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Comparative evaluation of physicochemical qualities of flours from steam-processed yam tubers

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Abstract

Three factors were comparatively evaluated during the atmospheric steaming of yam tubers and down-stream processing of the resultant flours. White yam (*Dioscorea rotundata* Poir), water yam (*D. alata* L.) and yellow yam (*D. cayenensis* Lam) tubers were used for this investigation. The effects of yam tuber variety (white, water and yellow), tuber steaming time (30, 60, 90, 120 min) and flour particle size (75, 125, 150, 180, 250, 375, 500 μm) on the physicochemical quality of yam flour were studied. The magnitude and extent of the factorial influence were measured/conducted using the effects on water absorption capacity, swelling index, iodine affinity of starch, solubility and gelatinization temperature. All three variables were observed to cause significant differences ($P \leqslant 0.05$) in all the test parameters of flour. Based on the results, it is recommended that (from an economic standpoint) tubers of water/yellow yam be steamed at a minimal time of 60 min and pulverized into flours of particle sizes of not less than 75 μm and not more than 375 μm. This combination will give rise to a steamed yam flour sample which exhibits optimum physicochemical characteristics.

Keywords: Comparative evaluation; Yam tuber variety; Steaming time; Particle size; Yam flour; Physico-chemical quality

1. Introduction

Yams are major food crops in West Africa, the Caribbean, islands of the south Pacific, South-East Asia, India and parts of Brazil (Coursey, 1984; Degras, 1993; Ihekoronye & Ngoddy, 1985; Okonkwo, 1985; Onayemi & Potter, 1974). Nutritionally, yam constitutes a better source of ascorbic acid and protein than cassava (Onayemi, 1986).

The processed form, in which yam tubers are consumed or preserved, is flour (Akoroda, 1987,1994). This product makes it possible to extend the supply of yam through the off-season, thereby reducing storage losses as well as marketing and transportation costs (Coursey & Ferber, 1979). Yam flour has found increasing use in bakery (Osisiogu, 1973; Martin & Ruberte, 1975; Coursey & Ferber, 1979; IITA, 1988).

The fact that varietal differences in tuber (Onyia, 1986; Kamenam, Beuchat, Chinnin, & Heaton, 1987; FAO, 1991), steaming time (Iwuoha, 1999) and particle size (Iwuoha & Nwakanma, 1998) affect the functional qualities of yam flour cannot be over-emphasized. There is a need for comprehensive investigation so that each factor/variable and all accompanying post-extraction handlings of the flour may be completely evaluated and comparatively accounted for.

In view of the foregoing, tuber variety, steaming time and particle size have been chosen as the condition/working variables. Therefore, the objective of this study was to comparatively evaluate the physicochemical properties of flour as functions of yam tuber variety (YTV), tuber steaming time (TST), and flour particle size (FPS).

2. Materials and methods

2.1. Materials

Wholesome, mature, dormant tubers of white yam, WHY (*Dioscorea rotundata* Poir), water yam, WTY (*Dioscorea alata* L.) and yellow yam, YLY (*Dioscorea cayenensis* Lam) were obtained from a local cottage yam farm and used for this investigation.

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2.2. Methods

2.2.1. Generation of samples

Tubers from the three species were pared off, washed and cut into chunks (2 cm thick each). The chunks from each yam tuber variety were divided into four batches. A Fisher water bath was used to steam the chunks at, 1 atm. pressure, and they were withdrawn after 30, 60, 90, and 120 min. The steamed chunks were subsequently cooled to room temperature (30 °C±2 °C). Both the steamed and cooled and untreated (i.e. 0 min) chunks were cut into 5 mm thick slices, dried in a forced-draught oven at 50 °C for 24 h, and ground in a Kenwood Portable Mill into flour to pass through a 1-mm sieve.

The pre-gelled and raw flour samples from the three yam varieties were separated into particle sizes of 75, 125, 150, 180, 250, 375, and 500 μm using a standard Tyler Sieve Series. Each sample was kept airtight for further analyses.

2.2.2. Analyses of samples

2.2.1.1. Moisture content determination. The AOAC (1990) procedures of exposing (2 g, db each test flour) sample in the oven at 105 °C for 3 h were followed for moisture content determination.

2.2.2.2. Water absorption capacity determination. The method of Sosulski (1962) as described by Abbey and Ibeh (1988) was adopted. Flour sample (1 g, db) of each treatment was weighed separately (and also together with a clean, dry centrifuge tube, into which it was placed). Distilled water was mixed with the flour to make up to 10 ml of dispersion. It was then centrifuged at 3500 rpm for 15 min. The supernatant was discarded and the tube with its contents reweighed. The gain in mass was the water absorption capacity of the flour sample.

2.2.2.3. Swelling index determination. Three gramme portions (db) of each flour were transferred into clean, dry, graduated (50 ml) cylinders. The flour samples were gently levelled and the volumes noted. Distilled water (30 ml) was added to each sample; the cylinder was swirled and allowed to stand for 60 min while the change in volume (swelling) was recorded every 15 min. The swelling power of each flour sample was calculated as a multiple of the original volume as done by Ukpabi and Ndimele (1990).

2.2.2.4. Iodine affinity of starch determination. The iodine affinity of starch was assayed according to method of Kawabata et al. (1984): Three grammes of flour samples (db) were introduced into 50 ml beakers and made up to 30 ml dispersions using distilled water. The dispersion was stirred occasionally within the first 30 min and then filtered through Whatman no.42 filter paper. A 10 ml aliquot of the filtrate was pipetted into a conical flask, phenolphthalein (four drops) was added, and the filtrate titrated with $0.1\mathrm{NI}_2$ solution to a bluish-black end-point. The starch cell damage (free starch content) was calculated using the titre value and expressed as iodine affinity of starch, IAS (ppm):

$$\mathrm{IAS\ (ppm)} = \frac{V_{\mathrm{D}}}{V_{\mathrm{A}}} \times \frac{V_{\mathrm{t}}}{M_{\mathrm{s}}} \times \frac{N_{\mathrm{a}}}{1000} \times 10^{6}$$

Where V_{D} = Total volume of dispersion
V_{A} = Volume of aliquot use for titration
V_{t} = Titre value
M_{s} = Mass (db) of flour used
N_{a} = Normality of iodine solution used

2.2.2.5. Solubility determination. The cold water extraction method, as described by Udensi and Onuora (1992), was adopted. Flour dispersion (10% $^{\mathrm{m}}/_{\mathrm{v}}$, db) was prepared with each of the flour samples by dispersing 1 g (db) of flour in a little distilled water and making it up to 10 ml. It was allowed to stand for 60 min while it was stirred every 10 min. Then it was allowed to settle for 15 min, after which 2 ml of the supernatant were pipetted into a weighed, dry Petri dish, evaporated to dryness and reweighed. The difference in mass is the total soluble solids. Solubility was calculated thus:

$$\mathrm{Solubility} = \mathrm{TSS}\ (\%) = \frac{V_{\mathrm{S}}}{2}\frac{M_{\mathrm{e}} - M_{\mathrm{d}}}{M_{\mathrm{s}}} \times 100$$

Where V_{s} = Total supernatant/filtrate
M_{d} = Mass of empty, dry petridish
M_{e} = Mass of petridish plus residual solids after evaporative drying
M_{s} = Mass of flour sample used in the preparation of the dispersion.

2.2.2.6. Gelatinization point determination. In the determination of gelling temperature, the method of Narayana and Narasinya-Rao (1982) was adopted. The flour sample (10 g db) was dispersed in distilled water in a 250-ml beaker and made up to 100 ml of flour suspension. A thermometer was clamped on a retort stand with its bulb submerged in the suspension, with a magnetic stirrer, and the system heated. The heating and stirring were continued until the suspension began to gel and the corresponding temperature was recorded.

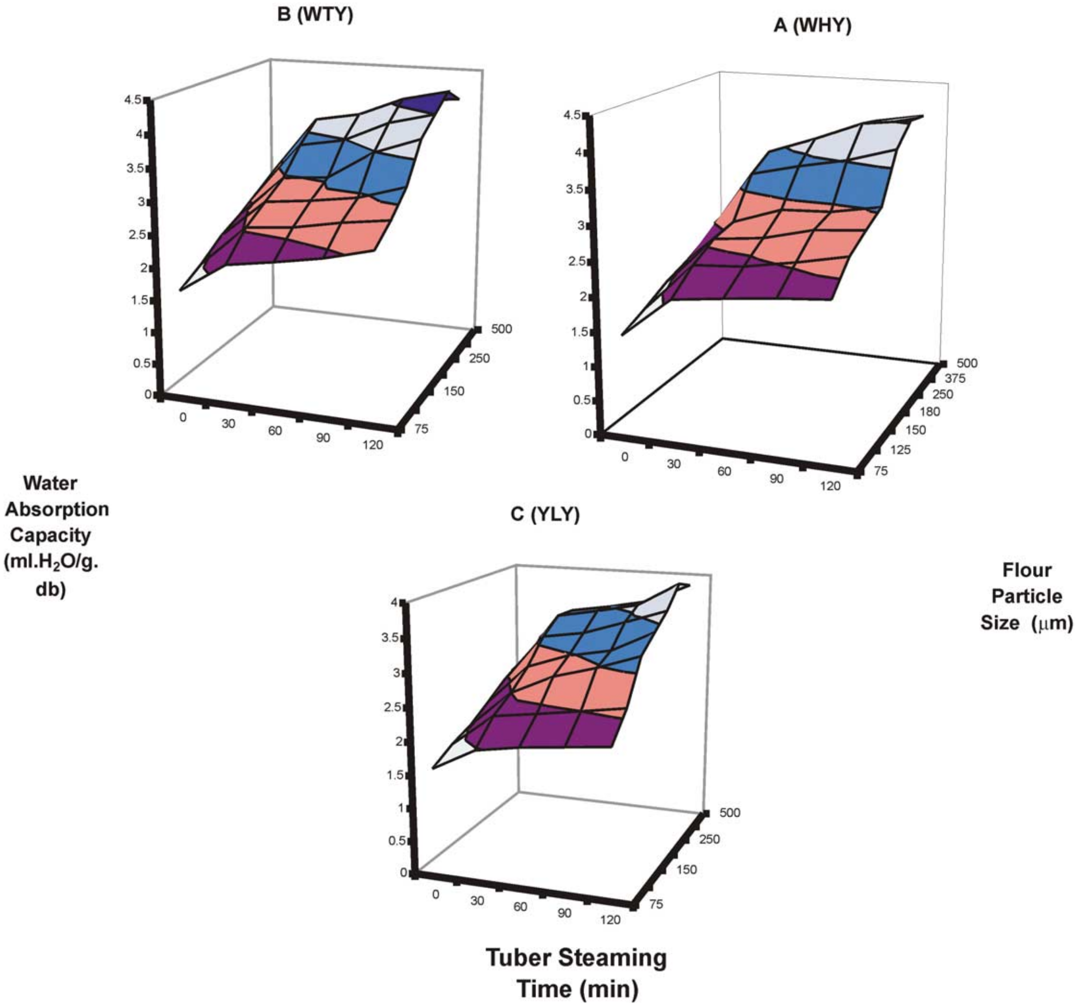

Fig. 1. Effect of tuber steaming time and particle size on water absorption capacity of yam flour: (A) White yam (WHY), (B) Water yam (WTY), (C) Yellow yam (YLY).

2.2.2.7. Range computation. Further to the analyses above, the ranges, *R*, for all the test parameters, were computed as shown below:

$$R = P_{xy(f)} - P_{xy(i)},$$

where

P = Value of parameter
X = Specific physico-chemical property
Y = Specific condition variable/factor
F = final value of the property under the prevailing factor/variable
I = initial value of the property under the prevailing factor/variable

2.2.2.8. % Increase in value computation. Percent increases in the values of the test parameters were computed, taking into account the raw/untreated sample and the means of treated samples from respective components of each factor/variable. Thus:

$$\% \text{ increase invalue} = \left\{\left[X_{Mij} - X_{Rij}\right]/X_{Rij}\right\} \times 100$$

where

X_{Mij} = mean treated sample (M) value of the property (i) under the prevailing factor/variable (j),
X_{Rij} = point raw/untreated sample (R) value of the property (i) for the prevailing factor/variable (j)

2.3. Statistical analyses of data

Two sets of analysis of variance (ANOVA) were carried out. In the first case, the mean values of the physicochemical parameters were assessed as functions of yam tuber variety, YTV (three types), tuber steaming time, TST (four durations) and flour particle size, FPS (seven sizes), which statistically fitted into a 3×4×7 factorial design/experiment according to the standard procedures of Steel and Torrie (1980). Secondly, the values of range and % increase in value of all the test

Table 1
Mean water absorption capacity of flour as a function of yam tuber variety, tuber steaming time and flour particle size

Source of variation	Components of variation	Water absorption capacity (ml H_2O/g db)		
		Range	Increase in value (%)	Mean±S.D.
Yam tuber variety (YTV)	White yam (WHY)	1.94X	50.8Y	3.03±0.59X
	Water yam (WTY)	2.07X	39.7X	3.24±0.42Y
	Yellow yam (YLY)	1.96X	39.1X	2.99±0.54X
	LSD (YTV)	0.15	1.22	0.04
Tuber steaming time (TST) (min)	30	1.67Q	32.0Q	2.85±0.49Q
	60	1.69Q	38.0R	2.98±0.52R
	90	1.92R	46.8S	3.17±0.59S
	120	2.01R	54.7T	3.34±0.61T
	LSD (TST)	0.11	0.15	0.05
Flour particle size (FPS) (μm)	75	0.63B	38.2B	2.23±0.16A
	125	0.54A	42.2C	2.55±0.15B
	150	0.70C	43.2D	2.84±0.21C
	180	1.11E	43.3D	3.08±0.31D
	250	0.90D	48.5F	3.49±0.26E
	375	0.92D	48.0E	3.76±0.28G
	500	0.70C	35.9A	3.65±0.24F
	LSD (FPS)	0.03	0.08	0.06

LSD, Least significant difference at $P \leqslant 0.05$. Means with uncommon letters (A–G, Q–T, X–Z) in the same column for the factor in under concerned differ significantly according to Fisher's test ($P \leqslant 0.05$).

Table 2
Mean swelling index of flour as a function of yam tuber variety, tuber steaming time and flour particle size

Source of variation	Components of variation	Swelling index (cm^3/cm^3)		
		Range	Increase in value (%)	Mean±S.D.
Yam tuber variety (YTV)	White yam (WHY)	2.10X	108Z	3.33±0.61X
	Water yam (WTY)	2.23Y	88.4X	3.56±0.66Z
	Yellow yam (YLY)	2.07X	95.5Y	3.39±0.43Y
	LSD (YTV)	0.03	1.10	0.04
Tuber steaming time (TST) (min)	30	1.76Q	77.3Q	3.09±0.53Q
	60	2.05S	93.4R	3.37±0.62R
	90	2.09S	104.4S	3.56±0.60S
	120	1.93R	111.8T	3.69±0.53T
	LSD (TST)	0.12	0.97	0.04
Flour particle size (FPS) (μm)	75	0.98D	125G	2.53±0.30A
	125	0.74A	113F	2.81±0.20B
	150	0.88B	99.3E	3.26±0.27C
	180	0.98D	98.7D	3.51±0.30D
	250	1.14E	93.8C	3.79±0.31E
	375	0.98D	86.1B	3.97±0.24F
	500	0.90C	83.9A	4.13±0.25G
	LSD (FPS)	0.03	0.07	0.06

LSD, Least significant difference at $P \leqslant 0.05$. Means with uncommon letters (A–G, Q–T, X–Z) in the same column for the factor in under concerned differ significantly according to Fisher's test ($P \leqslant 0.05$).

parameters were subjected to one-way classification as functions to the respective study factors/variables as per the method of Danzart (1986). The appropriate reduced sum of squares, mean and variance ratios were computed, and, where significant variations occurred, Fisher's (LSD = least significant difference) multi-comparison test was used to separate each factor means according to Roessler (1984).

3. Results and discussion

3.1. Water absorption capacity (WAC)

The primary values from the measurements of WAC (ml H_2O/g.db) in response to the various combinations of tuber steaming time (TST) and flour particle sizes (FPS) are illustrated using computer-generated surface

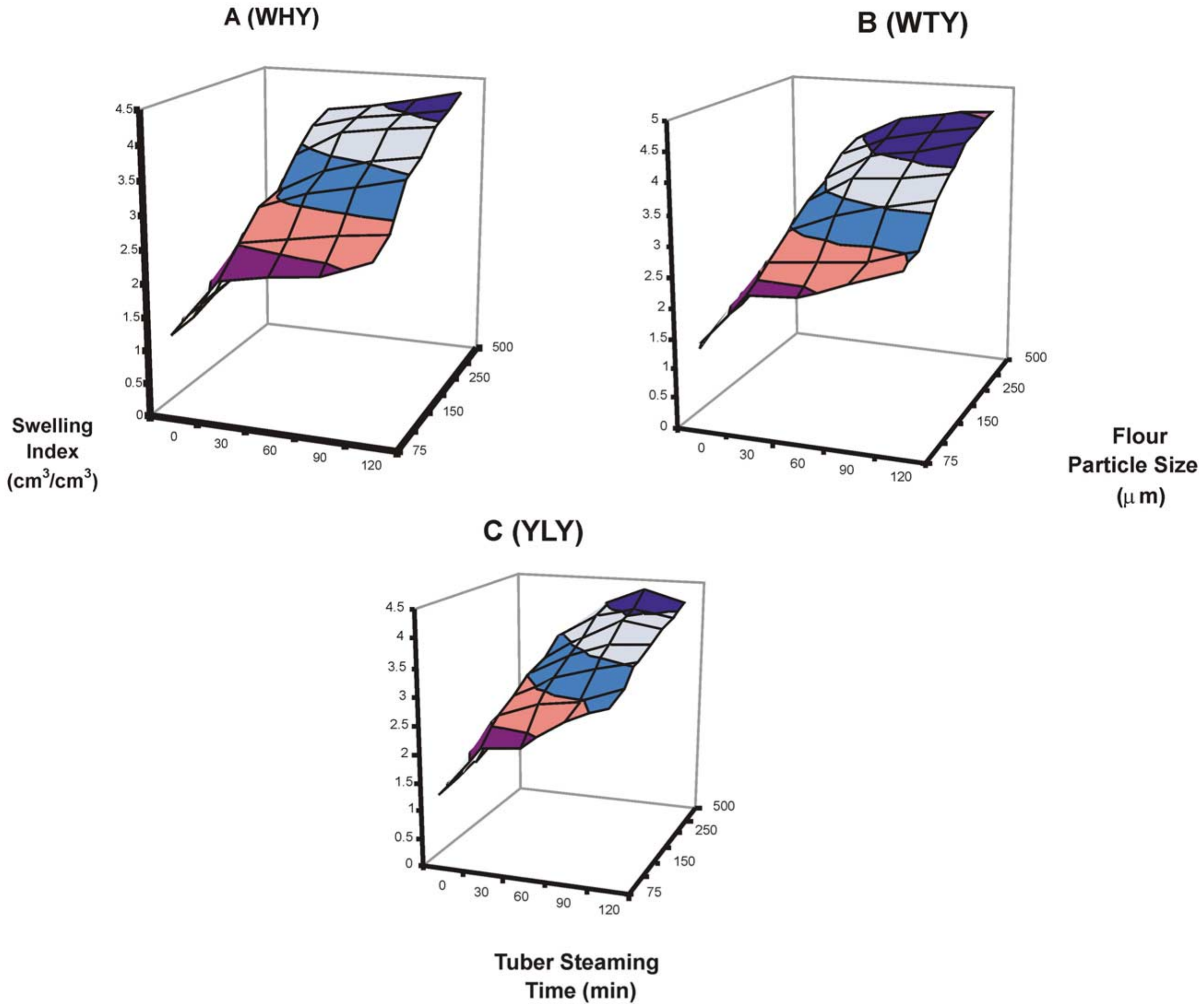

Fig. 2. Effect of tuber steaming time and particle size on swelling index of yam flour from White yam (WHY) (A), Water yam (WTY) (B), Yellow yam (YLY) (C).

charts for the three test varieties of yam; Fig. 1A (white yam, WHY), Fig. 1B (water yam, WTY) and Fig. 1C (yellow yam, YLY). For the WHY 3-D surface (Fig. 1A), the highest WAC (ml H_2O/g db) was 4.03 at (TST, FPS) of (120 min, 375 µm) while the lowest was 2.09 (30 min, 75 µm). For WTY (Fig. 1B), the highest was 4.24 (120 min, 375 µm) while the least was 2.17 (30 min, 75 µm). In the case of YLY (Fig. 1C), the greatest value was 3.94 (120 min, 375 µm) while the least was 1.98 (30 min, 75 µm). The obvious variations in the comparative maxima and minima call for further appraisal, e.g. by analyses of variance (ANOVA) to determine the significance of the differences and the possible separations. Even among the untreated (i.e. unsteamed) samples, the highest value was 2.88 (500 µm, WTY) while the lowest of all was 1.50 from WHY (75 µm).

Comparing the WAC as a function of yam tuber variety (YTV), the WTY's 3.24 was observed to be significantly higher than those of WHY and YLY. The values for the latter two were equivalent ($P \leqslant 0.05$, Table 1). The range of values followed the same trend as reported above for the mean values, without significant differences between them. On the other hand, the % increase in WAC values was significantly higher for WHY while figures for the other two test tubers indicated statistical equivalent ($P \leqslant 0.05$). This implies that WHY, WTY and YLY can serve as equal alternatives with reference to the WAC criterion for yam flours.

The WAC exhibited direct proportionality with the tuber steaming time (TST). The 120 min sample had the highest ($P \leqslant 0.05$) WAC, range and % increase in value. This means that, to impart a relatively high WAC characteristic into yam flour, its tuber must be steamed

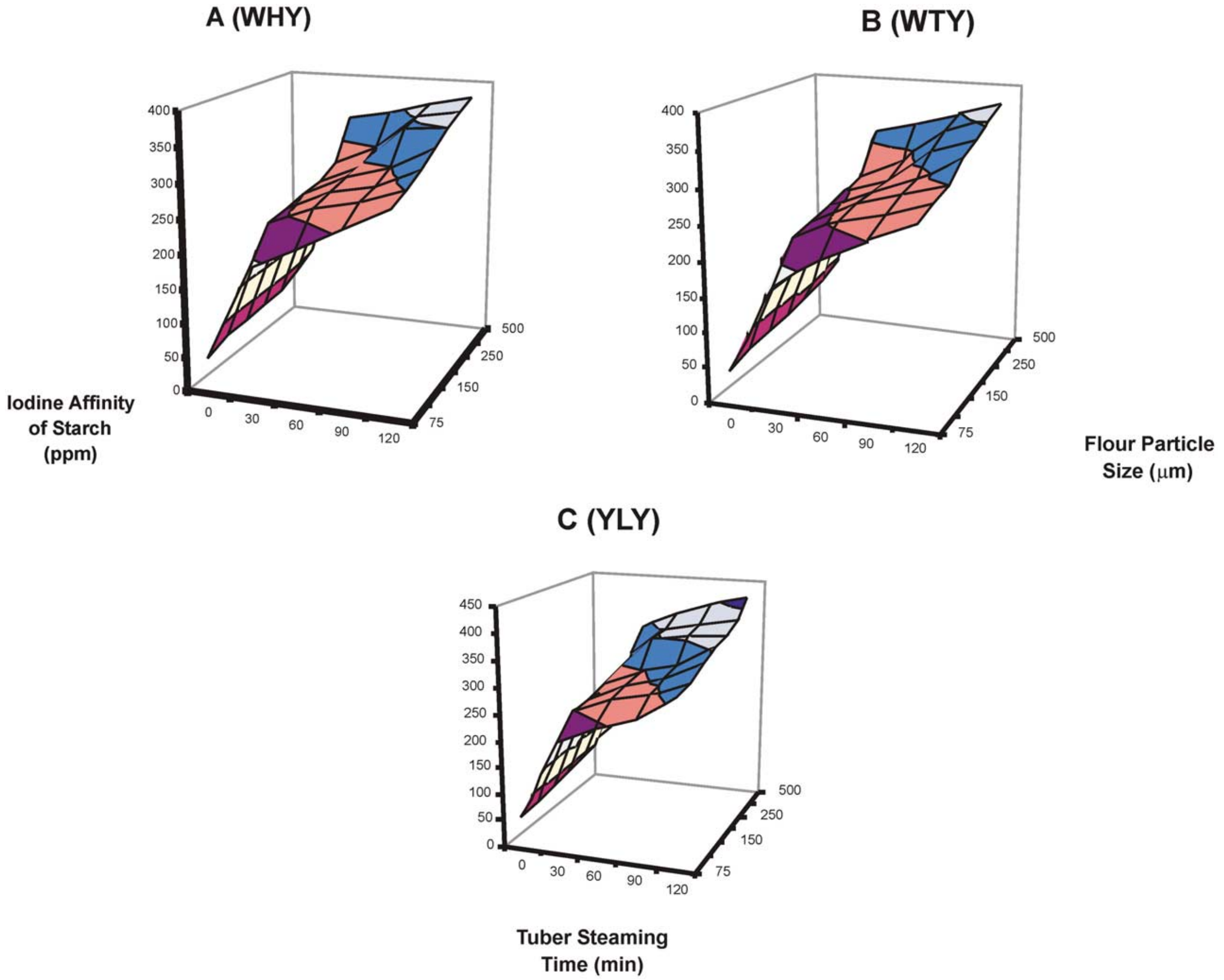

Fig. 3. Effect of tuber steaming time and particle size on iodine affinity of starch of flour from White yam (WHY) (A), Water yam (WTY) (B), Yellow yam (YLY) (C).

for a substantial. At 120 min steaming time, the WAC of yam flour increased by more than 50%. It is possible that severity/intensity of steaming induces bio-physical readjustments in the structural matrix of the tubers to increase their inherent capability to hold more water. The latter condition appears to favour WTY more than the other two varieties.

The effect of FPS exhibited the highest mean WAC (3.76) at 375 μm while the significantly least (2.23) was from the 75 μm sample ($P \leqslant 0.05$). However, the peak for the range was obtained from the 250 μm sample (48.51) which is significantly different from all the others ($P \leqslant 0.05$). The 250 μm sample appears to be a rival alternative to the 375 μm FPS sample.

It is evident from these results that all the test variables, YTV, TST and FPS are critical influential factors for determining the magnitude and extent of WAC of yam flour. Judging from the mean WAC, then the flour sample from the WTY tuber, steamed for 120 min and the dried chips pulverized into 375 μm particle size emerges as the best choice. Based on the range of WAC, any of the tubers, steamed for a minimum of 90 min, and pulverized to 180 μm flour will be the choice. Using the% increase in WAC value as the choice criterion, then the WHY tuber, steamed for 120 min and pulverized into 250 μm should be chosen.

3.2. Swelling index (SI)

According to the 3-D surface chart for SI (cm^3/cm^3) of flour as a function of TST and FPS for WHY (Fig. 2A), the greatest value was 4.26 (120 min, 500 μm). The highest for the WTY (Fig. 2B) was 4.58 (120 min, 500 μm), whereas the highest for the YLY (Fig. 2C) was 4.32 (90 min, 500 μm).

Table 3
Mean iodine affinity of starch for flour as a function of yam tuber variety, tuber steaming time and flour particle size

Source of variation	Components of variation	Iodine affinity of starch (ppm)		
		Range	Increase in value (%)	Mean ± S.D.
Yam tuber variety (YTV)	White yam (WHY)	183X	299Y	294 ± 46Y
	Water yam (WTY)	192Y	303Z	283 ± 45X
	Yellow yam (YLY)	204Z	280X	317 ± 50Z
	LSD (YTV)	7.0	1.2	4.1
Tuber steaming time (TST) (min)	30	165T	237Q	256 ± 40Q
	60	152S	278R	287 ± 40R
	90	144R	312S	313 ± 39S
	120	136Q	344T	337 ± 34T
	LSD (TST)	1.5	0.9	4.7
Flour particle size (FPS) (μm)	75	137F	347G	243 ± 39A
	125	124E	319F	272 ± 25B
	150	115D	315E	282 ± 30C
	180	115D	309D	293 ± 33D
	250	109C	305C	312 ± 41E
	375	100B	257B	326 ± 40F
	500	93A	243A	358 ± 27G
	LSD (FPS)	1.1	1.1	6.2

LSD, Least significant difference at $P \leqslant 0.05$. Means with uncommon letters (A–G, Q–T, X–Z) in the same column for the factor in under concerned differ significantly according to Fisher's test ($P \leqslant 0.05$).

Table 4
Solubility of flour as a function of yam tuber variety, tuber steaming time and flour particle size

Source of variation	Components of variation	Solubility (%, db)		
		Range	Increase in value (%)	Mean ± S.D.
Yam tuber variety (YTV)	White yam (WHY)	10.74Y	53.34X	13.15 ± 2.58Y
	Water yam (WTY)	7.89X	60.47Y	12.40 ± 2.02X
	Yellow yam (YLY)	11.08Z	53.42X	14.20 ± 2.72Z
	LSD (YTV)	0.16	0.83	0.14
Tuber steaming time (TST) (min)	30	5.75Q	22.78Q	10.46 ± 1.46Q
	60	6.76S	52.13R	12.96 ± 1.83R
	90	6.58R	66.33S	14.17 ± 1.71S
	120	8.01T	80.89T	15.41 ± 2.15T
	LSD (TST)	0.11	1.16	0.16
Flour particle size (FPS) (μm)	75	8.19F	47.73A	15.65 ± 2.39G
	125	7.67E	54.74B	14.69 ± 2.24F
	150	7.01D	54.88C	13.96 ± 2.12E
	180	6.73C	55.91E	13.32 ± 2.04D
	250	6.00B	61.61F	12.67 ± 1.89C
	375	5.90B	61.78G	11.81 ± 1.79B
	500	5.37A	55.62D	10.66 ± 1.60A
	LSD (FPS)	0.10	0.09	0.21

LSD, Least significant difference at $P \leqslant 0.05$. Means with uncommon letters (A–G, Q–T, X–Z) in the same column for the factor in under concerned differ significantly according to Fisher's test ($P \leqslant 0.05$).

From the ANOVA results and the multi-comparison of SI as a function of YTV, the WTY's 3.56 was the highest while the WHY's 3.33 was the lowest at $P \leqslant 0.05$ (Table 2). The range for WTY was also highest while its% increase was the least. Some workers have expressed the view that the bonding forces of the starch granules in WTY were responsible for the flour to exhibit high swelling (Ayernor, 1985; Kamenan et al., 1987). From these results, it can be inferred that YTV is a critical factor of SI of flour

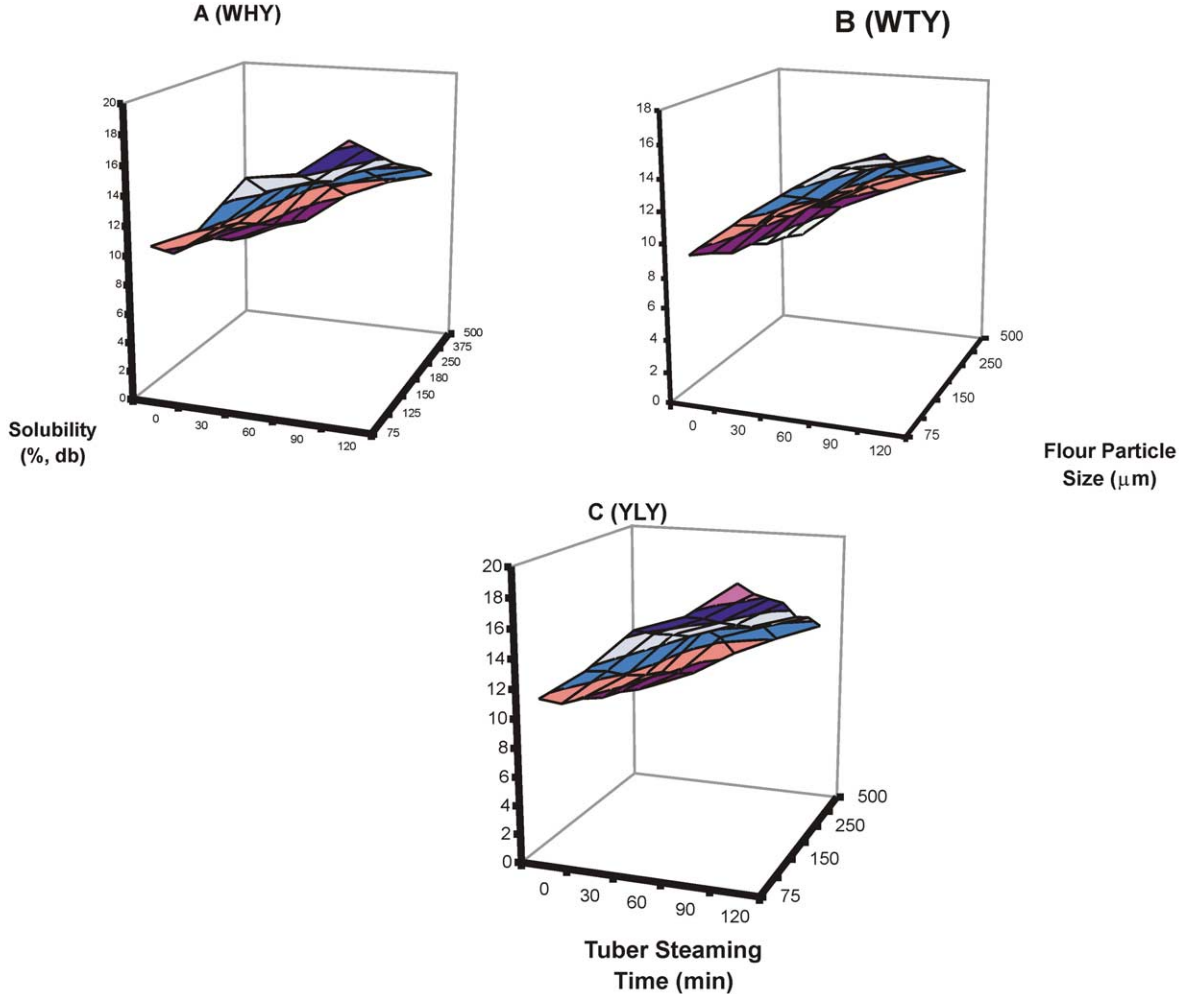

Fig. 4. Effect of tuber steaming time and particle size on solubility of flour from White yam (WHY) (A), Water yam (WTY) (B), Yellow yam (YLY) (C).

The TST showed a direct and significant relationship with the SI, with 120 min-steamed sampled yielding both the highest mean value and highest% increase in value ($P \leqslant 0.05$). This observation is not in line with the trend of response observed by Iwuoha (1999) when he investigated WHY tubers alone. Furthermore, the inverse relationship observed in the% increase in value as a function of FPS is a possible indication that there is a limit to swellability of flour from steamed yam.

It is clear from the foregoing that the three main variables (YTV, TST and FPS) have distinct and marked influence on the SI of steamed yam flour. The best alternative choices are thus; WTY (120 min, 500 µm), WHY (120 min, 75 µm), or WTY (60 min, 250 µm).

3.3. Iodine affinity of starch (IAS)

The primary values obtained from the measurements of the iodine affinity of starch, IAS (ppm) are shown in Fig. 3A (WHY), Fig. 3B (WTY) and Fig. 3C (YLY). The highest point value for WHY sample was 375 (120 min, 500 µm), the maximum for WTY was 368 (120 min, 500 µm) while the maximum for YLY was 416 (120 min, 500 µm). The above results show that the YLY flour sample contains starch granules with the highest affinity for iodine or, in consonance with reports by Raja, Ramakrishna, and Mathew (1987) and Raja (1992), contains more amylose, followed by WHY while the least was from WTY. Elsewhere, values of 200–273 have been reported for flakes from WTY (Rodriguez-Sosa & Gonzalez, 1972). This implies that WTY exhibits relatively lesser cell damage upon steaming. Statistical examination of these variations showed that the effect of YTV is significant. On mean values, the YLY sample is significantly highest (317, Table 3) at $P \leqslant 0.05$ while WTY is the lowest (283). On% increase in value, the reverse isthe case.

The effect of TST is directly proportional to both mean values and% increase in value while being inversely related to the range. This means that, with progressive steaming over time, the tubers are made susceptible to more/pronounced cell damage in the

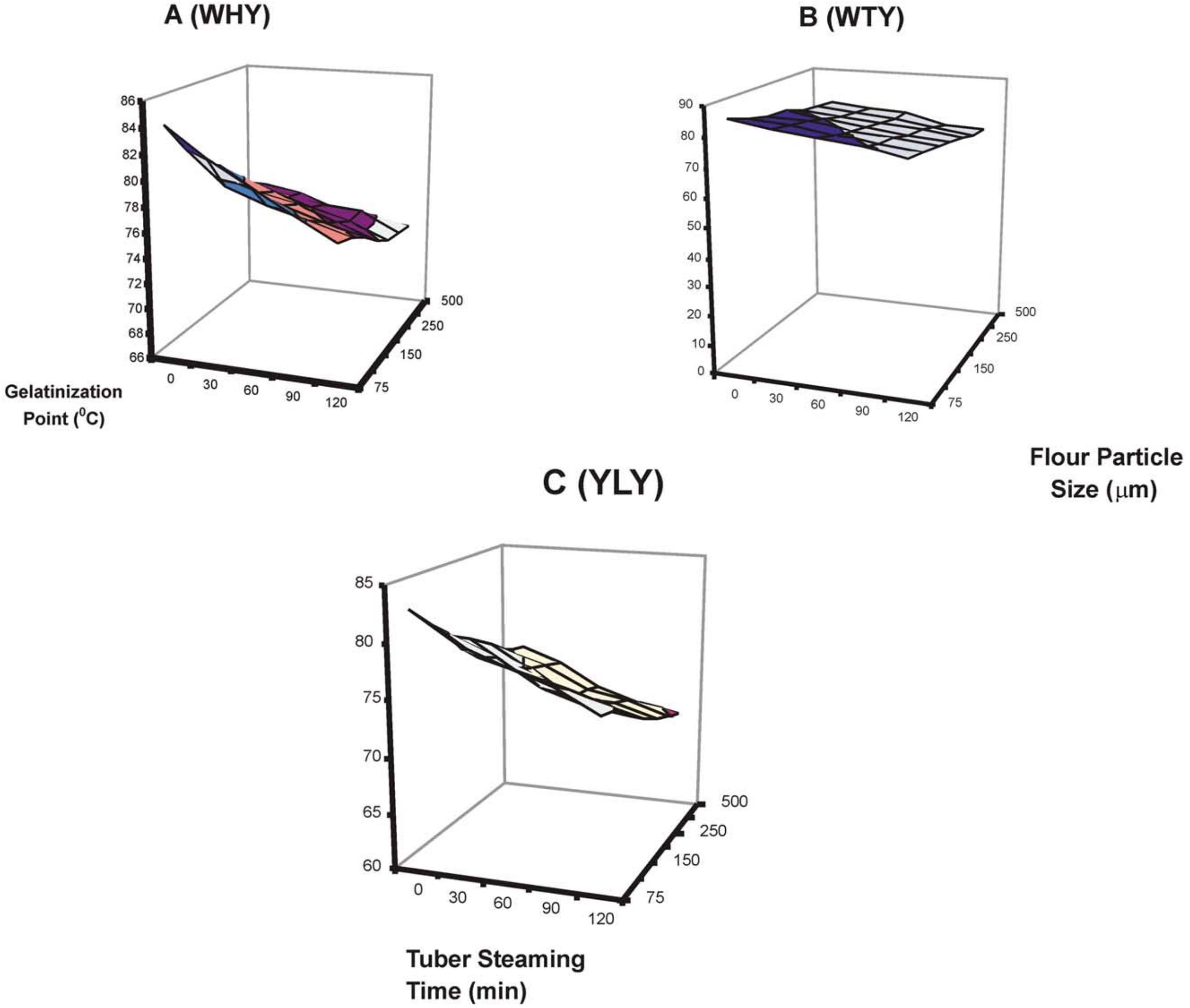

Fig. 5. Effect of tuber steaming time and particle size on gelatinization point of flour from White yam (WHY) (A), Water yam (WTY) (B), Yellow yam (YLY) (C).

resultant flour samples. Working with isolated, steamed WHY tuber, a value of 345 was obtained for its flour (Iwuoha, 1999). High values are preferred as a good quality indicator for yam flour that has the capacity to serve as ''instant yam'' (Ngoddy & Onuoha, 1985).

The effect of FPS is directly proportional to the mean values but inversely related to both the range and% increase in value. This shows that, the smaller the particle size of flour, the greater are the chances of large variations between the values, and also the greater the effective increase (i.e. the extent of impact). These features point to the preference for smaller FPS in accordance with an earlier yam study (Ayernor, 1976, 1985).

In view of observations, the sets of alternatives choices, if based on the IAS criterion, are thus: YLY (120 min, 500 µm), WTY (120 min, 75 µm), or YLY (30 min, 75 µm).

3.4. Solubility (TSS)

Instantaneous data from solubility, TSS (%, db) measures of flours from steamed yams are shown in Fig. 4A for WHY, Fig. 4B for WTY and Fig. 4C for YLY tubers. For WHY, the highest value was 18.63 (120 min, 75 µm) while the lowest was 6.94 from the untreated (500 µm). For WTY, the highest was 16.43 (120 min, 75 µm) while its raw counterpart of 500 µm FPS showed the lowest (6.12). In the case of YLY, the greatest was 19.86 (120 min, 75 µm) while its untreated version gave rise to the smallest value of 7.49. With the greatest IAS (i.e. index of cell/starch damage score) as per Table 3, YLY, not unexpectedly, steamed flour the highest solubility in an ambient aqueous environment.

Table 4 shows, as a further consolidating appraisal, that YTV factor effected significant variations ($P \leqslant 0.05$)

Table 5
Gelatinization point of flour slurry as a function of yam tuber variety, tuber steaming time and flour particle size

Source of variation	Components of variation	Gelatinization point (°C)		
		Range	Increase in value (%)	Mean ± S.D.
Yam tuber variety (YTV)	White yam (WHY)	9.4X	−3.95X	76.1 ± 2.3Y
	Water yam (WTY)	13.3Z	−5.18Y	77.4 ± 3.3Z
	Yellow yam (YLY)	11.0Y	−5.23Z	74.1 ± 2.8X
	LSD (YTV)	0.12	0.01	0.23
Tuber steaming time (TST) (min)	30	10.9S	−2.13Q	78.0 ± 2.9T
	60	11.0S	−4.05R	76.5 ± 2.9S
	90	10.7R	−5.62S	75.2 ± 2.7R
	120	9.3Q	−7.33 T	73.9 ± 2.5Q
	LSD (TST)	0.11	0.06	0.26
Flour particle size (FPS) (μm)	75	8.7F	−6.02G	79.7 ± 2.2G
	125	8.1E	−5.10F	78.2 ± 2.1F
	150	8.0D	−5.01E	76.9 ± 2.2E
	180	7.7C	−4.70D	75.6 ± 2.0D
	250	7.2B	−4.31C	74.5 ± 2.1C
	375	7.2B	−4.10B	73.66 ± 2.1B
	500	7.1A	−4.06A	72.8 ± 2.0A
	LSD (FPS)	0.09	0.00	0.35

LSD, Least significant difference at $P \leqslant 0.05$. Means with uncommon letters (A–G, Q–T, X–Z) in the same column for the factor in under concerned differ significantly according to Fisher's test ($P \leqslant 0.05$)

with the YLY sample maintaining the highest position. In terms of % increase in value, YLY and WHY are equal and less than WTY. The range results followed the trend of the mean values.

The TST bears a direct relationship with the mean values, the range and the% increase in values. It is obvious that extensive steam-processing, especially with increase in process time, will in turn impart doneness and softness to the tuber tissues and cells, which will result in greater solubility.

Flour particle size favours finer flour samples. It is observed that, at 500 μm, there is a triple decrease (i.e. in mean values, the range and % increase in value).

General observations have shown that the three test factors are critical determinants of TSS of steamed yam flour. Alternative choices, are: YLY (120 min, 75 μm), WTY (120 min, 375 μm), or YLY (120 min, 75 μm).

3.5. Gelatinization point (GPT)

The data for GPT (°C) test flour are reported in 3-D surface charts for WHY (Fig. 5A), WTY (Fig. 5B) and YLY (Fig. 5C). In the case of WHY, the least GPT (72.7) was obtained from 120 min TST of 500 μm FPS. For WTY, the least was 70.9 (120 min, 500 μm) while the least for YLY (69.3) was from (120 min, 500 μm). It can be argued that the YLY, that has the greatest cell damage (IAS, Table 3) and highest solubility (Table 4), will accordingly gel earliest at relatively lower temperature (Fig. 5C) ANOVA proved it to be significantly lowest (73.9, $P \leqslant 0.05$, Table 5).

The effect of TST is inversely proportional to the GPT. It must be underlined that this case is a matter of gelling an already pre-gelled sample. Therefore, the more severely pre-gelled sample will exhibit the least gelatinization temperature level.

In the case of FPS, the smaller the particles, the more compact and metastable will be the system or flour paste it will form; hence, the higher will be the energy required to gelatinize such a system, while the reverse is the case for the larger FPS flour samples (Ayernor, 1985; Iwuoha & Nwakanma, 1998; Iwuoha, 1999). For technical and economic reasons, the lower gelling points are preferred.

Comprehensive view of the parametric evaluation showed that these test variables (factors) are very critical. Alternative variable combinations are set out thus: YLY (120 min, 500 μm), WHY (30 min, 500 μm), or WTY (30 min, 75 μm).

4. Conclusions

From this investigation it was commonly observed that the test variables have significant effects on the physicochemical qualities of yam flour. There is inferential evidence that YTV, TST and FPS may be used by yam tuber processors, as strategic working tools, to manipulate/control the physicochemical properties of the resultant flours. In terms of YTV, WTY scored most, then YLY and then WHY. For TST, the mean was 96.00 ± 36.67 min. In the case of FPS, the best will be obtained from $\{\mathrm{FPS}(\mu\mathrm{m}) \mid 75 \leqslant \mathrm{FPS} \leqslant 375\}$.

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References

Abbey, B. W., & Ibeh, C. O. (1988). Functional properties of raw and heat processed cowpea flour. *Journal of Food Science*, *53*(6), 1775–1777 1791.

AOAC. (1990). *Official methods of analysis* (15th ed.). Washington, DC, USA: Association of Official Analysis Chemists (AOAC).

Ayernor, G. S. (1976). Particulate properties and rheology of pregelled yam (*Dioscorea rotundata*) products. *Journal of Food Science*, *41*, 180–182.

Ayernor, G. S. (1985). The yam (Dioscorea) starches. In J. Osuji (Ed.), *Advances in yam research: a biochemistry and technology of the yam tuber* (pp. 77–88). Enugu, Nigeria: ASUT.

Coursey, D. G., & Ferber, C. E. M. (1979). The processing of yams. In D. L. Pluckett (Ed.), *Small-scale processing and storage of tropical root crops* (pp. 189–212). Westview Press, Boulder, Colorado.

Coursey, D. G. (1984). Potential uitiltization of major root crops, with special emphasis on human, animal and industrial uses. In: Proc. 2nd Triennial Symp. Intl. Soc. Trop. Root Crops—Africa Branch, eds Terry, E. R. Doku, E. V. Arene, O. B. and N. M. Mahungu. Douala, Cameroon, 14–19 August, 1983, pp. 25–35.

Degras, L. (1993). *The yam-a tropical root Crop* (2nd ed.). London and Basingstoke: The Macmillan Press, Ltd.

Danzart, M. (1986). Univariate procedures. In J. R. Piggott (Ed.), *Statistical procedures in food research* (pp. 19–59). London, UK: Elsevier Appl. Sci.

FAO (1991). Yam (Dioscorea opp) processing. In: *Post-harvest and processing technologies of African staple foods: a technical compendium*. FAO Agric. Services Bulletin 89. Food and Agricultural Organization (FAO), Rome, pp. 225–235.

Ihekoronye, A. I., & Ngoddy, P. O. (1985). Processing of tropical roots and tuber crops. In: *Integrated food science and technology for the tropics*. MacMillan Publishers Ltd, London, pp. 270–282.

IITA. (1988). *Annual Report and Research Highlights, 1987/88*. Ibadan, Nigeria: International institute for Tropical Agriculture (IITA).

Iwuoha, C. I., & Nwakanma, M. I. (1998). Density and viscosity of cold flour pastes of cassava (*Manihot esculenta* Grantz), sweet potato (*Ipomoea batatas* L. Lam) and white yam (*Dioscorea rotundata* Poir) tubers as affected by concentration and particle size. *Carbohydr. Polym.*, *37*(1), 97–101.

Iwuoha, C. I. (1999). Effects of Processing on the Physico-chemical Properties of Instant yam Flour from *Dioscorea rotundata* Poir, PhD Dissertation, Federal University of Technology, Owerri, Nigeria.

Kamenan, A., Beuchat, L. R., Chinnan, M. S., & Heaton, E. K. (1987). Composition and physico-chemical properties of yam (*Dioscorea species*) flour prepared using different processes. *J. Food Proc. Preserv*, *11*, 299–308.

Kawabata, A., Sawayama, S., Nagashima, N., & del Rosario, R. R. (1984). Nakamura, M Some physico-chemical properties of starches from cassava, arrow root and sago. *J. Jpn. Soc. Starch Sci.*, *31*, 224–232.

Martin, F. W., & Ruberte, R. (1975). Flour made from edible yams (*Dioscorea* spp.) as a substitute for a wheat flour. *J. Agric. Univ. Puerto Rico*, *59*, 255–263.

Narayana, K., & Narasinga-Rao, N. S. (1982). Functional properties of raw and processed winged bean (*Psophocarpus tetragonolobus*) flours. *Journal of Food Science*, *47*, 1534–1538.

Ngoddy, P. O., & Onuoha, C. C. (1985). Selected problems in yam processing. In G. Osuji (Ed.), *Advances in yam research; the biochemistry and technology of the yam tuber* (pp. 295–318). Enugu, Nigeria: Biochemical Soc. Nigeria and ASUT.

Okonkwo, S. N. C. (1985). The botany of the yam plant and its exploitation in enhanced productivity of the crops. In G. Osuji (Ed.), *Advances in yam research; the biochemistry and technology of the yam tuber* (pp. 3–29). Enugu, Nigeria: Biochemical Soc. Nigeria and ASUT.

Onayemi, O., & Potter, N. N. (1974). Preparation and storage properties of drum-dried white yam (*Dioscorea rotundata* Poir) flakes. *Journal of Food Science*, *39*, 559–562.

Onayemi, O. (1986). Some chemical factors affecting the quality of processed yam. *Journal of Food Science*, *51*, 161.

Onyia, G. O. C. (1986). *Production of flour from stored yams of different species. In: NRCRI Annual Report*. Nigeria: Umudike.

Osisiogu, I. U. W. (1973). Industrial potentials of some yam and cocoyam starches. *Tropical Science*, *15*, 353–359.

Raja, K. C. M., Ramakrishna, S. V., & Mathew, A. G. (1987). Effect of steam-hydrothermal treatment (SHTT) on the physico-chemical properties of cassava (*Manihot esculenta* Crantz). *Journal of the Science Food Agriculture*, *39*, 59–71.

Raja, K. C. M. (1992). Studies on alkali-modified cassava starch: changes of structural and enzyme (alpha-amylase) susceptibility properties. *Strarch/Starke*, *44*, 133–136.

Rodriguez-Sosa, E. J., & Gonzalez, M. A. (1972). Preparation of yam (*D alata* L) flakes. *J. Agric Univ. Puerto Rico*, *56*, 39–45.

Roessler, E. E. (1984). Statistical evaluation of experimental data: multiple comparison. In D. W. Gruenwedel, & J. R. Whitaker (Eds.), *Food analysis: principles and techniques* (pp. 12–13). New York: Marcel Dekker.

Steel, R. G. D., & Torrie, J. H. (1980). Analysis of variance III: factorial experiments. In: *Principles and procedures of statistics-a biometrical approach*, (2nd ed.), McGraw-Hill Intl. Coy, London pp. 336–376.

Udensi, E. A., Onuora, J. O. (1992). Chemical and functional properties of some soyabean flour in the Nigerian market. Paper, 16th Ann. Conf. NIFST, 26–30 October, 1992, Enugu, Nigeria, 8pp.

Ukpabi, U. J., & Ndimele, C. (1990). Evaluation of the quality of gari produced in Imo State. *Nigerian Food Journal*, *8*, 105–110.