</sup>	<sup>e</sup> 2.00 <sup>b</sup>	<sup>b</sup> 2.30 <sup>b</sup>	<sup>a</sup> 2.40 <sup>b</sup>	<sup>b</sup> 2.30 <sup>b</sup>	<sup>d</sup> 1.90 <sup>b</sup>	<sup>f</sup> 1.70 <sup>b</sup>
Flour Treated with Microwave Radiation	<sup>f</sup> 1.60 <sup>c</sup>	<sup>e</sup> 1.70 <sup>b</sup>	<sup>e</sup> 2.00 <sup>b</sup>	<sup>b</sup> 2.10 <sup>c</sup>	<sup>a</sup> 2.20 <sup>b</sup>	<sup>a</sup> 2.20 <sup>c</sup>	<sup>d</sup> 1.80 <sup>b</sup>	<sup>g</sup> 1.50 <sup>c</sup>
Moisture (%)								
Untreated Flour (Control)	<sup>g</sup> 6.01 <sup>b</sup>	<sup>h</sup> 5.91 <sup>c</sup>	<sup>f</sup> 6.13 <sup>c</sup>	<sup>e</sup> 6.62 <sup>b</sup>	<sup>d</sup> 6.93 <sup>c</sup>	<sup>e</sup> 7.21 <sup>c</sup>	<sup>b</sup> 7.50 <sup>c</sup>	<sup>a</sup> 7.90 <sup>b</sup>
Flour Treated with Buffer pH 3	<sup>g</sup> 5.95 <sup>c</sup>	<sup>g</sup> 5.95 <sup>b</sup>	<sup>f</sup> 6.43 <sup>a</sup>	<sup>e</sup> 6.71 <sup>a</sup>	<sup>d</sup> 7.09 <sup>a</sup>	<sup>e</sup> 7.42 <sup>a</sup>	<sup>b</sup> 7.96 <sup>a</sup>	<sup>a</sup> 8.20 <sup>a</sup>
Flour Treated with Microwave Radiation	<sup>g</sup> 6.14 <sup>a</sup>	<sup>g</sup> 6.15 <sup>a</sup>	<sup>f</sup> 6.38 <sup>b</sup>	<sup>e</sup> 6.72 <sup>a</sup>	<sup>d</sup> 6.98 <sup>b</sup>	<sup>e</sup> 7.37 <sup>b</sup>	<sup>b</sup> 7.64 <sup>b</sup>	<sup>a</sup> 7.80 <sup>b</sup>

For each sample values in the same row preceded by different superscript are significantly different ( $p \leq 0.05$ )

For each physicochemical property values in the same column followed by different superscript are significantly different ( $p \leq 0.05$ )

Table 4. Change in pasting properties of breadfruit flour samples during storage

Sample/Storage Time (Weeks)	0	6	12
Peak Viscosity (cP)			
Untreated Flour (Control)	3882.00 <sup>b</sup>	2577.00 <sup>b</sup>	1470.00 <sup>b</sup>
Flour Treated with Buffer pH 3	3974.00 <sup>a</sup>	2998.50 <sup>a</sup>	3207.00 <sup>a</sup>
Flour Treated with Microwave Radiation	1809.00 <sup>c</sup>	1394.00 <sup>c</sup>	1293.00 <sup>c</sup>
Final Viscosity (cP)			
Untreated Flour (Control)	6528.00 <sup>b</sup>	4462.00 <sup>b</sup>	2473.00 <sup>b</sup>
Flour Treated with Buffer pH 3	6920.50 <sup>a</sup>	5163.00 <sup>a</sup>	6017.00 <sup>a</sup>
Flour Treated with Microwave Radiation	2893.00 <sup>c</sup>	2300.50 <sup>c</sup>	2142.00 <sup>c</sup>
Breakthrough Viscosity (cP)			
Untreated Flour (Control)	241.00 <sup>a</sup>	191.00 <sup>c</sup>	89.00 <sup>c</sup>
Flour Treated with Buffer pH 3	154.50 <sup>b</sup>	219.00 <sup>a</sup>	199.00 <sup>b</sup>
Flour Treated with Microwave Radiation	241.00 <sup>a</sup>	211.00 <sup>b</sup>	218.00 <sup>a</sup>
Setback Viscosity (cP)			
Untreated Flour (Control)	2887.00 <sup>b</sup>	2076.00 <sup>b</sup>	1092.00 <sup>b</sup>
Flour Treated with Buffer pH 3	3101.00 <sup>a</sup>	2383.50 <sup>a</sup>	3009.00 <sup>a</sup>
Flour Treated with Microwave Radiation	1325.00 <sup>c</sup>	1117.50 <sup>c</sup>	1067.00 <sup>c</sup>
Pasting Temperature (°C)			
Untreated Flour (Control)	78.20 <sup>c</sup>	79.05 <sup>b</sup>	79.10 <sup>b</sup>
Flour Treated with Buffer pH 3	79.10 <sup>b</sup>	79.08 <sup>b</sup>	79.05 <sup>c</sup>
Flour Treated with Microwave Radiation	79.35 <sup>a</sup>	80.28 <sup>a</sup>	79.90 <sup>a</sup>

For each pasting property values in the same column with different superscript are significantly different ( $p \leq 0.05$ )

better performance in terms of swelling power and water absorption capacity which were significantly higher ( $p \leq 0.05$ ) than that of other samples at the end of the storage period. This corroborates the fact that microwave treatment can help reduce the degradative changes in breadfruit flour during storage.

The moisture contents of the flour samples increased during storage which indicates that the flour samples absorbed moisture when stored on the shelf at room temperature. Flour is hygroscopic in nature with ability to absorb moisture, hence the increase in the level of moisture content of the samples during storage. The use of high density polyethylene might have reduced the level of moisture increase because of low water vapour permeability of the packaging material. At the end of the storage period sample treated with sodium acetate buffer pH 3 had the highest moisture content which suggests that the treatment seems to enhance the ability of breadfruit flour to absorb moisture during storage. However, the moisture contents of the three samples at the end of storage period were relatively low and would enhance shelf stability of the flour. The oil absorption capacities of the three breadfruit samples fluctuated during the storage with little reduction at the end of the storage period. There was significant difference ( $p \leq 0.05$ ) in the oil absorption capacity of the three flour samples at the end of the storage period.

Changes in peak viscosity, final viscosity, breakdown viscosity, setback viscosity and pasting temperature of the three breadfruit flour samples during storage are presented Table 4. Peak viscosity reflects the maximum viscosity developed during cooking and gives an indication of the viscous load to be encountered during mixing (Newport Scientific, 1998). The final viscosity indicates the ability of the starch-based food to form a viscous paste or gel after cooking and cooling (Adebowale *et al.*, 2008) and it is useful in predicting and defining the final textural quality of starchy foods. There were significant differences in the pasting properties of the three breadfruit flour samples. At the onset of the storage period (week zero) treatment with microwave radiation caused reductions in the peak, final and setback viscosities of breadfruit flour; similar reduction in the peak, final and setback viscosities of sweet potato starch and sweet potato flour treated with gamma radiation have also been reported (Ocloo *et al.*, 2011; Falade *et al.*, 2011). The high peak viscosity of sample treated with sodium acetate buffer pH 3 may be as a result of protective effect of sodium ion on the granules structure since cations with a positive charge are attracted to the negative portions on the starch granules (Oosten, 1990).

Thus allowing starch granules to be more resistant to rupturing and fragmentation during swelling and application of shear forces and thereby cause high peak viscosity. Sample treated with microwave radiation had the lowest setback viscosity indicating a lower tendency to retrograde. Breakdown viscosity defines the thermal breakdown of starch and can be considered as a measure of stability of cooked paste in actual use. The breakdown viscosity of the pH 3-treated sample was significantly lower than that of the other two samples indicating that the treatment contributed significantly to the ability of breadfruit flour to withstand shear thinning or breakdown in viscosity during cooking and thereby enhance the paste stability. There was significant difference in the pasting temperatures of the samples, the treatments seems to caused increase in the pasting temperature of breadfruit flour

The peak and final viscosities of the three breadfruit flour samples reduced during the storage, the reduction was however less pronounced in the samples treated with sodium acetate buffer pH 3 and microwave radiation. While the peak and final viscosities of control sample reduced by 62.13% and 62.11% that of pH 3-treated and microwave treated samples reduced by 19.30% and 13.06%, and 28.52% and 25.96% respectively at the end of the storage period. This pattern of result was consistent with the result of swelling power and water absorption capacity of breadfruit flour samples during storage. Mayaki *et al.* (2013) had also reported that plastic viscosity and swelling power of breadfruit flour reduced with increase in sugar content during storage. This observation indicates that the two treatments were able to significantly preserve ( $p \leq 0.05$ ) the pasting properties of breadfruit flour during storage

There was reduction in the breakdown viscosities of control and microwave treated samples at the end of the storage period, this reduction may be due to increased extensive amylose leaching during the hold period of 95°C. Leached amylose molecules may provide an amylose network in which swollen granules would become embedded and more resistant to shear (Jayakody *et al.*, 2007). The reduction in the breakdown viscosities of control and microwave treated samples during storage showed that the samples would be able to withstand heat and shear stress (shear thinning) during cooking and have improved paste stability as storage time increases. Breakdown viscosity of sample treated with sodium acetate buffer pH 3 however increased during storage indicating that fresh sample of this flour could withstand heat and shear stress during cooking better than stored sample. The setback viscosities of

the three breadfruit flour samples decreased during storage, the decrease was more pronounced in the control sample than in the treated samples. This suggests that the paste made from the three samples would have reduced tendency to retrograde as storage progresses.

## Conclusion

This study revealed that the two pre-treatments especially microwave radiation used in this work were able to cause reduction in the activity of amylolytic enzyme as indicated by the storage indices and thereby help to stabilize the physicochemical and pasting properties of breadfruit flour during storage which would enhance the shelf life and utilization of the flour.

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