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Studies on some engineering properties of breadfruit (*Artocarpus altilis*) starch flour

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Abstract: This research work evaluated some engineering properties of breadfruit starch flour following standard procedures with the aim of providing engineering data that would help its usage in food processed industries. Starch was extracted from matured breadfruit fruits, modified using acid and engineering properties were examined following standard procedures. Results of moisture contents, loose and packed bulk densities, density ratio and porosity were ranged from 8.23–9.13% dry basis (DB); 0.44–0.51 g·mL^{-1}; 0.60–0.66 g·mL^{-1}; 70.01–80.14% and 19.87–29.99%, respectively. Similarly, Carr index values ranged from 19.44–30.61% and Hausner ratio values ranged from 1.25–1.43, indicating that the flour samples investigated had poor (native), fair (modified) and good (potato) flow properties, using Carr index standard. Amylose, amylopectin and amylose-amylopectin ratio contents values ranged from 21.52–29.77%; 70.23–78.48% and 0.28–0.42%, respectively. Also, the flour samples thermal properties values using Differential Scanning Calorimeter (DSC) ranged from 106.4–129.09 °C; 31.93–78.36 °C; 106.2–175.75 °C; 214.90–278.6 J·g^{-1}; 35.5–148.82 °C; 2.26–10.95 J·g^{-1}·K^{-1}; 0.305–3.0 (×10^{-6}) W·m^{-1}· °C^{-1}, and 0.095–1.32 (×10^{-6}) m^2·s^{-1} for peak temperature, onset temperature, end temperature, enthalpy, temperature range, specific heat capacity, thermal conductivity and thermal diffusivity, respectively. Viscosity values as influenced by concentration and temperature ranged from 25.8–149 mPas for native starch and 41.9–109.6 mPas for modified starches. Hence, this research work provides engineering data that would help in process control, process design and bulk handling of breadfruit starch flour so as to promote its usage in food process industries.

Keywords: bulk handling; flow properties; physicochemical; rheology; thermal properties

Demands for starch in food processing, chemical and pharmaceutical industries are increasing geometrically annually. It is used in food processing industries as additives, preservative and quality enhancer in baked foods and confectioneries (Egbarevba 2019). It is also used extensively in other industries like health and medicine, agriculture, textiles, pulp and paper (Przetaczek-Rożnowska 2017). Starch from corn (*Zea mays*) contributed 80% of the world market production of starch while wheat, cassava and potatoes accounted for 8, 6 and 4%, respectively. Other starch sources include rice, barley, millet, and yam (Egbarevba 2019). Ever-increasing demand for starch in modern food industries for food formulation and development has led to dire need to source for starch from other non-conventional sources (Afolayan et al. 2012). Breadfruit (*Artocarpus altilis*) is a tree crop cultivated extensively in the tropics and subtropics. Breadfruit cultivation is distributed in countries across different continents of the world (Nuga and Ofodile 2010). In Africa, breadfruit is typically cultivated in West and Central Africa countries (Nuga and Ofodile 2010; Baerts and Lehmann 2017). Despite its huge production rate, breadfruit is highly perishable, and this accounts for its unavailability all year round. Therefore, processing it into different value-

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added products will minimise its postharvest losses. Recent technological advances and modern food consumption patterns have led to springing up of many food processing industries. This development has contributed significantly to starch consumption by these industries. In order to cater for these huge demands, food processing and other related industries depend largely on convectional starch sources. Therefore, utilising potential of breadfruit as a source of starch can help in bridging the lacuna. This work then focuses on processing starch powder from breadfruit and investigates its engineering properties with the view of providing engineering data that will enhance its processing and usage in food formulation.

MATERIAL AND METHODS

Source of materials

Freshly harvested matured unripe breadfruits were obtained from Teaching and Research farm, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria. All chemicals used in this research work were analytical grades except for potato starch flour (food grade) which was purchased from Niji Foods Farms, Ileero, Oyo State, Nigeria.

Samples preparation

Freshly harvested matured breadfruits (4 kg) were sorted and cleaned from extraneous materials. The cleaned fruits were peeled and its pulp was diced after pretreatment in an aqueous solution of sodium metabisulphite (1.25 g·L^{-1}) to prevent enzymatic browning (Adebayo et al. 2021). The diced pulp was drained and rinsed with portable water. Maceration of the diced pulp was done at low speed using a Stephan universal machine (Model NoP33/E, ProXES, Germany) for 5 min. The homogenate slurry obtained was sieved using an electrical SWECO separator (Model No. S18, SWECO, Belgium). The filtrate was subsequently left to settle for 3 h in a stainless decanting bowl, after which the supernatant was discarded. The starch slurry was dried using a hot air oven (SM9053, Uniscope Inc., UK) at 50 °C for 24 h. Starch flakes obtained were milled in a laboratory milling machine (GM300, Retsch, Germany) and sieved (sieve size: 500 μm) to obtain starch flour. The native starch yield was expressed in percentage dry weight of native starch per weight of edible portion of the sample. The native starch obtained was divided into two portions: the first lot was stored in properly labelled zip-lock bags while the second lot was modified using acid.

Acid modification of breadfruit starch. A portion of the starch sample was modified by acid hydrolysis using a method documented by Adebayo et al. (2021). Acid hydrolysis of the starch was done by suspending 200 g dry basis (DB) of native starch in 400 mL of 6% (v·v^{-1}) HCl solution at 27 ± 2 °C for 1 h without stirring. After hydrolysis, the suspension was neutralised with 10% (w·v^{-1}) sodium hydroxide solution to terminate the reaction. The starch slurry was then washed three times with distilled water, dried in a hot air oven at 50 °C for 24 h and then milled using a laboratory mill (GM300, Retsch, Germany). The modified starch was passed through a 500 μm mesh sieve and the resulting flour was stored in properly labelled ziploc bags and kept in an air tight jar till the time of usage.

Moisture content determination. Moisture content was determined using AOAC (2005) Official Method 925.10.

Packed bulk density determination. Packed bulk density was determined according to the method documented by Adebayo et al. (2021). A 10 mL graduated cylinder was filled with a known weight of the sample, bottom of the cylinder was gently tapped several times on a laboratory work bench until there was no further diminution of the sample level after filling to the 10 mL mark of the cylinder. Packed bulk density was then calculated using Equation (1):

$$BD = \frac{W_s}{V_s} \tag{1}$$

where: BD – bulk density (g·mL^{-1}); W_s – weight of starch sample (g); V_s – volume of starch sample (mL).

Loose bulk density determination. Loose bulk density was determined using a method documented by Yusuf (2004). A 10 mL graduated cylinder was gently filled with starch sample. The volume occupied was recorded. Loose bulk density was then calculated as weight of sample per unit volume of sample (g·mL^{-1}) using Equation (1).

Density ratio and porosity determination. The density ratio (D_r) which is the ratio of the bulk density to true density expressed as a percentage was determined using Equation (2) while the porosity was determined using Equation (3) (Mohsenin 1986):

$$D_r = \left(\frac{\rho_B}{\rho_T}\right) \times 100 \tag{2}$$

$$P = \left[1 - \left(\frac{\rho_B}{\rho_T}\right)\right] \times 100 \tag{3}$$

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where: D_r – density ratio; ρ_B – packed bulk density (g·mL^{-1}); ρ_T – loose bulk density (g·mL^{-1}); P – porosity.

Amylose and amylopectin ratio determination. The amylose content was determined using a method documented by Adebayo et al. (2021). Sample (100 mg) was measured into 100 mL standard flask, 1.0 mL of ethanol (95%) and 9.0 mL of 1.0 M NaOH were added, and the mixture was heated on a boiling water-bath for 10 min to gelatinise the starch. The gelatinised starch solution (5.0 mL) was subsequently transferred to a 100 mL standard flask, 1.0 mL of 1.0 M acetic acid and 2.0 mL of stock iodine solution was added to it and the volume was made up with distilled water. The content was thoroughly vortexed and allowed to settle for 20 min. The resultant colour was allowed to develop and absorbance was read at 620 nm using a UV-spectrophotometer (Model 752S, Jingxue Scientific Instrument Co. Ltd, Shanghai). The amylose content was then calculated from the standard curve of potato amylose. The amylopectin content was calculated by subtracting the determined amylose content from 100 and expressing it in percentage (%), Equation (4):

$$APC = 100 - AC \tag{4}$$

where: APC – amylopectin content (%); AC – amylose content (%).

Flowability properties determination. The flowability of the sample was determined using the data got from the determination of packed bulk density and that of loose bulk density of the starch to determine its rate of compression and compaction. The Hausner ratio and Carr index values were calculated to ascertain the flow property of the sample. The Hausner ratio was calculated as a ratio of the packed density of the starch to its loose bulk density as shown in Equation (5) (Adebayo et al. 2021) while the Carr index as the ratio of the difference between the packed density and loose density of the sample to its loose density, it was expressed as a percentage as shown in Equation (6) (Carr 1965). The Hausner ratio values were then compared with the Carr index values to ascertain if the flow was excellent, good, fair, or poor.

$$H_R = \frac{\rho_\infty}{\rho_0} \tag{5}$$

$$CI = \frac{\rho_B - \rho_L}{\rho_L} \times 100 \tag{6}$$

where: H_R – Hausner ratio; ρ_∞ – asymptotic constant density after certain amount of taps; ρ_0 – initial bulk density; CI – Carr index; ρ_B – packed bulk density (g·mL^{-1}); ρ_L – loose bulk density (g·mL^{-1}).

Differential scanning calorimetry (DSC). A Perkin-Elmer Diamond-I DSC with an internal coolant (Intercooler 1P) and nitrogen purge gas were used in the experimental study. The melting point and enthalpies of indium were used for temperature and heat capacity calibration, respectively. A high pressure stainless steel pan (PE nr B0182901) with a gold-plated copper seal (PE nr 042-191758) was used to achieve a constant moisture content at high temperature during DSC measurements. The sample mass used for the study was about 35 mg. A heating rate of 5 °C·min^{-1} was used to minimise any temperature lag due to the large mass of the steel pan. Thermal diffusivity of the starch samples was determined using a method described by Man et al. (2012). Temperature - time data of the samples generated by the DSC was used to calculate thermal diffusivities using Equation (7).

$$-\log\left(\frac{T_{\max} - T_i}{T_{\max} - T}\right) = \frac{1}{2.303}\left(\frac{5.78}{R} + \frac{\pi^2}{L^2}\right)\alpha t \tag{7}$$

where: T_{max} – maximum processing starch flour temperature; T_i – initial starch flour temperature; T – starch flour temperature at any time; R – radius of the crucible; L – length of the starch flour in the crucible; t – time; α – thermal diffusivity (m^2·s^{-1}).

Thermal conductivity was calculated mathematically using Equation (8):

$$\kappa = \rho\alpha C_p \tag{8}$$

where: κ – thermal conductivity (W·m^{-1}·°C^{-1}); ρ – bulk density (g·mL^{-1}); C_p – specific heat capacity (J·g^{-1}·K^{-1}); α – thermal diffusivity (m^2·s^{-1}).

Visco-elastic properties of breadfruit starch flour determination. The visco-elastic properties of breadfruit starch flour were investigated using a HAAKE Viscotester 500 (Thermo Fisher Scientific Pty Ltd., Germany). Breadfruit starch suspension (10–40 w·v^{-1}) prepared inside a test-tube was heated using a shaking bath to a preset temperature.

Statistical analysis

All experiments were conducted in triplicate. The data

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obtained was analysed descriptively and inferentially using Design Expert 13 for Windows.

RESULTS AND DISCUSSION

Physiochemical properties such as bulk density, moisture content, density ratio, porosity and flow parameters of native and modified breadfruit starch are presented in Table 1.

Values for initial moisture content of native and modified breadfruit starch were 8.23 and 9.13%, respectively. The initial moisture content values (8.23 and 9.13%) for both native and modified breadfruit starch flour, respectively were higher than 2.85% for potato starch (commercial starch). Adebayo et al. (2021) reported 1.35% for acid modified *Musa* spp. (ABB) starch which is lesser than the value obtained for modified breadfruit starch. However, Adebayo et al. (2021) documented that shelf stability of flour depends on whether or not its moisture content is less than 11%. This indicates breadfruit starch flour is shelf stable and will not undergo moisture-dependent deterioration.

Bulk density of native and modified breadfruit starch values were 0.44 and 0.48 g·mL^{-1} (loose) and 0.63 and 0.60 g·mL^{-1} (packed), respectively. Values obtained compared favourably with commercial potato starch values 0.51 g·mL^{-1} (loose) and 0.66 g·mL^{-1} (packed), respectively. The value of native breadfruit starch compared favourably with 0.64; 0.65; 0.68 and 0.68 g·mL^{-1} for cassava, *Musa* spp. (ABB), cocoyam and breadfruit starch, respectively (Adebayo et al. 2021). It was observed that acid hydrolysis of native breadfruit starch led to increased loose bulk density and decreased packed bulk density. Values for density ratio of native and modified starch samples were 70.01 and 80.14 %, respectively. The value of modified breadfruit starch compared favourably with potato starch (76.53%) while the value of native breadfruit starch was significantly lower compared with potato starch ($P \leq 0.05$). Adebayo et al. (2021) reported density ratio of 77 and 74% for native and modified *Musa* spp. (ABB), respectively. The differences in density ratio values are associated with decrease in bulk densities of native breadfruit starch to modified breadfruit starch. Porosity values of native and modified starch samples were 29.99 and 19.87%, respectively. The value of modified breadfruit starch compared favourably with that of commercial potato starch (23.47%) while there was significant difference between native breadfruit starch and commercial potato starch ($P \leq 0.05$). Carr index and Hausner ratio of native and modified breadfruit starch were 29.92; 1.43; 19.44 and 1.25%, respectively (Table 1). Values for modified breadfruit starch compared favourably with potato starch (30.61 and 1.31%) for both Carr index and Hausner ratio. The value of native breadfruit starch showed that it has a very good compressibility/compactness but poor flowability while modified breadfruit starch had poor compressibility/compactness but fair flowability; and potato starch had very good compressibility/compactness and good flowability Table 2 (Carr 1965). Acid modification of native breadfruit starch improved its flowability while its compressibility decreased.

Carr index provides an indirect measure of material fluidity, and the higher its value, the more cohesive the substance (Adebayo et al. 2021).

The values for amylose, amylopectin and amylose-amylopectin ratio are presented in Table 3. The amylose content values of native and modified starch were 21.48 and 22.84%, respectively. The amylose values

Table 1. Physicochemical properties of breadfruit starch

Parameter	Native starch	Modified starch	Potato starch
Moisture content (%)	8.23 ± 0.88^{a}	9.13 ± 0.63^{a}	2.85 ± 0.07^{b}
Loose bulk density (g·mL^{-1})	0.44 ± 0.06^{b}	0.48 ± 0.06^{ab}	0.51 ± 0.03^{a}
Packed bulk density (g·mL^{-1})	0.63 ± 0.02^{a}	0.60 ± 0.02^{a}	0.66 ± 0.04^{a}
Density ratio (%)	70.01 ± 0.88^{b}	80.14 ± 1.18^{a}	76.53 ± 4.21^{a}
Porosity (%)	29.99 ± 0.88^{a}	19.87 ± 1.17^{b}	23.47 ± 4.21^{b}
Carr's index	29.92 ± 0.77^{a}	19.44 ± 0.71^{b}	30.61 ± 7.36^{ab}
Hausner ratio	1.43 ± 0.02^{a}	1.25 ± 0.02^{b}	1.31 ± 0.07^{b}
Compressibility	very good	poor	very good
Flowability	poor	fair	good

Values reported are mean ± standard deviation in triplicate; mean values within each row bearing a different superscript roman letter are significantly different ($P \leq 0.05$)

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Table 2. Flowability classification Carr standard (Carr 1965)

Carr's index	Flowability	Hausner ratio
≤ 10	excellent	1.00–1.11
11.0–15.0	good	1.12–1.18
16–20	fair	1.19–1.25
21–25	passable	1.26–1.34
26–31	poor	1.35–1.45
32–37	very poor	1.46–1.59
> 38	awful	> 1.60

Table 3. Amylose-amylopectin composition of breadfruit starch

Parameters (%)	Native starch	Modified starch	Potato starch
AM	21.52 ± 0.26^{c}	22.84 ± 0.16^{b}	29.77 ± 0.11^{a}
APC	78.48 ± 0.26^{a}	77.16 ±0.16^{b}	70.23 ± 0.11^{c}
AM/APC	0.28 ± 0.01^{b}	0.30 ± 0.01^{b}	0.42 ± 0.01^{a}

AM – amylose; APC – amylopectin; values reported are mean ± standard deviation in triplicate; mean values within each row bearing a different superscript roman letter are significantly different ($P \leq 0.05$)

of native and modified breadfruit starch were significantly different with 29.77% for potato starch ($P \leq 0.05$). The low amylose content indicates low amylose-amylopectin ratio, hence it enhances digestibility (Egharevba 2019). There was an increase in the amylose content of modified breadfruit starch. The increase in amylose of modified breadfruit starch may be associated with the hydrolysis of starch structure during modification. The amylopectin content of native and modified breadfruit starch were 78.48 and 77.16%, respectively. There is a significant difference in all the amylopectin values of the starch samples ($P \leq 0.05$). Amylose-amylopectin ratio values of native and modified breadfruit starch were 0.28 and 0.30, respectively. These values were significantly lower than 0.42 for potato starch (Table 3). The lower the amylose-amylopectin ratio, the lower the glycaemic index (Santana and Meireles 2014). This implies that breadfruit starch has low a glycaemic index which makes it suitable for food formulations intended for diabetic consumers.

Thermal properties of native and modified breadfruit starch are shown in Table 4. The onset temperature, peak temperature, end temperature, gelatinisation enthalpy, temperature range, specific heat capacity and density of native and modified breadfruit starch were 31.93 °C; 126.07 °C; 175.75 °C; 239.73 J·g^{-1}; 143.82 °C; 3.62 J·g^{-1}·K^{-1}; 0.63 g·mL^{-1}; 78.36 °C; 129.09 °C; 166.56 °C; 214.90 J·g^{-1}; 88.2 °C; 2.26 J·g^{-1}·K^{-1}; and 0.60 g·mL^{-1}, respectively. These values were significantly different ($P \leq 0.05$) from potato starch with 72.7 °C; 106.4 °C; 106.2 °C; 278.6 J·g^{-1}; 33.5 °C; 10.95 J·g^{-1}·K^{-1} and 0.66 g·mL^{-1} for its onset temperature, peak temperature, end temperature, gelation enthalpy, respectively. The difference in gelatinisation temperatures for breadfruit starches may be attributed its amylose-amylopectin ratio.

The variation in gelatinisation enthalpy in starches as result of modification and starch type may be due to differences in quantity of longer chain amylopectin (Adebayo et al. 2021). The differences in temperature range (Table 4) suggested that the degree of heterogeneity of crystallites within the granules of the starches was different. The acid hydrolysis of native breadfruit starch decreased temperature range. The acid hydrolysed native breadfruit starch had increased onset gelatinisation temperature compared with native breadfruit starch. The increase in the onset temperature may be attributed to the depolymerisation of the amorphous region of the granules which destabilised the crystalline lamellae (Adebayo et al. 2021). Thermal conductivity and diffusivity of native and modified breadfruit starch were 3.01 × 10^{-6} W·m^{-1}·°C^{-1} and 1.32 × 10^{-6} m^{2}·s^{-1};

Table 4. Thermal properties of breadfruit starch

Parameter	Native starch	Modified starch	Potato starch
T_o (°C)	31.930	78.360	72.700
T_p (°C)	126.070	129.090	106.400
T_E (°C)	175.750	166.560	106.200
Enthalpy (J·g^{-1})	239.730	214.900	278.600
Temperature range (°C)	143.820	88.200	35.500
C_p (J·g^{-1}·K^{-1})	3.620	2.260	10.950
κ (10^{-6}) (W·m^{-1}·°C^{-1})	3.010	0.980	0.305
α (10^{-6}) (m^{2}·s^{-1})	1.320	0.726	0.095
ρ (g·mL^{-1})	0.630	0.600	0.660

T_o – on-set temperature; T_p – peak temperature; T_E – end temperature; C_p – specific heat capacity; κ – thermal conductivity; α – thermal diffusivity; ρ – density; values reported are results generated from differential scanning calorimetry (DSC)

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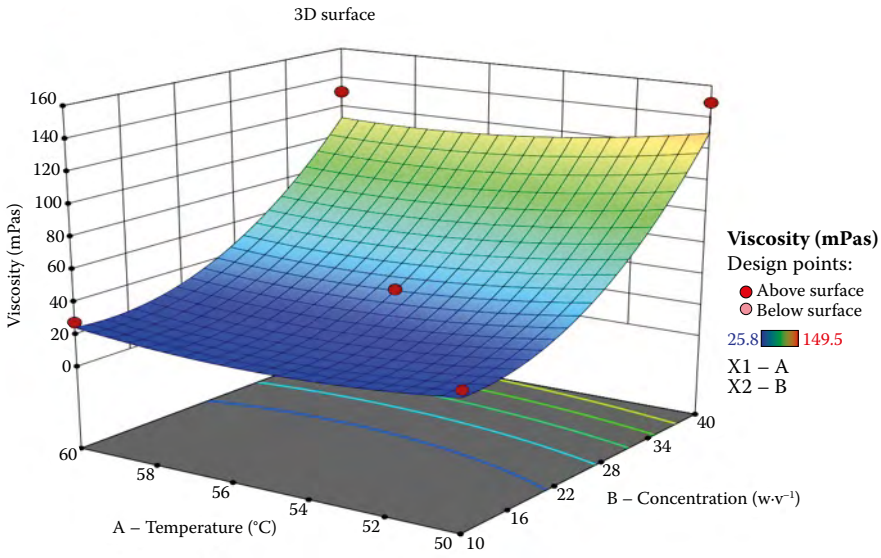
0.98×10^{-6} W·m·°C^{-1} and 0.726×10^{-6} m^2·s^{-1}, respectively. Effect of concentration and temperature on viscosity of both native and modified breadfruit starches were presented in Figure 1, respectively. The viscosity values ranged from 25.8 to 149 mPas and 41.9 to 109.6 mPas for native and modified starches, respectively. Figure 1 showed that as starch concentration increased, there is a corresponding increase in viscosity in both native and modified breadfruit starch. However, as the temperature increased from 50 to 56 °C, there is reduction in viscosity but further increase in temperature (> 56 °C) led to a slight increase in native starch viscosity. Similar trend was also observed for modified breadfruit starch. The interactive effects of concentration and temperature on viscosity of both native and modified breadfruit starch are quadratic. The maximum viscosity was observed at 50 °C temperature for both native and modified starch. The numerical model describing the effect of temperature (°C) and concentration (% w·v^{-1}) on viscosity of native and modified breadfruit starch is shown in Equations (9) and (10), respectively:

$$\mu = 895.54041 - 0.129444C - 31.54679T - \\ -0.051667CT - 0.123365C^2 + 0.289402T^2 \quad (9)$$

$$\mu = \sqrt{31.90688 + 0.022700C - 0.814787T - \\ -0.000105CT + 0.001230C^2 + 0.006491T^2} \quad (10)$$

where: μ – viscosity; C – concentration (g·cm^{-3}); T – temperature (°C).

(A)



(B)

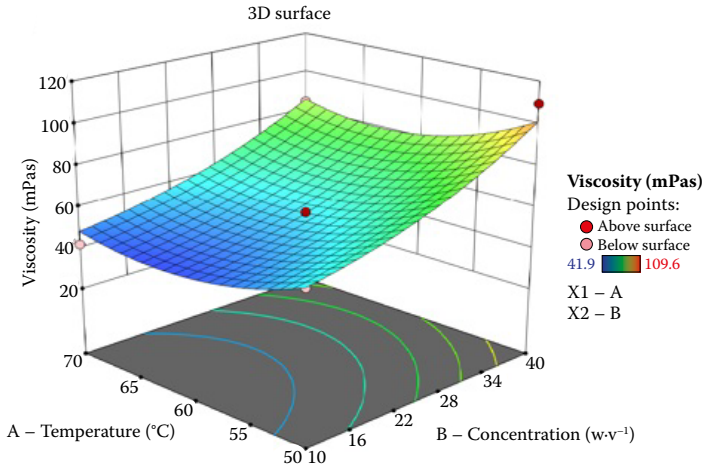


Figure 1. Effects of concentration and temperature on the viscosity of breadfruit starch: (A) native starch and (B) modified starch

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CONCLUSION

Studies on some engineering properties of breadfruit starch flour were investigated using documented procedures. Physicochemical, rheological and thermal properties of the breadfruit starch flour were examined and the following conclusions may be drawn:

i) Breadfruit starch flour exhibited favourable engineering properties and glycaemic index. Therefore, it may find application in food formulation and development.

ii) The native breadfruit starch flour demonstrated very good compressibility/compactness but poor flowability while modified breadfruit starch had poor compressibility/compactness but fair flowability.

iii) Viscosity of the reconstituted starch flour depends on both concentration and temperature. The interactive effects of concentration and temperature on viscosity of both native and modified breadfruit starch are quadratic.

REFERENCES

Adebayo W.A., Ogunsina B.S., Taiwo K.A., Chidoziri P.O. (2021): Studies on some physico-chemical and engineering properties of *Musa* spp (ABB) starch flour. African Journal of Food Science, 15: 289–297.

Afolayan M.O., Omojola M.O., Onwualu A.P., Thomas S.A. (2012): Further physicochemical characterisation of *Achromanes difformis* starch. Agriculture and Biology Journal of North America, 3: 31–38.

AOAC (2005): Official Methods of Analysis. 18th Ed. Gaithersburg, Association of Official Analytical, Chemistry International: 777–796.

Baerts M., Lehmann J. (2017): Prelude Medicinal Plants Database: *Treculia africana*. Royal Museum for Central Africa, Tervuren. Available at http://www.africamuseum.be/collections/external/prelude/view_plant?pi=912537 (accessed May 20, 2021).

Carr R.L. (1965): Evaluating flow properties of solids. Journal of Chemical Engineering, 72: 163–168.

Egharevba H.O. (2019): Chemical properties of starch and its application in the food industry. In: Emeje M. (ed.): Chemical Properties of Starch. IntechOpen, https://www.intechopen.com/books/chemical-properties-of-starch/chemical-properties-of-starch-and-its-application-in-the-food-industry (accessed May 10, 2021).

Man J.M., Cai J.W., Xu B., Zhang F.M., Liu Q.Q., Wei C.X. (2012): Spectrum analysis of crystalline structure of crop starches. Acta Agronomica Sinica, 38: 691–698.

Moshenin N.M. (1986): Physical Properties of Plant and Animal Materials. 2nd Ed. New York, Gordon and Breach Science Publishers: 51–87.

Nuga O.O., Ofodile E.A.U. (2010): Potentials of *Treculia africana* Decne – An endangered species of Southern Nigeria. Journal of Agriculture and Social, 2: 120–134.

Przetaczek-Rożnowska I. (2017): Physicochemical properties of starches isolated from pumpkin compared with potato and corn starches. International Journal of Biological Macromolecules, 101: 536–542.

Santana A.L., Meireles M.A.A. (2014): New starches are the trend for industry application: A review. Food and Public Health, 4: 229–241.

Yusuf A.B. (2004): Laboratory Manual on Food Technology, Nutrition and Chemistry. New York, Publishing Co. Inc.: 34–41.

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