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Quality Characterization of Instant Pounded Yam Flour and its Composites Using Principal Component Analysis

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Authors' contributions

This work was carried out in collaboration among all authors. Authors SBK and ASA designed the study. Authors SBK and WTO carried out and performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author ASA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The importance of producing acceptable composite instant pounded yam flour has been challenging in todays' consumer market due to various substitutes been utilized during its production process as a way of reducing the production cost hence the need to carry out quality assessment of the products.
Aims: This study examined the functional and pasting characteristics of composite Instant Pounded

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Yam Flour (IPYF) made from varying substitution levels (15%, 30% and 45%) of Dehulled White Sorghum Flour (DWSF), White Rice Flour (WREF) and High Quality Cassava Flour (HQCF).
Study Design: The study was a factorial design.
Place and Duration of Study: The study was carried out at Food Technology Department, Federal Institute of Industrial Research, Oshodi, Lagos State and Department of Food, Nutrition and Home Science, University of Port Harcourt (Processing and analysis of raw materials) between September, 2022 and May, 2023.
Methodology: Raw materials were processed into flours and combined with at varying levels. The functional and pasting properties of the flours (individual and composite samples) were subsequently determined and then subjected to Principal Component Analysis.
Results: Significant differences (P≤0.05) were found between the functional and pasting characteristics of the various flour samples, with IPYF having the highest mean value of 0.85 ± 0.02, 243.00 ± 3.00, 79.50 ± 1.00, 7.00 ± 0.56 and 83.10 ± 0.75 for pack bulk density, water absorption capacity, water binding capacity, peak time and pasting temperature respectively among others while HQCF has the highest mean value for oil absorption capacity (104.95 ± 2.77) and peak viscosity (350.75 ± 1.04), DWSF has the highest mean value setback viscosity (140.33 ± 0.92) and white rice flour has the highest mean value for trough viscosity (227.75 ± 1.84) and final viscosity (334.67 ± 1.62). Significant variations (P≤0.05) were also seen across the composite flours, with the peak viscosity of the HQCF-IPYF increasing with the level of replacement.
Conclusion: HQCF substitution level of 15% would be recommended for the production of composite IPYF that has the nearly similar and pasting characteristics of 100% Instant Pounded Yam Flour.

Keywords: Functional properties; pasting properties; instant pounded yam flour; composite flour; principal component analysis.

1. INTRODUCTION

In most Sub-Saharan African nations, yam (*Dioscorea esculenta*), is one of the key staple food crops that has been highlighted as one of the strategies to fight hunger, reduce post-harvest losses, and give rural farmers more leverage [1]. Apart from this, yam occupies an exalted position when it comes to African traditional rites and celebrations that only allow for the preparation of pounded yam [2]. However, researchers have developed the concept of Instant Pounded Yam Flour (IPYF) in response to the desire for a convenient food and the removal laboriousness involved in making pounded yam [3,4,5].

IPYF is a value-added yam product that is gaining popularity since it can be quickly transformed into pounded yam by gradually dissolving with continuous stirring of the flour in a measured quantity of boiling water over a fire until a solid mass with the correct texture is obtained [5,6]

Over the years, investors have begun the development of composite IPYF as a means of decreasing the cost of production and maximizing profit returns on investment [7]. Composite flour is an innovative flour that has attracted much attention in research as well as food product development [8,9,10,11,12].

Some of the components that are now being added to IPYF are flour made from staple cereal and tuber crops. These crops include cereals (sorghum, rice, maize) as well as roots and tubers (cassava and potatoes). Since functional and pasting qualities are among the important quality indices that define the degree of acceptability of starch-based foods products by consumers; therefore the level of substitution would has a considerable impact on the overall quality of the product [13]. Researchers have investigated the functional and pasting qualities of composite flour from various biological sources [11, 14, 15, 16].

The use of principal component analysis (PCA) to find patterns in data and express that data in a fashion that highlights its similarities and differences is growing; and the main goal of PCA is to keep as much variance in the data set as feasible while reducing the dimensionality of a data set made up of numerous connected variables [17].

In this work, Dehulled White Sorghum Flour, High Quality Cassava Flour and Rice flour were investigated for their possible use at varied levels of substitution in the manufacturing of IPYF composite. Based on their functional and pasting characteristics, the composite flour generated was compared and contrasted using principal component analysis (PCA).

2. MATERIALS AND METHODS

2.1 Materials

The yam tubers (*Dioscorea esculenta*), rice (*Oryza sativa*) (white variety) and sorghum (*Sorghum bicolor*) (white variety) were purchased from Ile-Epo commodity market in Lagos State while High Quality Cassava Flour (HQCF) was supplied by Wahan Food Nigeria Ltd.

2.2 Methods

2.2.1 Production of flours

The rice (white) was first cleaned and sorted to remove all extraneous matter before milling into flour and packaged to obtain the white rice flour. The sorghum (white) was also cleaned, sorted, dehulled and milled to obtain dehulled white sorghum flour. These flours and HQCF were used as substitute for the production of composite Instant Pounded Yam Flour (IPYF).

The method of FIIRO [6] was used in the production of Instant Pounded Yam Flour (IPYF). The processes are: weighing and sorting of raw yam tubers, washing and peeling, size-reduction (3-5mm in thickness), pre-treatment ($Na_2S_2O_5$ Solution (200ppm) for 15 min contact time), steam parboiling, drying (cabinet (60^{o}C for 5hr)), milling, cooling and packaging.

2.2.2 Production of composite IPYF

High Quality Cassava Flour (HQCF), Dehulled White Sorghum Flour (DWSF) and White Rice Flour (WREF) were used for the production of composite IPYF at three different levels (15, 30 and 45%) of substitutions (to know how the substitution level would affect the quality of the composite instant pounded yam flour).

2.3 Analyses

2.3.1 Functional properties

2.3.1.1 Loose and pack bulk densities

These were determined using the method of AOAC [18]. About 10 g of the flours was weighed into a 50 ml graduated measuring cylinder. The cylinder were not tapped (loose bulk densities) and gently tapped (pack bulk densities) against the palm of the hand until a constant volume was obtained.

Loose bulk density = (Weight of sample / Volume of sample without tapping) X 100

Pack bulk density **=** Weight of sample / Volume of sample after tapping) X 100

2.3.1.2 Water Absorption Capacity (WAC) and Oil Absorption Capacity (OAC)

The water absorption capacity (WAC) and oil absorption capacity (OAC) (replacing water with olive oil) of the samples was determined using the method described by Denga et al. [19]. About one gram (1 g) each of a sample was mixed with 10 ml of distilled water (or olive oil) and blended for 30 s. It was then allowed to stand for 30 min and centrifuged at 3,500 rpm for 30 min at room temperature. The supernatant was decanted and weight of water/oil absorbed by the flour was calculated and expressed as WAC (or OAC).

Water/Oil Absorption Capacity = (Volume of water/oil absorbed) / Weight of Sample

2.3.1.3 Water binding capacity

Water binding capacity of the samples was determined using the Ali and Hasnain [20] method. About 15 ml of distilled water was added into 1.25 g of the flour and was centrifuged for 10 min at 3000 rpm. The weight of the centrifuge tube and content was determined after decanting the water and allowed to drain for another 10 min. The bound water was determined by the change in weight. It was calculated by the following formula.

Water binding capacity (WBC) = (Bound water (g) / Weight of sample) X 100

2.3.1.4 Dispersibility

This was determined by the method describe by Edema et al. [21]. Samples were weighed (10 g each) into 100 ml measuring cylinder and distilled water added to reach a volume of 100 ml. The set up was stirred vigorously and allowed to settle for 3 h. The volume of settled particles was recorded and subtracted from 100. The difference was then reported as percentage dispersibility.

2.3.2 Pasting properties

The pasting properties of the samples were determined as described by Adebowale et al. [22] using a Rapid Visco Analyzer (RVA) (Model RVA - 4C, Newport Scientific, Warriewood, Australia) interfaced with a personal computer equipped with the Thermocline Software also supplied by Newport Scientific.

Approximately 3 g of each sample was weighed into a canister and made into slurry by adding 25 ml of distil water. This canister (covered with a stirrer) was inserted into the RVA. The heating and cooling cycles of the RVA was programmed such that the slurry was held at 50 ºC for 1 min, heated to 95 ºC within 3 min and then held at 95 ºC for 2 min. It was subsequently cooled to 50 ºC within 3 min and then held at 50 ºC for 2 min, while maintaining a rotation speed of 160 rpm. The viscosity was expressed as rapid viscosity units (RVU).

The following parameters were determined automatically by the RVA - peak viscosity (the maximum viscosity during pasting), breakdown viscosity (the difference between the peak viscosity and the minimum viscosity during pasting), setback viscosity (the difference between the maximum viscosity during cooling and the minimum viscosity during pasting), final viscosity (the viscosity at the end of the RVA run), pasting temperature (ºC) (the temperature at which there is a sharp increase in viscosity of flour suspension after the commencement of heating) and peak time (min) (time taken for the paste to reach the peak viscosity).

2.4 Statistical Analysis

The data obtained were subjected to Analysis of Variance (ANOVA) and Pearson correlation using SPSS (Version 17.0) software package. The significance of sample means was tested at $p<0.05$ probability level using Duncan's Multiple Range Test (DMRT).

Principal component analysis (PCA) was done with the Statistical Tool for Agricultural Research (STAR) Software (Version 2.0.1) to examine the variation in the functional and pasting properties of the flour samples. Solution was accepted when eigen values were greater than one (1) [23]. Factor loadings equal to or greater than 0.3 [23] were considered to be defining part of a principal component). Biplot and scree plot displays of PCA was used to visualize the variation pattern.

3. RESULTS AND DISCUSSION

3.1 Functional Properties of Flour Samples

Table 1 presents the functional properties of the flour samples. Density compares the weight and volume of any substance. It has an impact on materials handling and packaging design and how wet processing could be used in the food business [24,25]. The results of loose bulk density (LBD) and pack bulk density (PBD) of the flour samples for High Quality Cassava Flour (HQCF), rice flour (WREF), dehulled white sorghum flour (DWSF) and Instant Pounded Yam Flour (IPYF) ranged from 0.30 – 0.71(g/cm^3) and 0.48 – 0.85(g/cm^3) respectively. The result revealed that the samples differ significantly ($P≤0.05$) from one another with IPYF having the highest value for these two properties while HQCF had the least values. Shittu *et al*., [26] reported that the bulk density value for HQCF from 43 cassava varieties resistant to mosaic disease ranges from 0.39 – 0.55(g/cm^3) which was the same range of density obtained for 100% HQCF in this research work. This indicated that HQCF might need the least amount of packaging material due to its densities [27].

The capacity of flour to absorb significant amounts of water, preventing exudation while swelling for better meal consistency, is known as water absorption capacity. All flours and starches used in food preparations must possess the capacity to absorb water [28]. The water absorption capacity values of HQCF, DWSF, WREF and IPYF differs significantly ($p<0.05$) with values ranging from 120.79% to 229.41%. These variations in water absorption capacity values of the samples is an indication of the differences in the degree of engagement to form hydrogen and covalent bonds between starch chains as well as the degree of availability of water binding sites among the starches [29]; which might be due to various factors such as particle size, amylose/amylopectin ratio and molecular structure [30].

IPYF had the highest mean water absorption capacity values while DWSF had the least mean water absorption capacity; however these values do not differ significantly ($P≤0.05$) from WREF.

This implies that IPYF have more hydrophilic constituent than HQCF, DWSF and WREF; and hence would have better reconstitution ability [31].

Table 1. Functional properties of High Quality Cassava Flour (HQCF), Dehulled White Sorghum Flour (DWSF), White Rice Flour (WREF) and Instant Pounded Yam Flour (IPYF) and their composites

Sample		LDB (g/cm^3)	PBD (g/cm^3)	WAC (%)	OAC (%)	WBC (g/g)	Disp (%)
100 %	HQCF	0.30^{d} ± 0.02	0.48^{c} ± 0.02	128.01^{b} ± 3.01	104.95^{a} ± 2.77	137.00^{b} ± 3.12	76.50^{b} ± 0.5
	DWSF	0.36^{c} ± 0.02	0.58^{b} ± 0.01	120.79^{c} ± 3.81	76.47^{c} ± 3.74	131.68^{b} ± 2.17	69.00^{c} ± 0.20
	WREF	0.46^{b} ± 0.02	0.59^{b} ± 0.01	127.72^{cb} ± 4.78	72.28^{d} ± 2.14	133.33^{bc} ± 3.26	75.50^{b} ± 0.50
	IPYF	0.71^{a} ± 0.03	0.85^{a} ± 0.02	229.41^{a} ± 4.73	90.29^{b} ± 3.75	243.00^{a} ± 3.00	79.50^{a} ± 1.00
Composite Flours Sample and % Inclusion							
HQCF	15%	0.58^{c} ± 0.02	0.63^{c} ± 0.01	222.75^{a} ± 4.12	76.24^{b} ± 2.06	228.43^{a} ± 2.56	73.00^{a} ± 1.00
	30%	0.48^{e} ± 0.01	0.56^{d} ± 0.01	213.96^{b} ± 2.98	75.49^{bc} ± 1.92	213.86^{cd} ± 3.03	72.00^{ab} ± 1.00
	45%	0.47^{e} ± 0.02	0.55^{d} ± 0.01	201.98^{c} ± 4.10	89.22^{a} ± 2.10	200.99^{f} ± 4.61	71.00^{bc} ± 0.50
DWSF	15%	0.62^{b} ± 0.02	0.76^{b} ± 0.01	213.53^{b} ± 3.25	69.31^{e} ± 1.92	220.79^{b} ± 3.94	71.50^{bc} ± 1.00
	30%	0.54^{d} ± 0.02	0.76^{b} ± 0.02	196.04^{c} ± 4.01	72.82^{cd} ± 2.02	219.00^{bc} ± 4.03	70.50^{de} ± 0.50
	45%	0.47^{e} ± 0.01	0.64^{d} ± 0.01	182.97^{d} ± 3.95	68.63^{e} ± 1.81	190.00^{i} ± 3.00	70.00^{c} ± 1.00
WREF	15%	0.70^{a} ± 0.01	0.79^{a} ± 0.02	218.43^{b} ± 2.51	64.08^{f} ± 1.12	222.77^{ab} ± 4.15	72.50^{ab} ± 1.00
	30%	0.61^{b} ± 0.01	0.79^{a} ± 0.01	200.99^{c} ± 3.00	71.29^{de} ± 1.07	208.82^{de} ± 4.07	71.00^{bcd} ± 1.00
	45%	0.63^{b} ± 0.02	0.75^{b} ± 0.03	188.00^{d} ± 3.01	68.63^{e} ± 1.42	202.97^{ef} ± 4.10	71.00^{cde} ± 0.50

Note: Values are means of triplicate determinations; ± - SD value;
Mean values with different superscript within column are significantly different (P≤0.05).
LBD = Loose bulk density, PBD = Pack bulk density, WAC = Water absorption capacity, OAC = Oil absorption capacity, WBC = Water binding capacity, DISP = Dispersibility

Generally, the ability of any food materials to absorb water is more often than not attributed to its proteins content [32]. However, this cannot be said of these flour samples because they are mainly starch-based and are very poor in protein; therefore the observed differences in water absorbed may have been due to the nature of the starch in the flour samples [33]. Carbohydrate has also been linked to influence water absorption capacity of foods [34]. This view was also supported by Adegunwa et al. [30] who reported that observed differences in water absorption capacity of the carbohydrate based flours may be due to factors like their amylose/amylopectin ratio as well as their molecular structure.

Fat serves as a flavor keeper and enhances the mouth feel of foods; therefore the flour's ability to physically bind fat through capillary attraction is known as its oil absorption capacity [35]. The mean oil absorption capacity of the flour samples differs significantly (*P≤0.05*) with WREF having the least value (72.28%) while HQCF has the highest value (104.95%). The oil absorption capacity obtained for HQCF sample in this research work is lower than the range of 119.02–121.01% reported by Aidoo et al.[36] but higher than the range of values of 61.50 – 72.50% reported by Adebowale et al. [37] and Eleazu et al. [38].These variations might be due to geographical location as well as the genetic factors; while the variations in the sample results may be attributed to the difference in the hydrophilic components of the samples [39]. The higher the hydrophilic components (carbohydrate and protein), the lower the OAC, and vice versa; implying that HQCF has lower the hydrophilic components than the other samples. Generally, the ability of flour to absorb oil will makes it possible to improve flavor and mouth feel [24].

The capacity of starch or starch blends to reconstitute in water is measured by dispersibility. There was a significant (*P≤0.05*) difference in the dispersibility of the flours with IPYF having the maximum dispersibility. This might be as a result of IPYF absorbing more water than the other samples [40]; suggesting that it might reconstitute easily and create a fine paste free of lumps more effectively than the other flour [41]. This property is essential when it comes to instant foods as high dispersibility value would ensure samples free of lumps [42].

The range of values for LBD and PBD of the composite samples are 0.47 - 0.70 (g/cm^3) and 0.55 - 0.79 (g/cm^3) respectively. The results of the composite flours showed that the sample with the highest mean packed bulk density value had a 15% substitution of white rice flour, while the composite with the lowest mean packed bulk density value had a 45% substitution of HQCF, though it did not differ significantly (*P ≥ 0.05*) from the composite with 30% HQCF and 45% sorghum flour substitution.

With the exception of composites made with white rice flour, which do not significantly differ (*P ≤ 0.05*) at 30 and 45% levels of substitution, there was generally a decrease in the mean packed bulk density value of the composite flour as the level of substitution of the cereal and tuber flours to IPYF increased. This trend would enhance ease of dispersion as well a decrease in paste thickness which are two crucial factors in convalescent kid feeding, making higher bulk density desirable [43].

Similar to the composite IPYF, their mean water absorption capacity indicated a significant variation (*P≤0.05*), with values ranging from 188.00% to 222.75%. As the rate of substitution increases, the values fall regardless of the type of flour used. The loose connection of amylose and amylopectin in native starch granules and the reduced associative interactions within the granule structure may be responsible for this effect [44]. The discrepancies in the mean water absorption capacity values of the composite samples may also reflect differences in the degree of engagement to establish covalent and hydrogen bonds between starch chains and the degree of availability of water binding sites among the starches [45].

With the composite flours, the ability of HQCF-IPYF composite to absorb oil rises as the degree of substitution is increased, but that of DWSF-IPYF and WREF-IPYF composites fall as the level of substitution increases. The obtained values differed significantly (*P≤0.05*) across the IPYF composite samples with the value decreasing as the quantity of substitution increases. This might negatively affect the qualities of meals and the food capacity to reconstitute, texture and mouthfeel [40]. The correlation result (Table 3) showed that bulk density (LBD and PBD) had favorable positive correlations with water binding capacity (r ≤ 0.611, *P<0.01*) and (r ≤ 0.766, *P<0.01*) respectively for LBD and PBD, Awoyale et al. [46] also found a significant positive association between bulk density and water absorption index.

3.2 Pasting Properties of Flour Samples

The pasting qualities of starch-based meals are typically evaluated to determine whether their use as a functional ingredient in foods and other industrial goods is appropriate [47,48]. Pasting temperature, peak viscosity, viscosity at 95°C (trough), viscosity at constant 95°C (breakdown), viscosity at 50°C (final viscosity), and viscosity at constant 50°C (setback) are the characteristics that are significant and typically measured during the pasting cycle [49].

The pasting characteristics of High Quality Cassava Flour (HQCF), Dehulled White Sorghum Flour (DWSF), White Rice Flour WREF and Instant Pounded Yam Flour (IPYF) samples are presented in Table 2. The peak viscosity is the highest viscosity that the paste can reach while being heated (50°C and 95°C) as a result of the starch granules expanding and the subsequent leaching of the soluble ingredients into the solution. It illustrates the starch granules' capacity to expand without restriction before breaking down physically [50].

The mean peak viscosity of the flour samples varied significantly (*P ≤ 0.05*) for the flour samples. Both HQCF and IPYF had mean peak viscosities that were higher than those of either rice flour or sorghum flour. This result supported earlier claims made by Van Hung et al. [49] and Biliaderis [50] that cereal starches have lower peak viscosities than tuber and root starches; and that higher peak viscosities are associated with pastes with desirable texture [51,52]. According to Eriksson et al. [53], the difference in the peak viscosity of the flour samples can be attributable to the starch granules' varying degrees of swelling; noting that the associative bonding of the amylose fraction is responsible for the structure and pasting behavior of starch granule.

The trough viscosity (minimum viscosity value that assesses the ability of the paste to withstand breakdown during cooling of the samples) with rice flour having the highest mean value while sorghum flour had the lowest mean value showed a significant difference (p<0.05). This shows that compared to the other samples, rice flour was better able to endure shear at high temperatures [54].

When starch is cooked to 95°C, its breakdown viscosity usually decreases; this is a sign of starch gel stability or dissolution during cooking [48]. The differences in the breakdown viscosity of the flour samples were significant (*P≤0.05*). When the flour samples (HQCF, DWSF, WREF, and IPYF) were broken down, it was found that HQCF had the highest value and IPYF had the lowest value. The ability of the sample to tolerate heating and shear stress during cooking was shown to be inversely correlated with the degree

Table 2. Pasting properties of High Quality Cassava Flour (HQCF), Dehulled White Sorghum Flour (DWSF), White Rice Flour (WREF) and Instant Pounded Yam Flour (IPYF) and their composites

Sample		Peak Viscosity (RVU)	Trough Viscosity (RVU)	Breakdown Viscosity (RVU)	Final Viscosity (RVU)	Setback Viscosity (RVU)	Peak Time (Mins)	Pasting Temp. (ºC)
100 % Flours	HQCF	350.75^{a} ± 1.04	159.08^{b} ± 0.94	191.67^{a} ± 0.84	225.25^{c} ± 0.42	66.17^{c} ± 0.48	4.13^{c} ± 0.22	74.45^{b} ± 0.12
	DWSF	173.42^{d} ± 0.96	116.33^{c} ± 0.52	57.08^{c} ± 0.51	256.67^{b} ± 0.75	140.33^{a} ± 0.92	5.07^{b} ± 0.35	79.90^{ab} ± 1.26
	WREF	241.00^{c} ± 0.78	227.75^{a} ± 1.84	13.25^{b} ± 0.63	334.67^{a} ± 1.62	107.75^{b} ± 0.94	5.60^{b} ± 0.31	79.85^{ab} ± 0.68
	IPYF	310.17^{b} ± 0.96	225.25^{a} ± 1.52	84.75^{d} ± 0.92	333.58^{a} ± 1.86	108.33^{b} ± 0.64	7.00^{a} ± 0.56	83.10^{a} ± 0.75
Composite Flours Sample and % Inclusion								
HQCF	15%	254.83^{a} ± 1.03	234.3^{b} ± 1.08	20.50^{d} ± 1.43	282.58^{d} ± 1.68	48.25^{f} ± 1.02	7.00^{a} ± 0.12	76.65^{d} ± 0.06
	30%	244.65^{b} ± 1.54	225.00^{c} ± 2.54	24.80^{b} ± 1.21	317.83^{b} ± 2.53	92.83^{d} ± 1.25	6.53^{b} ± 0.20	73.45^{e} ± 0.05
	45%	245.08^{b} ± 1.48	215.3^{d} ± 2.16	29.75^{a} ± 0.95	305.67^{c} ± 1.64	90.33^{d} ± 1.36	5.33^{d} ± 0.15	73.40^{e} ± 0.03
DWSF	15%	161.25^{e} ± 1.03	242.75^{a} ± 2.04	14.50^{e} ± 0.92	334.75^{a} ± 3.74	92.00^{d} ± 1.16	6.33^{b} ± 0.18	81.45^{b} ± 0.16
	30%	157.42^{f} ± 1.12	144.42^{f} ± 1.52	15.58^{e} ± 0.84	246.45^{f} ± 1.57	102.03^{c} ± 1.06	6.16^{b} ± 0.25	81.45^{b} ± 0.12
	45%	113.50^{g} ± 1.06	138.90^{g} ± 1.28	22.58^{bc} ± 1.34	259.16^{e} ± 1.62	120.24^{a} ± 2.08	5.60^{c} ± 0.08	79.90^{c} ± 0.12
WREF	15%	243.67^{b} ± 1.39	183.25^{e} ± 1.73	5.50^{g} ± 1.65	259.08^{e} ± 1.05	75.83^{e} ± 1.07	7.00^{a} ± 0.14	82.35^{a} ± 0.21
	30%	224.75^{c} ± 1.06	213.50^{d} ± 1.98	11.25^{f} ± 1.30	304.00^{c} ± 1.82	90.50^{d} ± 1.25	5.73^{c} ± 0.12	79.97^{c} ± 0.08
	45%	188.75^{d} ± 1.10	221.08^{c} ± 2.18	22.58^{bc} ± 1.28	328.17^{a} ± 3.92	107.08^{b} ± 1.21	5.60^{c} ± 0.09	79.90^{c} ± 0.14

Note: Values are means of triplicate determinations; ± - SD value; RVU - Rapid Visco Unit.
Mean values with different superscript within column are significantly different (P≤0.05)

of viscosity breakdown, according to various author reports [22,48,55]. This suggests that IPYF would be more able to tolerate heating and shear stress during cooking than the other flour samples as the breakdown viscosity is typically regarded as a measure of paste stability [56].

The change in viscosity after cooking starch at 50°C is the final viscosity. The ability of a starch-based sample to form a gel or viscous paste after cooking and chilling, as well as the resistance of the viscous paste to shear stress during stirring, is one of the most frequently used parameters to define the quality of a starch-based sample [22]. The final viscosity of the flour samples differs significantly ($P \leq 0.05$). HQCF was the only sample with a higher hot paste viscosity than IPYF and the other samples.

The outcome confirms that after cooking and cooling, yam pastes generally produce firm gels rather than viscous gels. This is caused by the strong connection and high re-crystallization potential of the starch-water systems, which cause steadily increasing viscosities as yam starches cool [57]. Additionally, Uzodinma et al.[57] noted that the degree of starch-water binding, which may be influenced by processes that impact how the starch particles interact with water, determines how quickly the formation of stiffness happens in yam starches.

When a heated substance is cooled, its viscosity recovers, and this is known as setback viscosity. The mean setback viscosity value showed a significant difference ($P \leq 0.05$) for the flour samples with IPYF having the highest value. This result is in agreement with the findings of some authors [58,59, 60] who reported that yam starch has a high setback as a result of retrogradation in comparison with other root and tuber crops.

The pasting temperature is an indicator of the lowest temperature needed to cook a specific flour or starch sample. It is also the temperature at which the first discernible rise in viscosity, a marker of the first alteration brought on by the starch swelling is detected [61,62]. The pasting temperatures of the flour samples varied significantly ($P \leq 0.05$). Among the flour samples, IPYF sample had the highest mean pasting temperature, while rice flour had the lowest.

It is the temperature at which gelatinized starch reaches its maximum viscosity when being heated in water, and it represents the starch's ability to bind water [51].

The pasting characteristics of composites Instant Pounded Yam Flour (IPYF) from varying levels (15%, 30% and 45%) of High Quality Cassava Flour (HQCF), Dehulled White Sorghum Flour (DWSF) and White Rice Flour (WREF) inclusion (Table 2) revealed that the mean value of the peak viscosity of the composite IPYF varies significantly ($P \leq 0.05$), with the composites from HQCF increasing with increasing levels of replacement while those from sorghum and rice flour decreasing with increasing levels of substitution. The good texture of pounded yam generally benefits from high peak viscosity, which is mostly dependent on high viscosity and fairly high gel strength [51]. An indicator that the flours can be utilized for the production of samples that require low gel strength and elasticity is the relative effect of peak viscosity decreasing with an increase in sorghum and rice flour substitution [22].

In the composite IPYF samples, the mean trough viscosity values increases as the proportion of WREF to IPYF increases, whereas for HQCF and DWSF, the mean trough viscosity values decreases as the rate of replacement increases. With the mean value increases with increasing levels of replacement, the breakdown viscosity of the composite samples also varies significantly ($P \leq 0.05$), which is unfavorable since it results in uneven viscosity and the cohesive nature of the starch paste [56].

The mean setback viscosity values for the composite flours likewise varied significantly ($P \leq 0.05$) from one another. The mean setback viscosity value of the flour samples reduces with an increase in HQCF substitution; this suggests that the flour may be relatively more stable when cooked [48, 63]. However, the mean setback viscosity increase as the quantity of white rice flour substitution increases, this suggests that the level of retrogradation during cooling increases proportionately as well [64]. Higher setback viscosity values have typically been linked to cohesive paste and high-quality pounded yam or fufu [51,65].

In general, as the level of substitution is increased, the peak time of the composite flours decreases. This suggests that the heating/cooking time required for gelatinization was generally decreased during the preparation of composite IPYF. Therefore, when all other parameters are similar, flours with shorter peak times may be preferable in terms of heat consumption during cooking.

Table 3. Pearson correlation between the functional and pasting properties of the flour samples

Parameters	LBD	PBD	WAC	OAC	WBC	Disp	PkVis	TrVis	BdVis	FlVis	SbVis	PkTe	PgTp
Loose Bulk Density (LBD)	1												
Pack Bulk Density (PBD)	.796**	1											
Water Absorption Capacity (WAC)	-.049	-.099	1										
Oil Absorption Capacity (OAC)	-.093	-.019	.599**	1									
Water Binding Capacity (WBC)	.611**	.766**	.372*	.340	1								
Dispersiblity (Disp)	-.208	-.196	-.397*	-.514**	-.592**	1							
Peak Viscosity (PkVis)	.283	.146	.403*	.383*	.241	-.243	1						
Trough Viscosity (TrVis)	.401*	.218	.317	.326	.284	-.275	.975**	1					
Breakdown Viscosity (BdVis)	-.550**	-.356	.440*	.383*	-.249	.073	.043	-.151	1				
Final Viscosity (FlVis)	.361	.233	.256	.373*	.226	-.189	.924**	.912**	.034	1			
Setback Viscosity (SbVis)	.234	.336	-.028	.449*	.164	-.198	.597**	.554**	.295	.662**	1		
Peak Time (PkTe)	.584**	.521**	-.169	-.087	.581**	-.555**	.039	.177	-.724**	.013	-.009	1	
Pasting Temp (PgTm)	.401*	.632**	-.401*	-.604**	.290	.186	-.369	-.348	-.235	-.259	-.194	.228	1

***. Correlation is significant at the 0.01 level (2-tailed).*
**. Correlation is significant at the 0.05 level (2-tailed)*
Bold value indicates a strong correlation (r > 0.75)

For all the composite flours, there were slight decreases in the pasting temperature with increase in the level of substitution. For technical and economic reasons, flours with low pasting temperature may be preferred when all other properties are equal.

Peak viscosity has a strong positive correlation with trough viscosity (r ≤ 0.975, *P<0.01*) and final viscosity (r ≤ 0.924, *P<0.01*). Also, trough viscosity has a strong positive correlation with final viscosities (r ≤ 0.912, *P<0.01*). Breakdown viscosity has strong negative correlation (r ≤ - 0.724, *P<0.01*) with peak time; while final viscosity has a positive correlation with setback viscosity (r ≤ 0.662, *P<0.01*) (Table 3).

3.3 Principal Component Analysis of the Flour Samples

Principal component analysis (PCA) gives details on similarities or otherwise between samples; as well as the inter-relationships between the measured variables. Fig. 1 gives the PCA plots of the flour (IPYF and the composites) samples.

The distance between the flour samples location (shown by their numbers on the score plot) is directly related to how different or similar they are from each another. Positive correlation exists between properties whose curves are close to one another on the plot, and negative correlation exists between properties whose curves run in the opposite directions.

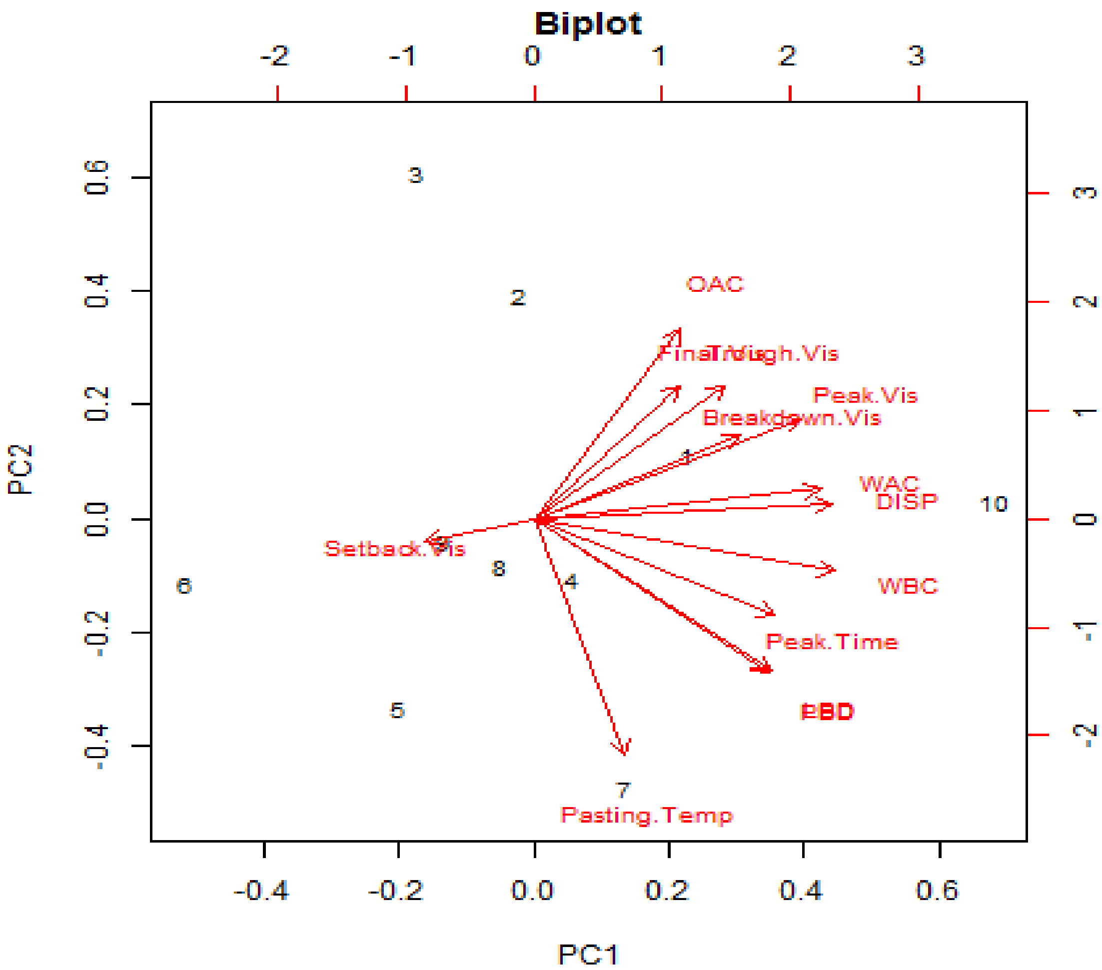

Fig. 1. Loading plot with first and second components of the principal component analysis of the variables of the functional and pasting attributes of the flour samples

Where: (1) - IPYF with 15% HQCF; (2) - IPYF with 30% HQCF; (3) - IPYF with 45% HQCF; (4) - IPYF with 15% DWSF; (5) - IPYF with 30% DWSF; (6) - IPYF with 45% DWSF; (7) - IPYF with 15% WREF; (8) - IPYF with 30% WREF; (9) - IPYF with 45% WREF; (10) – 100% IPYF

According to the variables investigated (as shown in red), the flour samples (10) (numbered in black) is divided into four groups by the first two axes, with each group having similar characteristics based on the measured properties (as shown in red). The first group (positive coefficient PC 1 and PC 2) contains two flour samples (1 and 10); the second group with positive coefficient for PC1 and negative values for PC2 also had two samples (4 and 7). The third group with negative values for both PC1 and PC2 had four samples (5, 6, 8 and 9) while the last group with two samples (2 and 3), had negative coefficient for PC1 and positive coefficient for PC2.

A total of 93.49% of the variability was explained by the first, second, third and fourth PCs (Table 4) which were described by 47.07%, 20.91%, 15.72% and 09.79% respectively of the variation.

While all remaining composites are on the negative side of the first principal component (PC1), the 15% composite samples (1, 4 and 7) and the 100% IPYF flour samples were all positioned on the positive side of the Biplot (Fig. 1). Additionally, the second principal component (PC2) had all of the HQCF composites and 100% of IPYF on the positive side and the rest on the negative.

Based on its ability to absorb water and the dispersibility of the flour, Sample 10 (100% IPYF) was clearly distinguished from the other flour samples. On the basis of their relative setback viscosity and pasting temperature, samples 7 (IPYF with 15% WREF) and 9 (IPYF with 45% WREF) stood out from the other samples; while sample 6 (45% DWSF composite) had a big negative score in PC1, sample 10 (100% IPYF) displayed a large positive score. Sample 3 (45% HQCF composite) had a big positive score in the second principal component, whereas Sample 7 (15% WREF composite) had a large negative score (PC2).

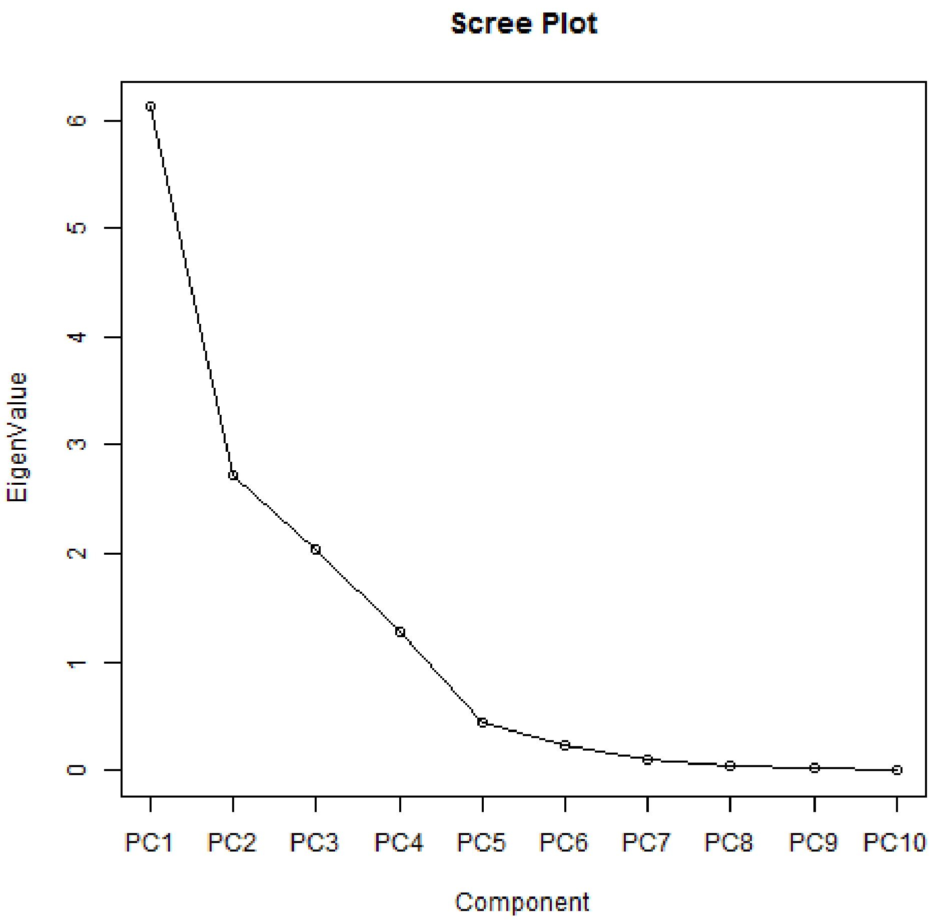

Fig. 2. Scree plot with first and second components of the principal component analysis of the variables of the functional and pasting attributes of the flour samples

Table 4. Eigenvalues, total variance, cumulative variance and correlation coefficients between measured variables and the first four principal components that described the variation measured characteristics on flour samples

Factor	Principal components			
	1	2	3	4
Loose Bulk Density (LBD)	0.294	**-0.336**	*	0.272
Packed Bulk Density (PBD)	0.294	**-0.338**	-0.122	0.174
Water Absorption Capacity (WAC)	**0.358**	*	0.265	-0.119
Oil Absorption Capacity (OAC)	0.183	**0.419**	-0.240	-0.294
Water Binding Capacity (WBC)	**0.374**	-0.116	*	-0.134
Dispersibility (DISP)	**0.373**	*	-0.203	-0.177
Peak Viscosity (Peak Vis)	**0.332**	0.222	*	-0.102
Trough Viscosity (Trough Vis)	0.238	0.295	0.153	**0.530**
Breakdown Viscosity (Breakdown Vis)	0.257	0.185	**-0.446**	-0.233
Final Viscosity (Final Vis)	0.180	0.296	-0.208	**0.589**
Setback Viscosity (Setback Vis)	-0.137	*	-0.269	*
Peak Time	0.229	-0.212	0.252	-0.218
Pasting temperature	0.113	**-0.522**	-0.269	*
Eigen values of correlation matrix	6.119	2.718	2.044	1.273
Explained proportion of total variance %	47.07	20.91	15.72	09.79
Cumulative proportion of total variance %	47.07	67.98	83.70	93.49

N.B - Bold values indicate correlation coefficients with value equal to or greater than 0.3 in absolute value;
** - Loading value <0.1.4.0*

4. CONCLUSION

The functional and pasting properties of Instant Pounded Yam Flour (IPYF) and the composites from High Quality Cassava Flour (HQCF), white rice flour (WREF), dehulled white sorghum flour (DWSF) were significantly (p<0.05) affected by their level of substitutions (15%, 30% and 45%). Based on the PCA, 15% level of substitution with HQCF would give an acceptable composite IPYF close to 100% IPYF.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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