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# Effect of solid-state fermentation and drying methods on the physicochemical properties of flour of two plantain cultivars grown in Malaysia

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**Abstract**

The present work assessed the effect of solid-state fermentation (SSF) and drying methods [hot air drying (HAD) and hot air drying assisted by microwave finish drying (MFD)] on the physicochemical, functional and gelatinisation properties of flours of Nangka and Tanduk plantain cultivars. Drying methods and SSF did not affect the fat, dietary fibre and carbohydrate contents of the plantain flours. However, both treatments significantly affected the pH and titratable acidity of the flours. In addition, SSF coupled with MFD significantly increased the water absorption and oil absorption capacities of the flours more than the flours obtained from the hot air drying. Similar trend was observed with the swelling characteristics of the flours. Fermented and MFD flours had higher swelling power than flours obtained by hot air drying. Optical microscopy revealed that drying methods employed in the present work did not significantly alter the starch granules birefringence of the plantains.

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## Introduction

Plantain receives increased attention as an important source of food especially in tropical and subtropical regions of the world (Maskan, 2000). Nonetheless, plantain is highly susceptible to spoilage due to its high moisture contents and metabolic activity, which persists even after harvest (Demirel and Turhan, 2003). The postharvest losses are significant especially in developing countries due to poor storage facilities or inept technologies for food processing (Falade and Olugbuyi, 2010). This justifies continuous effort to process plantain to prevent postharvest losses. Although drying is the cheapest and oldest food processing method, it could have detrimental effect on product quality (Maskan, 2000). For instance, the long drying times and high temperature employed in traditional air drying to remove water from sugar-containing fruits such as plantain may negatively impact on the nutrients, flavour and colour, and could reduce rehydration capacity and bulk density of the dried products (Lasekan *et al*., 1996; Lin *et al*., 1998). In addition, long drying time and low energy efficiency during the falling rate of hot air drying could reduce thermal conductivity (Adu and Otten, 1996; Maskan, 2000) thus limiting heat transfer to the inner parts of the product (Feng and Tang, 1998). The need to curb the aforementioned shortcomings associated with traditional air drying served as an impetus to the use of microwave drying in foods (Feng and Tang, 1998). Although microwave drying ensures product quality, the procedure is expensive and could result in poor product quality if not properly applied (Adu and Otten, 1996; Feng and Tang, 1998). Thus, harmonising desirable features of hot air and microwave drying methods is worthwhile. It has been suggested that microwave drying should be applied at low moisture content for finish drying (Feng and Tang, 1998). Thus, the present work hypothesised that microwave-assisted hot air drying will improve product quality of two Malaysian plantain cultivars.

Fermentation is an important processing method for reducing postharvest losses, and can improve flavour, colour, and other quality attributes of foods (Igbabul *et al*., 2014a; 2014b). A typical type of fermentation is solid-state fermentation (SSF) which can be defined as the fermentation involving solids in absence (or near absence) of free water; however, substrate must possess enough moisture to support growth and metabolism of microorganism (Pandey *et al*., 2003). The process represents a technological

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alternative for processing a great variety of foods to improve their nutritional quality and to obtain edible products with palatable sensory characteristics (Pandey *et al*., 2003), and can be used to obtain value-added products from agro-industrial wastes (Sadh *et al*., 2018). The present work hypothesised that SSF will improve quality attributes of plantain flour. Information on the effects of SSF and drying methods on product quality of Nangka and Tanduk plantain cultivars is at best non-existent. Therefore, the objective of the present work was to determine the effects of SSF and different drying methods on the physicochemical properties of flours made from Nangka and Tanduk plantain cultivars.

## Materials and methods

### *Materials*

Two cultivars of plantain (Musa paradisiaca) of the AAB group (cv. Tanduk and cv. Nangka) locally grown in Malaysia were obtained from a local supplier in Serdang, Selangor, Malaysia. The plantains were at the pre-climacteric stage with peel colour index at 1. Uniform sized fingers were selected from each cultivar. They were washed, peeled then dipped in 0.3% citric acid solution and sliced to 4 mm thickness with a laboratory food slicer (Fold-up electric Food Slicer Model, CFE 1954, Philips Atlantis). The slices were immediately rinsed in 0.3% citric acid solution for 10 min and drained to inhibit enzymatic browning.

### *Preparation of fermented plantain flour*

Solid-state fermentation process: the plantain slices were divided into two portions, one part was allowed to undergo solid-state fermentation in a shallow wide basin for 24 h by mixing the plantain slices with 20% (v/w) distilled water (5 kg to 1 L) to create an enabling environment for the growth of microorganisms. The other portion was left unfermented.

### *Drying procedure*

Hot air drying: a portion of both the fermented and unfermented plantain slices were dried in a hot air oven at 60°C to attain moisture content of less than 10%. Dried plantain slices were ground using a Panasonic food processor (Model MK–5087M) to particle size of ~0.01 mm. The flour obtained was packed in aluminium pouches and vacuum sealed with a VacMaster to prevent moisture absorption and stored in the refrigerator at 4°C until further analysis.

Hot air drying assisted by a microwave finish drying: the other batch of fermented and unfermented plantain slices were first dried in the hot air oven at 60°C up to one-half of their original moisture content, i.e. the point where convectional drying slows down (Funebo *et al*., 1998; Maskan 2000). Thereafter, the samples were taken out and allowed to stand for 20 min to equilibrate the moisture content and then finish-dried in a programmable domestic microwave oven (SHARP Model R-202/R-352) with maximum output of 800 W and 2,450 MHz. The oven has adjustable power (wattage) and time controllers, and was fitted with a turntable. Some preliminary tests conducted on partially air-dried samples resulted in burning or charring of samples at high microwave power levels. Thus, a microwave power of 240 W (30 P) was selected for finish-drying purpose, and was terminated when moisture content of the sample was less than 10%. The dried plantain slices were ground using a Panasonic food processor (Model MK–5087M) to particle size of ~0.01 mm. The flour obtained was packed in a polyethylene bag and vacuum sealed with a VacMaster to prevent moisture absorption and stored in the refrigerator at 4°C until further analysis.

### *Chemical composition analysis of flour samples*

The moisture content of fresh and processed plantain flours was determined gravimetrically following the procedure described by the AACC (2000). Crude protein (N × 6.25), crude fat, ash were determined using the method of AOAC (1997). Total dietary fibre was determined using the methodology described by Megazyme K-TDFR 05/12, following the procedures 985.29 and 991.42 described by the AOAC (1997). Carbohydrate was determined by difference. In addition, pH and titratable acidity (expressed as malic acid %) of the flour samples were determined following the procedures described by the AOAC (1997).

### *Colour evaluation*

The colour of the fresh and processed plantain flours were measured by a Hunter Lab colorimeter (Ultra Scan Vis, Hunter Lab, Virginia, USA) in the reflectance mode using the International Commission on Illumination (CIE) $L^*$ $a^*$ $b^*$ classification system with the D65 illuminant. The colour parameters were expressed as $L^*$ (whiteness = 100, darkness = 0); $a^*$ (redness = positive, greenness = negative); and $b^*$ (yellowness = positive, blueness = negative). The total change in colour $\Delta E$, of the processed plantain flours with reference to the fresh plantain fruit were computed as:

$$\Delta E = \sqrt{(L^*_o - L^*)^2 + (a^*_o - a^*)^2 + (b^*_o - b^*)^2}$$

where subscript "o" denotes the colour reading of fresh plantain fruit, *L*; a** and *b** indicate brightness, redness and yellowness of processed plantain flour samples, respectively. A larger *ΔE* denotes greater colour change from the reference fresh plantain fruit. In addition, the hue angle H* and Chroma C* expressed as $H^* = \tan^{-1} b^*/a^*$ and $C^* = \sqrt{a^2 + b^2}$, respectively, were also calculated.

*Determination of functional properties of flour*

The swelling power of the plantain flours were measured in triplicate following the method of Yu *et al*. (2012). Analyses were carried out at 50, 60 and 80°C. The water and oil absorption capacities were determined based on the standard methods (Heywood *et al*., 2002; Traynham *et al*., 2007).

*Differential thermal analysis (DTA)*

The thermal properties of plantain flour samples were studied on a Mettler Toledo differential scanning calorimeter (DSC 823e, Mettler, Switzerland) equipped with a thermal analysis data station (STARe Software, version 9.0x, Schwerzenbach, Switzerland). Nitrogen (99.99% purity) was used as the purge gas at the rate of 50 mL/min. Approximately 8 mg of flour samples were loaded into a 40 µL capacity aluminium pan (ME-27331) and were hermetically sealed before heating in the DSC. An empty aluminium pan, which was also hermetically sealed, was used as reference for all DSC runs. The DSC analyser was calibrated using indium. Sample and reference pans were heated at a rate of 10°C/min from 27°C to 120°C. Onset temperature ($T_o$), peak temperature ($T_p$), and end set/conclusion temperature ($T_e$) of gelatinisation were calculated automatically from the thermograms of the samples. The gelatinisation temperature range ($T_{R)}$ was calculated as ($T_c - T_o$). The measurements were done in triplicate for each sample and the results were expressed as mean values.

*Polarized light microscopy*

Birefringence of starch granules of the samples of UBF was observed under polarised light with a binocular microscope (Nikon Eclipse 80T Binocular) and then photographed using a Nikon camera attached to the optical microscope at 40× magnification.

*Statistical analysis*

All experiments were carried out at least in triplicates, the results were analysed using the general linear model procedure of SAS (SAS Institute Inc., Cary, NC), and the means were separated by Tukey's honest significant difference test at significant level of 5% ($p < 0.05$). Results were presented as mean ± standard deviation.

## Results and discussion

*Chemical composition*

The effect of solid-state fermentation (SSF) and drying methods on chemical composition of flours of Nangka and Tanduk plantain cultivars is shown in Table 1. In Nangka plantain, drying method and fermentation were significant sources of variation that affected the moisture content of the flour. Flours obtained from hot air drying had significantly ($p < 0.05$) higher moisture content than those obtained from microwave finish drying (MFD). Fermented flour had higher ($p < 0.05$) moisture than unfermented flour. The increase in moisture content of fermented flour is consistent with the findings of Torres *et al*. (2007) who observed that fermentation increased moisture content of pigeon pea flour. The increase in moisture content could be explained by water absorption during fermentation. Contrary to the observation in Nangka plantain, the effect of both drying methods and fermentation on moisture content of flour was insignificant in Tanduk plantain. The range (6.69 - 10.11%) of moisture content obtained in the present work is acceptable for stable shelf life and it is consistent with earlier findings (Pacheco-Delahaye *et al*., 2008; Falade and Olugbuyi, 2010). Neither fermentation nor drying method influenced ($p > 0.05$) the ash and protein content of flour of both Nangka and Tanduk plantains. However, fermented Nangka flour tended to have lower ash content as compared to the unfermented flour. The decrease in ash content of fermented foods has been attributed to leaching of soluble minerals into the fermenting medium (Nnam, 1995; Beebe *et al*., 2000; Osman, 2007). However, since SSF was employed in the present work, the numerical decrease in ash could be due to the utilisation of the minerals (ash) by the microorganisms for metabolic activities (Nnam, 1995; Beebe *et al*., 2000; Osman, 2007). The present finding is consistent with the report of Igbabul *et al*. (2014a) who observed higher ash content in unfermented cocoyam flour when compared with the fermented cocoyam flour.

The non-significant difference in the protein contents of the fermented and unfermented plantain flours suggests lack of substantial microbial biomass during fermentation. Increased protein content has been associated with submerged fermentation (Torres *et al*., 2007; Igbabul *et al*., 2014a) contrary to SSF used in the present work. The similarity in the protein content of flour obtained from hot air drying (HAD) and MFD is an indication that the temperature employed did not cause protein degradation.

Neither fermentation nor drying method

Table 1. Effect of solid-state fermentation and drying methods on chemical composition of flours of Nangka and Tanduk plantain cultivars.

| Cultivar | Fermentation | Drying | Chemical composition (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ash | Fat | Moisture | Protein | Dietary fibre | Carbohydrate | pH | Titratable acidity |
| Nangka | Fermented | HAD[1] | 1.98 ± 0.01 | 0.64 ± 0.02 | 10.11$^{a}$ ± 1.23 | 2.45 ± 1.67 | 9.90 ± 0.70 | 84.83$^{a}$ ± 1.74 | 5.40$^{c}$ ± 0.00 | 0.43$^{b}$ ± 0.00 |
| | | MFD[2] | 1.88 ± 0.10 | 0.64 ± 0.01 | 8.64$^{b}$ ± 0.72 | 2.17 ± 0.69 | 9.85 ± 0.70 | 86.66$^{a}$ ± 0.17 | 5.19$^{d}$ ± 0.01 | 0.46$^{a}$ ± 0.00 |
| | Unfermented | HAD[1] | 2.28 ± 0.11 | 0.50 ± 0.01 | 7.77$^{bc}$ ± 0.06 | 2.30 ± 0.01 | 10.17 ± 0.70 | 87.16$^{a}$ ± 0.17 | 5.78$^{a}$ ± 0.01 | 0.31$^{d}$ ± 0.00 |
| | | MFD[2] | 2.32 ± 0.16 | 0.66 ± 0.00 | 6.69$^{c}$ ± 0.16 | 2.02 ± 0.22 | 10.35 ± 0.60 | 88.33$^{a}$ ± 0.29 | 5.54$^{b}$ ± 0.01 | 0.40$^{c}$ ± 0.00 |
| | | *p* value | 0.0669 | 0.5463 | 0.0230 | 0.7040 | 0.8775 | 0.0697 | < 0.0001 | < 0.0001 |
| Tanduk | Fermented | HAD[1] | 2.51 ± 0.17 | 0.82 ± 0.22 | 7.77 ± 0.18 | 3.18 ± 0.37 | 13.51 ± 0.71 | 85.73$^{a}$ ± 0.29 | 5.92$^{c}$ ± 0.02 | 0.32$^{a}$ ± 0.00 |
| | | MFD[2] | 2.55 ± 0.50 | 0.70 ± 0.13 | 7.41 ± 0.06 | 2.75 ± 0.19 | 13.35 ± 0.71 | 86.60$^{a}$ ± 0.58 | 5.94$^{c}$ ± 0.01 | 0.26$^{b}$ ± 0.00 |
| | Unfermented | HAD[1] | 2.35 ± 0.05 | 0.99 ± 0.01 | 8.39 ± 0.81 | 2.91 ± 0.82 | 13.69 ± 0.69 | 85.36$^{a}$ ± 0.34 | 6.36$^{b}$ ± 0.03 | 0.16$^{c}$ ± 0.00 |
| | | MFD[2] | 2.69 ± 0.08 | 0.82 ± 0.00 | 6.85 ± 0.12 | 2.90 ± 0.01 | 13.62 ± 0.70 | 86.74$^{a}$ ± 0.10 | 6.69$^{a}$ ± 0.01 | 0.17$^{c}$ ± 0.01 |
| | | *P* value | 0.1098 | 0.080 | 0.0878 | 0.4155 | 0.9630 | 0.0618 | < 0.0001 | < 0.0001 |

Means with different superscripts within the same column for each cultivar are significantly different ($p < 0.05$). HAD[1] = hot air drying, MFD[2] = microwave finish drying.

influenced the fat content, dietary fibre and carbohydrate content of flour made from Nangka and Tanduk plantain cultivars. Nonetheless, MFD tended to increase the carbohydrate content of flour as compared to HAD possibly due to lower moisture content. The similarity between the fermented and unfermented flour with respect to crude fat and dietary fibre contradicts the findings of Torres *et al*. (2007) and Igbabul *et al*. (2014a). Chukwu *et al*. (2010) observed that fermentation decreased the carbohydrate content of locust bean. Enwere (1998) and Omafuvbe *et al*. (2004) posited that reduction in carbohydrate induced by fermentation could be due to the use of the carbohydrate as source of energy by the fermenting microorganisms for growth and metabolism, or the conversion of oligosaccharides to simple sugars in the course of fermentation. This indicates that the SSF employed in the present work did not enable substantial growth and metabolism of microorganisms to cause significant reduction of carbohydrate.

The pH and titratable acidity (TTA) ranged from 5.19 – 6.69 and 0.16 – 0.46, respectively. Both fermentation and drying methods significantly ($p < 0.05$) affected the pH and TTA of the plantain flours. In Nangka plantain, flour obtained by HAD had significantly higher pH ($p < 0.05$) and lower ($p < 0.05$) TTA as compared to flour obtained by MFD. Drying methods did not significantly influence the pH of fermented Tanduk flour. However, oven dried flour had higher TTA than flours obtained from MFD. In unfermented Tanduk flour, HAD had lower pH when compared with MFD. The changes in pH and TTA could be due to the effect of thermal treatments on depolymerisation which produces thermic deposits in starch molecules. Regardless of plantain cultivar, fermented flour had significantly lower ($p < 0.05$) pH and higher ($p < 0.05$) TTA than unfermented flour. This observation could be attributed to the production of acids by fermenting microorganisms. This observation is consistent with the report of Ojokoh *et al*. (2014) who observed lower pH and higher TTA in fermented groundnut and plantain blends.

The effect of SSF and drying methods on colour parameters of Nangka and Tanduk plantain cultivars is shown in Table 2. Plantain samples subjected to HAD produced flours with significantly higher ($p < 0.05$) lightness ($L*$) and lower redness ($a*$) as compared to samples subjected to MFD in both Nangka and Tanduk cultivars. Flour obtained from MFD had significantly higher ($p < 0.05$) $b*$ as compared to those subjected to HAD in both plantain cultivars. The lower $L*$ observed in MFD flours is contrary to the finding of Maskan (2000) who reported that microwaved assisted hot air drying enhanced flour lightness as compared to full hot air drying

Table 2. Effect of solid-state fermentation and drying methods on colour parameters of flours of Nangka and Tanduk plantain cultivars.

| Cultivar | Fermentation | Drying | Colour parameters | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | L* | a* | b* | Hue | Chroma | ΔE |
| Fresh pulp | - | - | 86.46 ± 0.60 | 4.68 ± 0.01 | 18.73 ± 0.05 | 75.96 ± 0.04 | | |
| Nangka | Fermented | HAD[1] | $80.57^{bc}$ ± 0.70 | $2.18^{c}$ ± 0.07 | $14.77^{c}$ ± 0.13 | $81.60^{c}$ ± 0.19 | $14.93^{c}$ ± 0.14 | $16.77^{c}$ ± 0.72 |
| | | MFD[2] | $79.41^{c}$ ± 0.01 | $2.63^{a}$ ± 0.02 | $16.86^{b}$ ± 0.07 | $81.13^{d}$ ± 0.05 | $17.06^{b}$ ± 0.07 | $15.20^{d}$ ± 0.00 |
| | Unfermented | HAD[1] | $83.94^{a}$ ± 0.25 | $1.69^{d}$ ± 0.04 | $16.57^{b}$ ± 0.13 | $84.18^{a}$ ± 0.09 | $16.66^{b}$ ± 0.14 | $19.82^{a}$ ± 0.26 |
| | | MFD[2] | $81.67^{b}$ ± 0.49 | $2.38^{b}$ ± 0.00 | $19.42^{a}$ ± 0.19 | $83.01^{b}$ ± 0.06 | $19.57^{a}$ ± 0.18 | $17.37^{b}$ ± 0.49 |
| | | *p* value | 0.0023 | 0.0001 | < 0.0001 | < 0.0001 | < 0.0001 | 0.0025 |
| Fresh pulp | - | - | 88.97 | 9.58 | 28.58 | 71.48 | | |
| Tanduk | Fermented | HAD[1] | $82.85^{bc}$ ± 0.65 | $2.88^{b}$ ± 0.07 | $15.93^{b}$ ± 0.49 | $79.75^{b}$ ± 0.06 | $16.18^{b}$ ± 0.50 | $19.94^{b}$ ± 0.12 |
| | | MFD[2] | $79.63^{c}$ ± 0.40 | $3.65^{a}$ ± 0.02 | $20.33^{a}$ ± 0.06 | $79.81^{b}$ ± 0.08 | $20.66^{a}$ ± 0.05 | $14.72^{d}$ ± 0.26 |
| | Unfermented | HAD[1] | $85.71^{a}$ ± 0.48 | $3.05^{b}$ ± 0.02 | $16.77^{b}$ ± 0.07 | $79.68^{b}$ ± 0.02 | $17.04^{b}$ ± 0.07 | $21.50^{a}$ ± 0.33 |
| | | MFD[2] | $83.38^{b}$ ± 0.14 | $2.97^{b}$ ± 0.07 | $20.64^{a}$ ± 0.16 | $81.80^{a}$ ± 0.14 | $20.86^{a}$ ± 0.16 | $17.72^{c}$ ± 0.21 |
| | | *p* value | 0.0009 | 0.0005 | 0.0001 | < 0.0001 | 0.0001 | < 0.0001 |

Means with different superscripts within the same column for each cultivar are significantly different ($p$ < 0.05). HAD[1] = hot air drying, MFD[2] = microwave finish drying, *L** = brightness, *a** = redness, *b** = yellowness, ΔE = total change in colour.

or microwave drying. The discrepancy between the current findings and that of Maskan (2000) could be due to differences in microwave power (watts) output employed. The present work employed 250 W while Maskan (2000) employed ≥ 350 W. Thus, the lower lightness observed in MFD flour could have resulted from non-enzymatic browning caused by low microwave power (250 W) output used in the present work. The higher redness (*a**) observed in MFD flour could be due to its reduced *a** since *L** is negatively correlated with *a**. MFD significantly increased ($p$ < 0.05) the *b** of flour samples when compared with that of HAD. Preferred colour of flour is the one close to the colour of fresh sample. Thus, with respect to *a** and *b**, MFD was superior to HAD. This contention was clearly demonstrated by the lower *ΔE* observed in MFD flour as compared to HAD flour, thus suggesting that the colour of flour produced by MFD did not deviate much from the fresh plantain cultivars. Similarly, the significantly higher Chroma (measure of colour saturation) of MFD flour indicates that MFD reduced colour degradation of flour, and this could be attributed to significant reduction in drying time (about 5 h) as compared to 24 h employed in HAD.

Fermented flours had significantly lower ($p$ < 0.05) *L** and higher ($p$ < 0.05) *a** as compared to the unfermented flours in both Nangka and Tanduk plantain cultivars. Fermentation did not affect *b** in both plantain cultivars. Moreover, fermentation depressed hue angle and *ΔE*, but its effect on Chroma was inconsistent. The increase in *a** and decrease in *ΔE* in fermented flour relative to unfermented flour indicate that the colour of fermented flour did not deviate much from the colour of the pulp of both Nangka and Tanduk plantain cultivars.

*Functional properties*

The effect of SSF and drying methods on functional properties of flours of Nangka and Tanduk plantain cultivars is shown in Table 3. The bulk density of plantain flour ranged from 61 – 62.5%. MFD increased bulk densities of flour of Nangka and Tanduk plantain cultivars when compared with HAD. Bulk density is influenced by changes in particle size, and intermolecular forces of attraction between particles (Fagbemi, 1999). The increment of the bulk density of fermented MFD flour as compared to HAD flour indicates higher compactness, which could be due to reduced particle size (Perez-Sira, 1997). The higher bulk density is an advantage in the transportation and bulk storage

Table 3. Effect of solid-state fermentation and drying methods on functional properties of flours of Nangka and Tanduk plantain cultivars.

| Cultivar | Fermentation | Drying | Functional properties | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Bulk density (%) | WAC (%) | OAC (%) | SP50 (g/g) | SP60 (g/g) | SP80 (g/g) |
| Nangka | Fermented | HAD[1] | 61.0[b] ± 0.00 | 130.21 ± 5.19 | 75.24[b] ± 5.16 | 2.91[b] ± 0.06 | 3.27 ± 0.14 | 6.71[bc] ± 0.95 |
| | | MFD[2] | 62.50[a] ± 0.00 | 134.31 ± 1.15 | 88.95[ab] ± 2.72 | 3.40[a] ± 0.13 | 3.60 ± 0.15 | 6.47[c] ± 0.33 |
| | Unfermented | HAD[1] | 60.21[b] ± 0.70 | 125.39 ± 1.97 | 89.59[ab] ± 0.39 | 2.87[b] ± 0.12 | 3.12 ± 0.05 | 8.71[a] ± 0.76 |
| | | MFD[2] | 61.50[ab] ± 0.70 | 118.57 ± 6.99 | 100.52[a] ± 3.51 | 2.99[ab] ± 0.10 | 3.04 ± 0.35 | 8.29[ab] ± 0.17 |
| | | *p* value | 0.0400 | 0.0890 | 0.0083 | 0.0230 | 0.2390 | 0.0130 |
| Tanduk | Fermented | HADı | 61.50[ab] ± 0.70 | 109.16 ± 2.93 | 86.70 ± 5.29 | 2.83 ± 0.11 | 2.67[bc] ± 0.25 | 6.15 ± 0.07 |
| | | MFD[2] | 62.50[a] ± 0.70 | 105.86 ± 4.43 | 92.69 ± 4.05 | 2.84 ± 0.06 | 3.32[a] ± 0.06 | 6.44 ± 0.57 |
| | Unfermented | HAD[1] | 61.00[b] ± 0.00 | 98.43 ± 0.68 | 94.62 ± 6.52 | 2.76 ± 0.04 | 2.97[ab] ± 0.04 | 6.48 ± 0.57 |
| | | MFD[2] | 61.50[ab] ± 0.00 | 98.95 ± 7.71 | 82.03 ± 5.98 | 2.67 ± 0.02 | 2.69[c] ± 0.08 | 5.89 ± 0.21 |
| | | *p* value | 0.0006 | 0.0810 | 0.3683 | 0.1734 | 0.0086 | 0.3265 |

Means with different superscripts within the same column for each cultivar are significantly different ($p < 0.05$). HAD[1] = hot air drying, MFD[2] = microwave finish drying, WAC = water absorption capacity, OAC = oil absorption capacity, SP = swelling power at 50, 60 and 80°C.

of the flour. Fermentation influenced bulk density in both Nangka and Tanduk cultivars. The higher bulk density in fermented flour is consistent with the findings of Igbabul *et al*. (2014a) who reported that cocoyam culms fermented for 24 and 48 h had higher bulk density as compared to unfermented flour. In addition, Igbabul *et al*. (2014b) did not observe significant difference in the bulk density of fermented mahogany bean flour.

The water absorption capacity (WAC) of plantain flour ranged from 98.95 – 134.31%. The WAC of fermented Nangka and Tanduk plantain flours tended to be higher than the unfermented flours. This could be due to loss of moisture during drying caused by quick tempering of plantain pulp during fermentation. This observation corroborates the findings of Igbabul *et al*. (2014a) who observed that fermented cocoyam flour had higher WAC as compared to unfermented flour. However, fermentation reduced WAC of mucuna bean flour (Udensi and Okonkwo, 2006), sorghum, pearl millet and maize flours (Alka, 2012), and sorghum flour (Elkhalifa *et al*., 2005). The WAC reflects the amount of water available for gelatinisation. In addition, Hoover and Sosulski (1986) reported that changes in WAC of flour every so often reflect variation in the degree to which covalent and hydrogen bonds are formed between starch molecules as well as the availability of water binding sites among the starches. The increase in WAC in fermented flour makes it desirable for making bakery products. In the present work, drying methods did not affect WAC of flour of both Nangka and Tanduk plantain cultivars.

The oil absorption capacity (OAC) of plantain flour ranged from 75.24 – 100.52%. The OAC is the ability of the protein of the flour to physically bind fat by capillary attraction (Kinsella and Melachouris, 1976). It measures the quantity of oil that can be absorbed by the food matrix. This property is very important as it increases the mouth feel and serves as flavour retainer in foods (Kinsella and Melachouris, 1976). In Nangka plantain, there was a numerical decrease in OAC in fermented flour as compared to the unfermented flour. During fermentation, dissociation and denaturation of protein may take place and this may expose the polar amino acid of the proteins of the plantain, thereby promoting the hydrophobicity of such proteins (Vautsinas and Nakai, 1983). The present observation is consistent with the findings of Igbabul *et al*. (2014b). Elkhalifa *et al*. (2005) reported that fermentation increased the OAC of some cereals. In the present work, fermentation did not exert consistent effect on OAC of flour of Tanduk plantain. However, drying method had significant effect ($p < 0.05$) on OAC of flour of Nangka plantain. In Nangka plantain, regardless

Table 4. Effect of solid-state fermentation and drying methods on gelatinisation properties of flours of Nangka and Tanduk plantain cultivars.

| Cultivar | Fermentation | Drying method | Gelatinization properties | | | |
|---|---|---|---|---|---|---|
| | | | $T_o$ (°C) | $T_p$ (°C) | $T_e$ (°C) | $T_R$ (°C) |
| Nangka | Fermented | HAD[1] | 49.18 ± 1.12 | $91.77^c$ ± 0.20 | 119.91 ± 0.01 | 70.73 ± 2.06 |
| | | MFD[2] | 46.40 ± 2.90 | $97.66^b$ ± 3.30 | 119.87 ± 0.01 | 73.48 ± 2.92 |
| | Unfermented | HAD[1] | 48.33 ± 2.05 | $99.25^a$ ± 2.33 | 119.89 ± 0.00 | 71.56 ± 2.22 |
| | | MFD[2] | 51.32 ± 4.12 | $95.93^{bc}$ ± 2.58 | 119.51 ± 0.56 | 68.19 ± 3.56 |
| | | *p* value | 0.3878 | 0.0058 | 0.4943 | 0.2851 |
| Tanduk | Fermented | HADı | $53.04^{ab}$ ± 3.63 | 100.20 ± 0.59 | 119.92 ± 0.28 | $66.88^{ab}$ ± 3.68 |
| | | MFD[2] | $49.54^b$ ± 2.45 | 86.43 ± 5.54 | 119.88 ± 0.05 | $70.34^a$ ± 2.41 |
| | Unfermented | HAD[1] | $60.21^a$ ± 0.74 | 93.75 ± 2.36 | 119.88 ± 0.01 | $56.67^b$ ± 0.75 |
| | | MFD[2] | $57.54^{ab}$ ± 1.86 | 98.83 ± 3.18 | 119.87 ± 0.01 | $62.33^{ab}$ ± 1.85 |
| | | *p* value | 0.0387 | 0.4148 | 0.2280 | 0.0380 |

Means with different superscripts within the same column for each cultivar are significantly different ($p < 0.05$). HAD[1] = hot air drying, MFD[2] = microwave finish drying, $T_o$ = onset temperature, $T_p$ = peak temperature, $T_e$ = end set temperature, $T_R$ = temperature range.

of fermentation status, HAD flour had significantly lower ($p < 0.05$) OAC as compared to MFD flour. This observation is consistent with those of Hayta *et al*. (2002) who found that microwave dried tarhana (wheat flour - yoghurt mixture) had higher OAC as compared with tunnel dried tarhana.

Swelling is a function of the ratio of amylose to amylopectin and the characteristics of each fraction in terms of molecular weight distribution degree, length of branching and conformation (Onitilo *et al*., 2007). The swelling power of plantain flour at 50°C, 60°C and 80°C is shown in Table 4. Regardless of cultivar, fermentation and drying method increased the swelling power of the flours. This observation is consistent with those of Bolaji *et al*. (2014). This finding may be due to the decrease in gelatinisation temperature of plantain flour. The mode of swelling of flour is a good indicator of the extent to which starch granules are packaged and reflect the forces of attraction between the granules (Biliaderis, 1982).

The effect of SSF and drying methods on differential thermal analysis of flour of Nangka and Tanduk plantain cultivars is shown in Table 4. The onset ($T_o$), peak ($T_p$), end set ($T_e$) and range ($T_R$) temperature ranged from 48.33 – 60.21, 86.43 – 100.20, 119.51 – 119.52, 56.57 – 73.48°C, respectively. In Nangka flour, drying methods and fermentation did not influence $T_p$, $T_e$ and $T_R$. Fermented and MFD flour had significantly higher ($p < 0.05$) $T_p$ than the flour obtained by HAD. Conversely, in unfermented flours, HAD samples had significantly higher ($p < 0.05$) $T_p$ than the unfermented MFD flour. The differences in $T_p$ could be due to the distribution of the amylopectin and amylose as well as the heterogeneity, size and shape of the starch granules of the flour (Tribess *et al*., 2009). In Tanduk flour, drying had significant effect on $T_o$ and $T_R$ ($p < 0.05$), but did not have significant effect on $T_c$ and $T_p$. Fermented HAD flour had higher To and lower $T_R$ than MFD flour. In contrast, in unfermented flour, MFD had lower To and higher $T_R$ than HAD. The $T_p$ of flour of Nangka (91.77 – 99.25°C) and Tanduk (86.43 – 100.20°C) plantains observed in the present work was higher than those reported in plantain-banana flour (Tribess *et al*., 2009) and in banana flour (Perez-Sira, 1997). In Tanduk, the significantly lower To and higher $T_R$ in MFD flour is an indication that heat treatment changes the heterogeneity of amylopectin crystals in the flour. The $T_R$ is a good indicator of the range of temperature at which heat-induced disorganisation of amylopectin of flour occurs (Pelissari *et al*., 2012). Similar trend was observed in Nangka flour, but the values were statistically insignificant.

*Optical microscopy*

The images obtained in the optical microscopy are shown in Figure 1. Relating the image data obtained by light microscopy with the drying process can provide valuable information concerning the influence of the process on the starch granule. Intact granules, which did not break during the gelatinisation process, retain their birefringence (Maltese cross). Therefore, we can affirm that the starch of the flours obtained in all drying experiments did not undergo internal breakdown, and did not undergo gelatinisation, which can be confirmed by the birefringence.

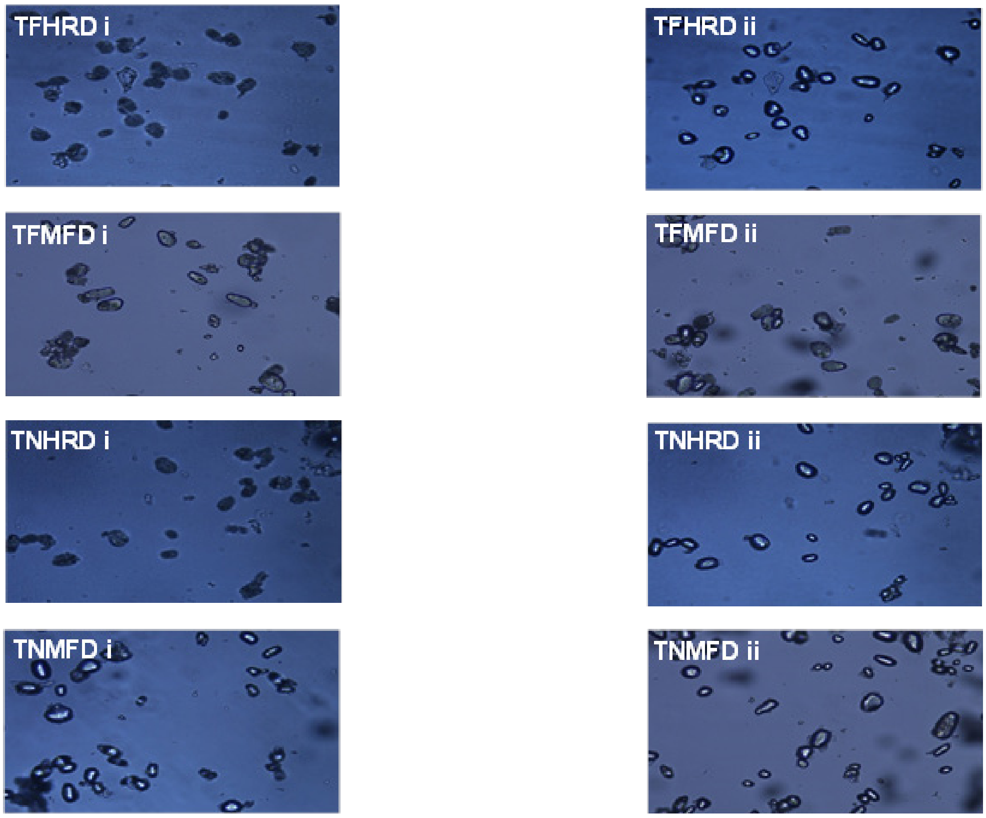


Figure 1. Images of normal and polarised light microscopy of starch granules of plantain flours as influenced by solid-state fermentation and drying methods. TFHRD = Tanduk fermented hot air dried, TFMFD = Tanduk fermented microwave finished dried, TNHRD = Tanduk unfermented hot air dried, TNMFD = Tanduk unfermented microwave finished dried.

## Conclusion

Whilst solid-state fermentation and drying methods showed no significant ($p > 0.05$) influence on the fat, dietary fibre and carbohydrate contents of the plantain flours, both treatments however, significantly ($p < 0.05$) affected the pH and titratable acidity (TTA) of the flours. In addition, SSF coupled with MFD significantly ($p < 0.05$) increased the water absorption and oil absorption capacities of the flours more than the flours obtained from the hot air drying. Similar trend was observed with the swelling characteristics of the flours. Fermented and MFD flours had higher swelling power than flours obtained by hot air drying. Optical microscopy revealed that drying methods employed in the present work did not significantly alter the starch granules birefringence of the plantains. The results of the present work demonstrated that green pulp of Nangka and Tanduk plantain cultivars subjected to SSF and MFD produced flour with reduced colour degradation and improved functional properties thus making such flour possible ingredients in local and industrial applications.

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