Comparative Evaluation of Physico-chemical Characteristics of Flours from Steeped Tubers of White Yam (*Dioscorea rotundata* Poir), Water Yam (*Dioscorea alata* L.) and Yellow Yam (*Dioscorea cayenensis* Lam)

C.I. Iwuoha

Keywords: White yam- Water yam- Yellow yam- Yam tuber specie- Tuber steeping duration- Flour particle size- Physico-chemical property

Summary

The study examined Yam Tuber Species (YTS), Tuber Steeping Duration (TSD) and Flour Particle Size (FPS) as factors of flour. Data were collected using white yam, water yam and yellow yam steeped in water (30 ± 2 °C, pH 6.78) and withdrawn, and the flour classified, and analyzed for each parameter. Results obtained showed that all the test parameters, Water Retention Capacity (WRC), Swelling Index (SI), Solubility (TSS) and Iodine Affinity of Starch (IAS) correlated very much better and significantly ($P_r < 0.10$) with FPS than with TSD. Inverse relationships were observed with all the parameters. Analysis of variance (ANOVA) results indicated that no significance existed in the main factors for YTS (WRC and TSS). Otherwise, the study variables were found to be critical determinants for the magnitude and extent of the physicochemical properties of steeped yam flour pastes. The study also observed that white yam, steeped for up to 4 days at tropical ambient temperatures, and the resultant flour classified / pulverized into ≤ 125 μm FPS will yield the optimum physicochemical features in the paste.

Résumé

Evaluation comparative des caractéristiques physico-chimiques de farines rouies de tubercules d'igname blanche (*Dioscorea rotundata* Poir), d'igname ailée (*Dioscorea alata* L.) et d'igname brune (*Dioscorea cayenensis* Lam)

Cet essai étudie l'influence de l'espèce (EI), de la durée de trempage des tubercules (DTT) et la taille des particules après mouture (TPM) sur les propriétés physico-chimiques de la farine et de la pâte d'igname. Les données comparées proviennent de tubercules d'ignames blanche, ailée et brune qui ont été trempés dans l'eau (30 ± 2 °C, pH 6,78). La farine produite a été tamisée et analysée suivant différents paramètres. Les résultats obtenus ont montré une corrélation positive (P≤ 0,10) entre, d'une part, la Capacité de Rétention d'Eau (CRE), l'Indice de Gonflement (IG), la Solubilité (S), et l'Affinité Iodique à l'Amidon (AIA), et d'autre part, la Taille des Particules de la Farine (TPM). Par contre, aucune corrélation n'a été obtenue avec la durée de rouissage. Une relation négative a été obtenue entre les autres facteurs étudiés. Une analyse de la variance n'a pas montré de différences significatives entre les principaux facteurs étudiés (CRE, S) caractéristiques des espèces d'igname. Il apparaît de plus que les variables étudiées influencent fortement les propriétés physico-chimiques de la pâte produite à partir de la farine de tubercules d'igname rouis. Cette étude a montré que l'igname blanche trempée dans l'eau à température ambiante pendant 4 jours et moulue pour donner des particules de ≤ 125 µm produit la pâte qui présente les meilleures propriétés physico-chimiques.

Introduction

White Yam (WHY) is the most popular species especially in the savannah areas. Yellow Yam (YLY), Water Yam (WTY) and Cluster Yam (CLY) are also widely grown in the southern forest areas of Nigeria. Aerial Yam (ARY) and Chinese Yam (CHY) are less important in Nigeria (11). Nigeria produces 16 Mt of yam tubers (68% of world yam production), at 10.7 t/ha. This accounts for about 75% of Africa's yam production (6).

Yam tubers are usually consumed in the forms of chunks, flour, fufu, and slices resulting from any of the processes of boiling, drying, fermentation, frying,

Department of Food Science & Technology, Federal University of Technology, Owerri, P.M.B. 1526, Owerri, Imo State, Nigeria.
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milling, pounding, roasting, and steaming (2, 6, 9, 11, 12, 13). Yams, which supply up to 4956 kJ of energy per kg of tuber, form primary staple food in Nigeria and account for over 50% of daily carbohydrate intake of peoples in the “yam zone” of west Africa (i.e. Benin, Ivory Coast, Ghana, Nigeria and Togo), south America and south-east Asia (9, 14).

Different varieties and species of yam tubers have been utilized to obtain industrial products such as starch, steroids, arrow poison, insecticides, and tannin (6); and novel products such as lager beer, ice cream, jellies, candies and chips for snacks (6, 13). Yam flour is utilized as dough conditioner in bread-making, as stabilizer in ice-cream, as well as a thickener in soups (6, 9, 11, 13).

All the pre-milling treatments, such as steeping, steaming, boiling, roasting and drying, which yam tubers are subjected to are bound to affect the physical, techno-functional, and psycho-rheological characteristics of the resultant products and recipient food systems and their acceptability as against the native or raw flour. The magnitude, severity and extent of variations in the flour, will depend also on the variety of yam and duration of process (2, 9, 10, 11). Among the flour quality indices are Iodine Affinity of Starch (IAS), Solubility (TSS), Swelling (SI) and Water Retention Capacity (WRC). These parameters are good tools or indicators of engineering properties, rheological and sensory performance of flour (11). Among the processing methods is our indigenous technology of fermentation which is obtained through steeping of tubers at ambient tropical conditions (12, 13). The gravity, degree and significance of influence of steeping conditions on the quality of fermentation modified flour have not been properly elucidated and documented. There is need for thorough investigations to appraise effects of the pre-milling and post-milling variables of steeped yam tubers on the quality of the flour. In their separate contributions, Achi (2) has analyzed only the chemical composition of steeped yam tubers; while Iwuoha (11), in a study using white yam species only, has analyzed physico-chemical and pasting properties of the resultant flours. These efforts so far lacked the varietal comparative information envisaged, which the present work aims to fulfill.

In view of the issues raised above, this study examines the effects of Yam Tuber Species (YTS), Tuber Steeping Duration (TSD) and Fluor Particle Size (FPS) on some physico-chemical properties of the resultant flour.

Methodology

Source of materials

Some tubes of White Yam, WHY (*Dioscorea rotundata* Poir); Water Yam, WTY (*Dioscorea alata* L) and Yellow Yam, YLY (*Dioscorea cayenensis* Lam) obtained from a cottage farm in Nguru, Aboh-Mbaise Local Government Area, Imo State, Nigeria were used.

Raw flour

Tubers of WHY, WTY and YLY were pared down, washed, cut into 5 mm thick chips, dried at 50 °C for 24 h in an oven, milled into powder in a kenwood portable mill and filtered through a 1 mm mesh sieve and sealed for analyses.

Steeping duration variation

Tubers from each Yam Tuber Specie (YTS) were pared down, washed, cut into 5 cm thick chunks. Each batch of chunks from each YTS was steeped in deionized water in a mass – to – liquid ratio of 1: 4. They were left to stand for 2, 4, 6, and 8 days with daily change of water. At the end of each steeping / soaking experiment (steep-out), the yam chunks were withdrawn, drip-dried, cut into 5 mm thick chips and spread on aluminum trays and finished off as was done in the raw flour sample.

Flour particle size variation

The bulk flour samples from both the raw and the steeped yam tubers were respectively separated into particle sizes of 125, 250, and 500 µm using a standard tyler sieve series.

Moisture determination

The moisture content was determined by drying at 105 °C for 3 h according to the method of AOAC (3).

Water retention capacity determination

Water Retention Capacity (WRC) is primarily a parameter that measures the amount (in ml) of water hold-able by each gramme of dry flour. The method of Sosulski (16), as described by Abbey and Ibeh (1), was adopted.

Swelling index determination

The procedure reported by Ukpabi and Ndimele (19) was followed.

Solubility determination

The cold water extraction method as described by Udensi and Onuora (18) was adopted.

Iodine affinity of starch determination

The procedure by Kawabata *et al.* (12) was followed and values obtained were expressed in the units of parts per million (ppm). All the measurements were triplicated.

Correlation analyses

The values from physico-chemical properties measurements concerning the three yam tuber species for varying steeping duration and flour particle size were subjected to correlation analyses. Tuber Steeping Duration (TSD) and Flour Particle Size (FPS) as variables were paired with each of the physico-chemical properties, respectively, for each of the yam tuber species. The correlation coefficient (r), quality of fit (r^2) and level of significance of the correlation coefficient (P_r) were determined as per Edwards (7).

Variance analyses

The mean values of the physico-chemical properties were assessed as functions Yam Tuber Specie (YTS: three types), Tuber Steeping Duration (TSD: four durations) and Flour Particle Size (FPS: three sizes) which fitted into a 3 (YTS) % 4 (TSD) % 3 (FPS) factorial design. The standard procedures for three-way analysis of variance (ANOVA) as described by Steel and Torrie (17) were followed. Evaluated parameters included, reduced Sum of Squares (SS), Mean Square or variance (MS), and Variance Ratio (F_{cal}). In cases where significant differences existed, Fisher's LSD (least significant difference) multi-comparison test was used to separate the main factors' means (15).

Results and discussion

Water Retention Capacity (WRC)

The mean values of WRC measurements for flours from the three Yam Tuber Species (YTS) are illustrated (Figure 1).

The WRC as a function of Tuber Steeping Duration (TSD) is depicted in figure 1A and as a function of Flour Particle Size (FPS) its values are shown in figure 1B. The values progressively decreased as a function of TSD (Figure 1A) by 17.90% (WHY), 15.86% (YLY) and 11.98% (WTY), after 8 days of tuber steeping in water (pH 6.78) at ambient temperature (30 ± 2 °C.). The performance of WRC was wavy in trend (Figure 1A) which maintained consistently falling state after 4 days. Folled the performance of WRC, then the falling values with TSD is expected because the tissue degrading resulting from fermentation via steeping (2) will lead to inability of tissue to hold water with progressive steeping duration. Similar results were obtained using cocoyam (*Colocasia esculenta* var. *inumbu*) corm (10).

Similar to the TSD, the WRC value also decreased as FPS increased. The greatest outstanding reduction was obtained from the 500 µm of WHY (33.16%) while the least was from 125 µm of WHY (2.48%). After these relationships were subjected to correlation analyses it was observed (Table 1) that the correlation coefficient r) of WRC as a function of TSD is -0.9530 (WTY), -0.7664 (WHY) and -0.7410 (YLY).

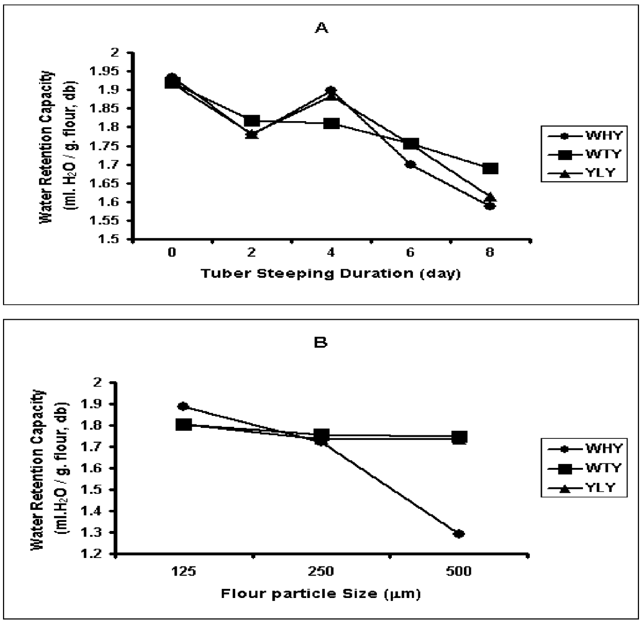

Figure 1: Effects of tuber steeping duration (A) and particle size (B) on the water retention capacity of flour from White Yam (WHY), Water Yam (WTY) and Yellow Yam (YLY).

Only WTY has very good quality of fit (r^2= 0.9083) and level of significant of r (P_r= 0.010). In the case of WRC= f (FPS), r= -0.9978, r^2= 0.9956, P_r= 0.001 (WHY), r= -0.8273, r^2= 0.6844, P_r= 0.100 (WTY) and r= -0.7559, r^2= 0.5714, P_r= 0.200 (YLY).

Table 1

Correlation coefficients and levels of significance for Tuber Steeping Duration (TSD), and Flour Particle Size (FPS) with some physico-chemical properties of flour from White Yam (WHY), Water Yam (WTY) and Yellow Yam (YLY)

Yam Tuber Species (YTS)	Variable – Parameter pair	Correlation coefficient, r	Quality of Fit, r^2	Level of Significance of r, P_r
WHY	TSD - WRC	- 0.07664	0.5874	0.200
	FPS - WRC	- 0.9978	0.9956	0.001
	TSD - SI	- 0.7040	0.4957	NS
	FPS - SI	- 0.9161	0.8392	0.050
	TSD - TSS	- 0.5905	0.3487	NS
	FPS - TSS	- 0.9997	0.9993	0.0005
	TSD - IAS	- 0.7337	0.5383	0.250
	FPS - IAS	- 0.9801	0.9606	0.010

Yam Tuber Species (YTS)	Variable – Parameter pair	Correlation coefficient, r	Quality of Fit, r^2	Level of Significance of r, P_r
WTY	TSD - WRC	- 0.9530	0.9083	0.010
	FPS - WRC	- 0.8273	0.6844	0.100
	TSD - SI	- 0.7279	0.5298	0.250
	FPS - SI	- 0.9286	0.8622	0.050
	TSD - TSS	- 0.5504	0.3029	NS
	FPS - TSS	- 0.9597	0.9209	0.025
	TSD - IAS	- 0.6559	0.4301	NS
	FPS - IAS	- 0.9941	0.9882	0.005
YLY	TSD - WRC	- 0.7410	0.5491	0.200
	FPS - WRC	- 0.7559	0.5714	0.200
	TSD - SI	- 0.7549	0.5699	0.200
	FPS - SI	- 0.8580	0.7362	0.100
	TSD - TSS	- 0.4398	0.1934	NS
	FPS - TSS	- 0.9857	0.9716	0.010
	TSD - IAS	- 0.8257	0.6818	0.050
	FPS - IAS	- 0.9928	0.9856	0.005

NS= Not Significant; TSD= Tuber Steeping Duration (day); FPS= Flour Particle Size (µm);
WRC= Water Retention Capacity (ml. H_2O/g. flour, db); SI= Swelling Index (cm^3/cm^3);
TSS= Solubility (%, db); IAS= Iodine Affinity of Starch (ppm).

Satisfactory quality of fit is associated with WHY sample, only. It means that there is very high level of confidence that the influence of FPS on the WRC of WHY sample predominated (i.e. superimposing over every other causes).

When the entire sources of variation on WRC were subjected to ANOVA, the results (Table 2) indicated that only the factors of TSD and FPS were very highly significant under the conditions of the study (P< 0.05).

Table 2
Three-way analysis of variance data for physico-chemical properties as functions of Yam Tuber Specie (YTS), Tuber Steeping Duration (TSD) and Flour Particle Size (FPS)

Parameters	Source of Variation	Reduced Sum of Squares (SS)	Degree of Freedom (DF)	Variance	F_{cal} (P = 0.05)	F_{tab}	Remarks
WRC (ml. H_2O / g. flour, db)	Total	0.4895	35				
	YTS	0.0047	2	0.00233	1.95	3.89	NS
	TSD	0.2625	3	0.0875	73.16	3.49	VHS
	FPS	0.1101	2	0.0550	45.99	3.89	VHS
	YTS%TSD	0.0341	6	0.0057	4.77	3.00	S
	YTS%FPS	0.05785	4	0.0145	12.12	3.26	HS
	TSD%FPS	0.0059	6	0.0098	0.82	3.00	NS
	Residual	0.01435	12	0.001196			
SI (cm^3/cm^3)	Total	1.4154	35				
	YTS	0.2191	2	0.1096	69.45	3.89	VHS
	TSD	0.5088	3	0.1696	107.51	3.49	VHS
	FPS	0.2869	2	0.1435	90.92	3.89	VHS
	YTS%TSD	0.2033	6	0.0339	21.48	3.00	VHS
	YTS%FPS	0.1614	4	0.0403	25.57	3.26	VHS
	TSD%FPS	0.0170	6	0.0028	1.79	3.00	NS
	Residual	0.0189	12	0.0016			

Parameters	Source of Variation	Reduced Sum of Squares (SS)	Degree of Freedom (DF)	Variance	F_{cal} (P = 0.05)	F_{tab}	Remarks
TSS	Total	80.5025	35				
(%, db)	YTS	1.2548	2	0.6274	3.86	3.89	NS
	TSD	32.4984	3	10.8328	66.64	3.49	VHS
	FPS	41.7762	2	20.8881	128.49	3.89	VHS
	YTS%TSD	1.5981	6	0.2664	1.64	3.00	NS
	YTS%FPS	1.1704	4	0.2926	1.80	3.26	NS
	TSD%FPS	0.2538	6	0.0423	0.26	3.00	NS
	Residual	1.9508	12	0.1626			
IAS	Total	9039.6389	35				
(ppm)	YTS	1603.3889	2	801.6944	58.68	3.89	VHS
	TSD	3609.1944	3	1203.0648	88.06	3.49	VHS
	FPS	2371.0556	2	1185.5278	86.78	3.89	VHS
	YTS%TSD	778.3889	6	129.7315	9.50	3.00	HS
	YTS%FPS	352.9444	4	88.2361	6.46	3.26	HS
	TSD%FPS	160.7222	6	26.7870	1.96	3.00	NS
	Residual	163.9445	12	13.6620			

WRC= Water Retention Capacity; SI= Swelling Index; IAS= Iodine Affinity of Starch;
HS= Highly Significant; NS= Not Significant; S= Significant; VHS= Very Highly Significant

Separations of the components of variation (Table 3) showed that, for TSD, the highest significantly value was from the 4 days-steeped sample (1.86 ml. H_2O/g. flour, db) while the least was from the 8th day (1.63 ml. H_2O/g. flour, db).

Table 3

Mean values for the physico-chemical properties of flour as functions of Yam Tuber Specie (YTS), Tuber Steeping Duration (TSD) and Flour Particle Size (FPS)

Source of variation	Components of variation	Parameter			
		Water Retention Capacity (ml. H_2O/g. flour, db)	Swelling Index (cm^3/cm^3)	Solubility (%, db)	Iodine Affinity of Starch (ppm)
YTS	White Yam	1.74 ± 0.16^A	1.93 ± 0.19^A	11.30 ± 1.59^A	84.67 ± 20.41^A
	Water Yam	1.77 ± 0.06^A	1.74 ± 0.20^C	10.91 ± 1.38^A	69.58 ± 11.08^B
	Yellow Yam	1.76 ± 0.11^A	1.83 ± 0.15^B	10.90 ± 1.47^A	71.67 ± 8.98^B
	LSD_{YTS} (P= 0.05)	0.03	0.04	0.36	3.29
TSD (day)	2	1.79 ± 0.07^R	1.95 ± 0.13^Q	10.83 ± 1.05^R	78.33 ± 10.27^R
	4	1.86 ± 0.08^Q	1.95 ± 0.16^Q	12.48 ± 1.20^Q	89.44 ± 17.23^Q
	6	1.74 ± 0.08^S	1.75 ± 0.19^R	11.00 ± 1.18^R	71.44 ± 9.60^S
	8	1.63 ± 0.05^T	1.68 ± 0.15^S	9.82 ± 1.19^S	62.00 ± 10.42^T
	LSD_{TSD} (P= 0.05)	0.04	0.04	0.41	3.80
FPS (μm)	125	1.83 ± 0.10^X	1.95 ± 0.22^X	12.31 ± 1.03^X	84.83 ± 16.67^X
	250	1.74 ± 0.09^Y	1.80 ± 0.17^Y	11.12 ± 1.11^Y	76.08 ± 11.31^Y
	500	1.70 ± 0.11^Z	1.74 ± 0.13^Z	9.68 ± 0.96^Z	65.00 ± 12.25^Z
	LSD_{FPS} (P= 0.05)	0.03	0.04	0.36	3.29

$^{A-C,\ R-T,\ X-Z}$ Means not followed by same superscripts along the columns, differ significantly at P= 0.05 as per Fisher's test
LSD= Least significant difference

It means that the 4 days steep will be enough to give flour with relatively best WRC. For FPS, the greatest value (1.83 ml. H_2O/g. flour, db) was from ≤ 125 μm FPS, which suggests that reducing the steeped tuber flour to particle sizes of 125 μm will give product of relatively better water absorption than the larger sizes.

Swelling Index (SI)

Figure 2 is the illustration of the relationship of the Swelling Index (SI) to the TSD and FPS for all the Yam Tuber Species (YTS).

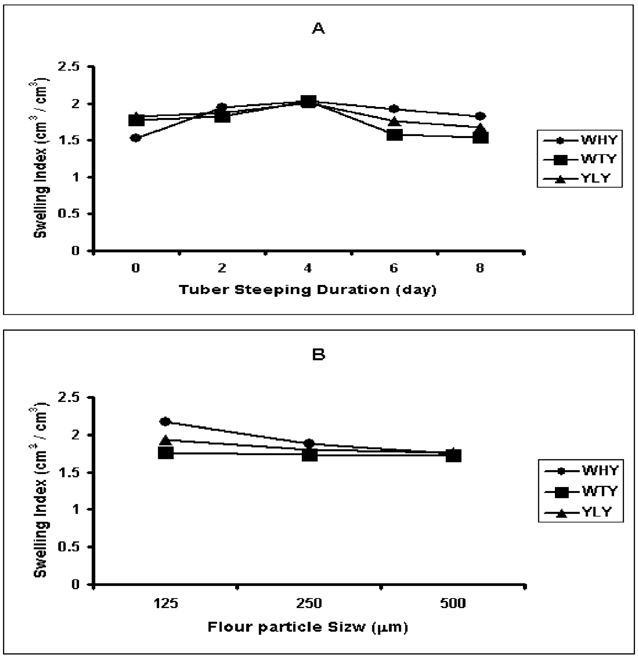

Figure 2: Effects of tuber steeping duration (A) and particle size (B) on the swelling index of flour from White Yam (WHY), Water Yam (WTY) and Yellow Yam (YLY).

There is a general / common pattern of rising and then falling in values with TSD. The maxima was the 4^{th} day while the minima was the 8^{th} day. The greatest values at the maxima were increases of 33.29% (WHY), 14.52% (WTY) and 10.24% (YLY). The WHY has shown potentials for high swelling power above all the others. It means that the possible changes caused by steeping, in the morphology of the starch moities in the resultant flour, is the inducement of higher swelling features (4, 5, 8) to the tubers with its peak effect on the 4^{th} day and with the maximum reflection in the WHY.

For SI as a function of FPS (Figure 2B), a trend of reduction in value with increasing FPS was observed. The 125 μm FPS samples were of the highest. However, in terms of performance, WHY increased by 42.65%, YLY increased by 5.94% while WTY increased by – 0.28%. This goes to confirm why WHY is the Yam Tuber Specie (YTS) of choice for fufu (stiff dough), then followed by YLY a was observed by Iwuoha (11) due to its unique swellability.

Results from correlation analyses (Table 1) showed that inverse relationship existed between SI and TSD but with lower quality of fit (r^2) and very lower level of confidence in r. In the case of SI and FPS, very high levels of r, r^2 and P_r were shown. It was indicative that the dependence of SI on FPS far exceeds that on TSD.

Further analyses, via ANOVA (Table 2), showed that variations caused by the 3 factors (YTS, TSD and FPS) are very highly significant ($P< 0.05$). These mean that each of them constitute critical determinant for the SI of flour from yam tubers. When comparison was effected on the components of each factor, the results (Table 3) showed that with respect to YTS, WHY's value (1.93 cm^3/cm^3) the significantly highest ($P= 0.05$) while WTY's 1.74 cm^3/cm^3 was the least. For TSD, the 2 days and 4 days samples are statistically highest and equivalent (1.95 cm^3/cm^3, $P= 0.05$). For FPS, flour of 125 μm size was highest (1.95 cm^3/cm^3, $P= 0.05$). It is indicative here that WHY steeped for up to 4 days and pulverized to 125 μm flour featured as the best, physico-chemically, under the conditions of this investigation.

Solubility (TSS)

Mean values of solubility (TSS) of flour from 3 YTS are expressed in graphs as functions of TSD (Figure 3A) and FPS (Table 3).

A general trend of increases to a maximum of at the 4^{th} day of steeping and decreases thereafter. It is pointing out that after the 4^{th} day of steeping, the starchy moities in the flour lose their solubility because fermentation effects continual degradation of starchy fraction which likely favour the fiber fraction which exhibits lesser solubility and other prevailing influence interfere with the reaction means that organic acids and gases released during the process adsorb on the residual starch granules thereby interfering with the granules' functional capability (2, 4). Judging between the raw / untreated (control) and the maximum performance, the increases were highest with WHY (69.11%), higher with YLY (47.50%) and high with WTY (42.26%).

As a function of FPS (Figure 3B), solubility reduced with increasing FPS. This is indicative that smaller particle size flour dissolve faster than the larger particles, due possibly to larger surface area exposure associated with smaller particle sizes. This is with the opinion of Iwuoha (11) that finer particles will easily solvate and dissolve relatively faster than their larger counterparts.

Table 1 shows that r indicates inverse relationship between TSS and TSD, very lower r^2 and P_r. For TSS as a function of FPS, r j – 1.00, r^2 j 1.00 and P_r m 0.0005. It means that the influence of FPS on TSS is beyond doubt.

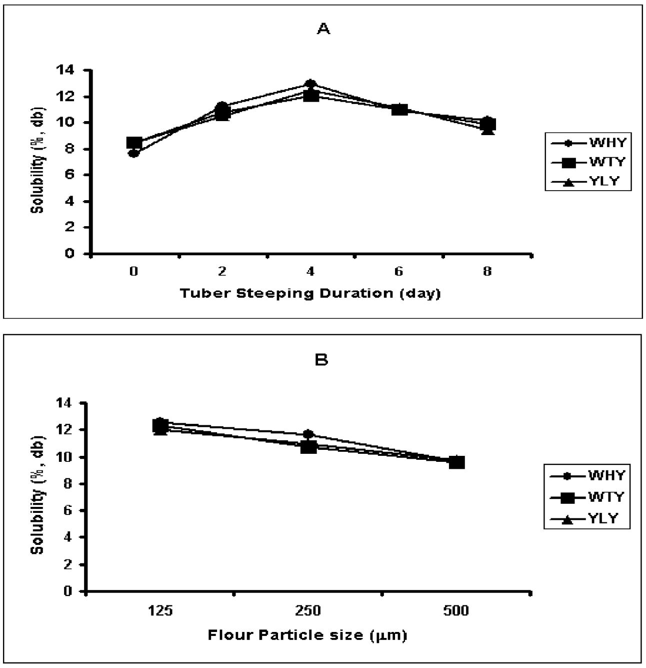

Figure 3: Effects of tuber steeping duration (A) and particle size (B) on solubility of flour from White Yam (WHY), Water Yam (WTY) and Yellow Yam (YLY).

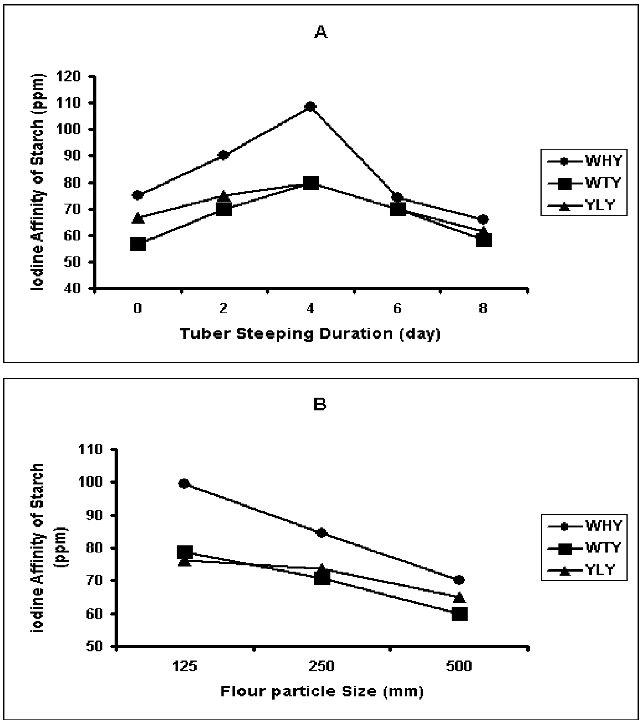

Figure 4: Effects of tuber steeping duration (A) and particle size (B) on the iodine affinity of starch of flour from White Yam (WHY), Water Yam (WTY) and Yellow Yam (YLY).

Results in table 2 indicated that both TSD and FPS effect very highly significant variations on TSS of steeped yam flour. It further indicates that any of the 3 YTS can be a satisfactory alternative but that any of the components of TSD and FPS must be chosen as a careful determinant of TSS.

In table 3, the 4th day sample exhibited the highest value (12.48%, db; P= 0.05), while the 2nd day's (10.83%, db) and the 6th day's (11.00%, db) samples are statistically equal. The more economic and technically-based choice will be for the 2nd day's as against the 6th day's. The 125 µm flour sample featured the significantly highest value (12.31%, db) while the least was from 500 µm's (9.68%,db).

Iodine Affinity of Starch (IAS)

Figure 4 depicts Iodine Affinity of Starch (IAS) of the flour from WHY, WTY and YLY as a function of TSD and FPS.

Apart from actual magnitude, their performance and response are generally similar to those of TSS. The semblance is based on the starch which is the common denominator for the two parameters. However, the striking differences are in the areas of (i) what IAS is estimating: it is a measure of the extent of starch damage; the extent of free starch; (ii) what it is indicating in the starch fraction: it is a measure of the ratio of amylose to amylopectin in the available starch moities. In view of these, very highly significant difference is recorded for YTS (Table 2) because the extent of starch damage and / or the ratio of amylose to amylopectin in starches from the yams are bound to differ.

The FPS factor of IAS was observed to favour the finer particle in that starches in yam flour are predominant (> 60%) and are very small (6).

Conclusion

The study has shown that when yam tubers are steeped at tropical ambient temperature (30 ± 2 ^{0}C) their bio-physics and hence the functional and physico-chemistry of the resultant flours will definitely alter. White yam distinctly and significantly performed very well above the other two species. The 4th day of steeping seems to be the duration under the conditions of steeping at which the starchy moities are exposed to the most conducive environment which aids them to exhibit their best biochemical/biophysical reactivity in the flour. In a complementary role, the finer particle sizes aid, via large surface exposure, in bringing out the expected characteristics. Further work should investigate the experiments at above ambient temperatures (i.e. ≥ 35 to 50 ^{0}C) to check whether remarkable improvements can be obtained in the characteristics of the resultant flour.

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Literature

1. Abbey B.W. & Ibeh C.O., 1988, Functional properties of raw and heat processed cowpea flour. J. Food Sci. 53(6), 1775-1777, 1791.

2. Achi O.K., 1991, Effect of natural fermentation of yams (*Dioscorea rotundata*) on characteristics of processed flour. J. Food Sci. 56(1), 272-272, 275.

3. A.O.A.C., 1990, Official Methods of Analysis, 15th eds. Association of Official Analysis Chemists (A.O.A.C.), Washington, DC, USA.

4. Camargo C., Colonna P., Buleon A. & Richard-Molard D., 1988, Functional properties of sour cassava (*Manihot utilissima*) starch: polvilho azedo. J. Sci. Food Agric. 45, 273-289.

5. C.I.R.A.D., 1994, Cassava sour starch, a rural agro-industrial product. *In*: Images of Research. Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), Paris, France, pp. 78-81.

6. Degras L., 1993, The yam -a tropical root crop, 2nd eds. The Macmillan Press, Ltd, London and Basingstoke, XV + 408 p.

7. Edwards A.L., 1976, An introduction to linear regression and correlation. W.H. Freeman and Coy, San Francisco, U.S.A., pp. 20-31, 33-43, 81-86, 103-105, 150-158.

8. George M., Moorthy S.N. & Padmaja G., 1995, Biochemical changes in cassava tuber during fermentation and its effect on extracted starch and residue. J. Sci. Food Agric. 69, 367-371.

9. Ige M.T. & Akintunde F.O., 1981, Studies on the local techniques of yam flour production. J. Food Tech. 16(3), 303-311.

10. Iwuoha C.I. & Kalu F.A., 1995, Calcium oxalate and physico-chemical properties of cocoyam (*Colocasia esculenta* and *Xanthosoma sagittifolium*) tuber flours as affected by processing. Food Chem. 54, 61-66.

11. Iwuoha C. I., 1999, Effects of processing on the physico-chemical properties of instant yam fufu flour from *Dioscorea rotundata* Poir, Ph. D Thesis, Federal University of Technology, Owerri (FUTO), Nigeria. 151 p.

12. Kawabata A., Sawayama S., Nagashima N., del Rosario R.R. & Nakamura M., 1984, Some physico-chemical properties of starches from cassava, arrow root and sago. J. Jpn. Soc. Starch Sci. 31(4), 224-232.

13. Kordylas J.M., 1990, Traditional and industrial processing of tubers. *In*: Processing and preservation of tropical and subtropical foods. Macmillan Education Ltd. London, pp 34-48, 74-108.

14. Okonkwo S.N.C., 1985, The botany of the yam plant and its exploitation in enhanced productivity of the crops. *In*: Advances in yam research. The biochemistry and technology of the yam research (Osuji G., eds). The biochemical society of Nigeria and ASUT, Enugu, Nigeria, pp. 3-29.

15. Roessler E.E., 1984, Statistical evaluation of experimental data: multiple comparison. *In*: Food analysis: Principles and techniques, eds. Gruenwedel D.W., Whitaker J.R. & Marcel D., New York, pp. 12-13.

16. Sosulski F.W., 1962, The centrifuge methods for determining flour absorption in hard red spring wheat. Cereal Chem. 39, 344.

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

18. Udensi E.A. & Onuora J.O., 1992, Chemical and functional properties of some soybean flour in the nigerian market. Paper, 16th Ann. Conf. NIFST, 26-30 Oct., 1992, Enugu, Nigeria, 8 p.

19. Ukpabi U.J. & Ndimele C., 1990, Evaluation of the quality of gari produced in Imo State. Nigerian Food J. 8, 105-110.

C.I. Iwuoha, Nigerian, Ph.D Food Sci. & techn., Associate Dean, Department of Food Science & Technology, Federal University of Technology, Owerri, P.M.B. 1526, Owerri, Imo State, Nigeria.