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Prediction of Sensorial Properties (Color and Taste) of Amala, a Paste From Yam Chips Flour of West Africa, Through Flour Biochemical Properties

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Abstract. Color and taste are permanent features of amala, a traditional thick paste obtained from yam chips flour. To assess these attributes, 23 yam chips presenting various quality attributes were processed. The sensory attributes of their derived amala were determined and some biochemical characteristics of yam flours measured. A panel defined five main taste attributes for amala: sweetness, bitterness, acidity, fermented, and roasted tastes. Amala color was measured instrumentally and sensory scores were highly correlated with flour biochemical analyses; amala sweetness was positively correlated with glucose and fructose content of the flour, whereas amala acidity and fermented taste were linked to organic acids and lactic acid contents of flour, respectively. In addition, darkness, bitterness, and roasted tastes of amala could be tightly predicted by multiple regression analysis from phenolic compound and glucose–fructose contents. Phenolic content of yam flour plays thus a key role on sensorial quality of amala. However, polyphenol oxidase and peroxidase activities were almost null in yam flours and their specific role on yam flour phenolic content needs to be clarified.

Key words: Biochemical composition, *Dioscorea spp*., Flour, Sensorial analysis, Yam

Introduction

Yam tubers like other root and tuber crops are subject to physiological deterioration after harvest leading to fresh weight losses up to 60% after 9 months storage [1], up to 70% rotted tubers after 5 months, and up to 60–70% losses of consumable dry matter after 10 months [2]. Drying can improve shelf life of watery tubers and a unique process has been developed for yam in Nigeria and Benin that includes hand peeling, blanching in water at 63 ± 3 °C, and sun drying for 5–7 days [3]. Tubers from *Dioscorea rotundata* cultivars, and particularly from the kokoro group, are generally used for this process [4]. They are thought to give the best amala, the paste obtained from dry yam flour. However, a recent study showed that dried Florido (*D. alata*) tubers can give an amala as appreciated as the one produced from kokoro tubers [5]. The market of this product has increased considerably in the recent 30 years in such a way that amala is more frequently consumed in urban areas of Nigeria and Benin (Cotonou in particular) than the very traditional pounded yam [6]. Indeed, amala is much more easy to prepare in urban way of life: the flour obtained after crushing and milling yam chips is just boiled in water to get a colored gel-like paste. Apart from its texture that most of consumers like it elastic and nonsticky [3], the commercial amala has faintly sweet and bitter taste. In addition, amala darkens during cooking and its final color varies from whitish to dark brown. The color is thus a major attribute of amala and largely affects its acceptability by consumers [4]. The majority of consumers prefer brownish (milk chocolate color) amala whereas a dark brown color is thought to be linked to bad drying conditions [5].

The discoloration of fresh yams is clearly linked to polyphenol content of tubers [7, 8] and in particular to the presence of cyanidin glycosides [9, 10], catechin, and procyanidin oligomers [11]. In addition, bitterness of *D. rotundata* and *D. alata* species seemed also linked to polyphenolic compounds [12] and particularly to proanthocyanins [13]. Several studies have been published on the role of polyphenol oxidase (PPO) and peroxidase on the browning phenomenon of fresh yam after wounding or cutting [14–16]. However, very little is known about the browning phenomenon of dried yam and amala even if an enzymatic phenomenon could be involved [4, 17].

This paper deals with the sensory (color and taste) assessment of amala and the study of the biochemical origin of these quality attributes. In addition, the role of the enzymatic machinery on amala browning phenomenon will be investigated.

Experimental

Yams

Healthy yam tubers of *D. rotundata* cvs. Yakarango, Omoya, Gnidou, and of *D. alata* cv. Florido were obtained from the International Institute of Tropical Agriculture, Cotonou, Benin. Yam tubers were harvested in the beginning of the main dry season (November–December) of 1999. They were then stored at 15 °C until use. The maximum storage duration was of 6 months and neither germination nor apparent mould development occurred in this condition.

In addition, one sprouted yam tuber sample (*D. rotundata* kokoro type cultivar) was bought at Cotonou's market.

Dried Yam Flours and Amala Preparation

General procedure for preparing dried yam flours was the following: fresh tubers were hand peeled and rapidly placed in an aluminum pot containing cold water. The pot was heated from ambient temperature to $63 \pm 2\,^{\circ}C$ (about 25 min was necessary to get the desired temperature) and heating was stopped; yam tubers were let overnight in the heated water. They were then dried in an oven at $45 \pm 5\,^{\circ}C$ for 3–5 days, crushed in a traditional mortar, and finally ground into flour by passing through a centrifuge mill (Roetsch, Haan, Germany) with 250-μm outlet sieve. Variations in the procedure were used to get a large range in dried yam flour quality:

1. three levels of peeling were used: no peeling, fair peeling (only the skin was removed) standard peeling (5-mm thick removed);
2. use or no use of leaves of *Tectona grandis* in the steeping bath;
3. use or no use of ogi (a fermented maize slurry) liquor during steeping (one third of total volume);
4. steeping at $30\,^{\circ}C$ (ambient temperature) or precooking at 57, 63, or $75\,^{\circ}C$; and
5. use of sprouted or not sprouted tubers.

Twenty-two yam chips samples were thus processed at the laboratory level and one insect-attacked sample was bought at Cotonou's market. Each cultivar was at least treated with three similar procedures, thus allowing a two-way analysis of variance on these samples. In addition, two tubers of each cultivar were peeled, crushed, and freeze-dried.

For preparing amala, 30 g of dried yam flour was dispersed in water (100 ml) at ambient temperature and then poured into 140-ml boiling water. The mixture was let to boil again for 45 sec and then 30 g of yam flour was added and the mixture vigorously stirred without heating until getting an homogeneous paste. The paste was then heated for 2 min and finally stored in an empty plastic icebox for a maximum of 30 min.

Sensorial Analysis

Assessor training and descriptor selection were carried out according to Rousset et al. [18, 19]. Nineteen subjects were first trained during 14 sessions for flavor description by tasting the following references: salty (NaCl), sweet (sucrose), acid (citric acid), bitter (caffeine), and astringent ($KAl(SO_4)_2$) solutions, by smelling food products (milk, bread, wheat flour, rice). Subjects also tasted six amala, *a priori* chosen for having various flavors, and freely listed descriptive attributes. From the 25 listed attributes, 5 were selected by consensus being representative and sufficient to describe amala: sweet, bitter, astringent, fermented, and roasted. The subjects were then trained to quantify these attributes on a semistructured scale (0–5) by tasting three amala with three replications. At the end of training, 17 assessors were selected among whom 15 came regularly. The 20 remaining amala were finally assessed without replications under daylight, 3–4 at each session.

An hedonic test was also performed to know the trend for the ideal amala [20]. For this, 35 naive subjects tested seven amala *a priori* selected as the best ones. Each attribute of each amala was rated on a structured scale from -50 to $+50$ (much less or much more intense than I cannot eat it, respectively) passing by 0 (ideal) and a global appreciation was given of each amala from 0 to 20.

Physicochemical Analyses

Color of flour and amala was measured with Minolta CR-210 chromameter as described by Hounhouigan et al. [21].

Dry matter was determined after heating at $130\,^{\circ}C$ for 2 hours. Soluble sugar and organic acid contents were determined by HPLC using an HPX87H column (Biorad, Hercules, USA) eluted at $60\,^{\circ}C$ with 5 mM sulphuric acid with refractometric and UV 210-nm detectors [22]. Total phenols and proanthocyanin compounds were assayed by a procedure derived from that of Swain and Hillis [23]. Total phenols were extracted from 350-mg yam flour with 1-ml methanol/water (85/15 v/v) for 1 hour at ambient temperature. After centrifugation at 7000 *g* for 5 min, 100 μl of the supernatant was diluted with 6.9-ml water and 1 ml of Folin–Ciocalteu reagent (F9252, Sigma) was added. After 6 min, 2 ml of Na_2CO_3 20% (p/v) was added and the mixture placed in dark for 1 hour before reading the optical density at 760 nm. Phenol content was then calculated by comparison with gallic acid standard solutions. Proanthocyanins were extracted from 700 mg of yam flour with 3-ml methanol/hydrochloric acid solution (1.5 *N*) (85/15, v/v) for 90 min at ambient temperature. After centrifugation at 7000 *g* for 5 min, the supernatant was diluted twice with water and 1 ml of the diluted extract was placed in each of two test tubes. Ten milliliters of *n*-butanol/concentrated hydrochloric acid (95/5 v/v) was added in each tube. One tube was then placed in a boiling water bath for 40 min and then cooled under running water for 5 min whereas the other was placed in dark at ambient temperature. Optical density was then measured at 550 nm with the nonheated tube as blank. Proanthocyanin content was then calculated assuming a molar coefficient extinction of cyanidin of 47,000 $cm^{-1}\ M^{-1}$.

PPO activity was determined with a procedure derived from that of Adamson and Abigor [14]. Catechol was dissolved in 0.2 *M* phosphate buffer (pH 6.8) to obtain a 125 mM catechol stock solution; this concentration was checked to be at least five times higher than the measured K_m of yam PPO. Fifty milliliters of catechol stock solution was vigorously shaken just before use and then equilibrated at $37\,^{\circ}C$ for 3 min. It was then poured in a double

wall beaker conditioned at 37 °C with circulated water. The probe (CellOx325) of a WTW oxymeter (Weilheim, Germany) was immersed in the solution that was continuously stirred by a magnetic stirrer. One gram of yam flour was rapidly poured into the solution and the evolution of the oxygen concentration in the dispersion was registered for 3 min. The maximum slope of the curve was determined. The chemical oxygen consumption rate obtained without addition of any sample was then subtracted and the PPO activity calculated in μM O_2 consumed per minute and g (db).

Peroxidase activity was determined with a procedure adapted from that of Ikediobi et al. [15]. Peroxidase was extracted from 50 mg of yam flour with 1 ml of 0.2 *M* phosphate buffer (pH 7.0) for 15 min at ambient temperature followed by centrifugation at 7000 *g* for 5 min. The substrate was prepared just before use by mixing 0.5 ml of 1% (p/v) aqueous pyrogallol with 6 ml of 0.3% (v/v) aqueous H_2O_2; substrate concentrations were calculated to be 3 and 10 times higher than their respective affinity (K_m) for yam peroxidase. An inhibition by the substrate was observed for pyrogallol at a concentration higher than $3 \times K_m$. The reaction was run in 10-mm glass cuvette containing 0.1 ml of peroxidase extract and 2.9 ml of substrate; the blank was obtained by replacing the peroxidase extract by pure buffer (pH 7.0). The maximum increase in absorbance at 460 nm was determined; one unit of peroxidase activity was defined as an increase in absorbance of 0.001 min^{-1}.

Results and Discussion

Chemical Characterization of Yam Flour

Mean values of color parameters of laboratory-prepared yam flours (Table 1) were similar to those measured for market flours in Cotonou (Benin) whose mean brown index (100-L*) was about 21 [3]. No significant difference between cultivars was observed for the dried flour color parameters. The main soluble sugar in yam flours was glucose with minor amounts of fructose: both were assayed as a whole as they were not completely separated in the used chromatographic conditions. Mean value of glucose and fructose content was twice higher than reducing sugar content of market yam flour [3]. Citric acid was the main organic acid followed by lactic acid (Table 1). The latter evidenced that a lactic fermentation occurred during steeping overnight and/or drying as already observed by Achi and Akubor [24]. Total organic acid content of laboratory-prepared yam flours was similar to the calculated one (from the titratable acidity) of market yam flours [3]. Oxalate level was low (between 0 and 1.3 mg/g db). It was much lower than the value measured on fresh *D. alata* yams (close to 4 mg/g db; [25]); this may be due to the procedure used to prepare yam flours as oxalate can be solubilized during parboiling [26]. Florido flours had significantly higher sugar content and Omoya the lowest one whereas no significant differences between cultivars were observed for organic acid content.

Total phenol content appeared relatively low but was in the range measured on fresh yams: from 0.2 [7] to 30 μM/g (db) for *D. rotundata* and *D. alata* species [27, 28]. No significant difference was evidenced between the four cultivars. Proanthocyanin content was low representing roughly 10% of total phenol content but seemed higher in the Florido cultivar (*D. alata* specie). Indeed, Ozo et al. [11] identified catechin and procyanidin polymers, particularly dimers B1 and B2, in fresh yams whose content was more important in *D. alata* cultivars.

The activity of PPO was low (around 3 μM O_2 min^{-1} g^{-1} db for ambient temperature steeped samples) or even null (for samples precooked at 75 °C) in yam flours. PPO activity was 10–50 μM O_2 min^{-1} g^{-1} (db) for freeze-dried fresh yams which corresponded to 250–1250 μM O_2 min^{-1} per 100-g fresh yam and was of the same order than the

Table 1. Physical and biochemical characteristics of the yam flours

				Metabolites (mg g^{-1} db)			Phenolic compounds (μM g^{-1} db)		Polyphenol oxidase
	100-L*	a*	b*	Glucose and fructose	Citrate	Lactate	Phenols	Proanthocyanins	(μM O_2 min^{-1} g^{-1} db)
Mean value[a]	19.8	1.7	10.1	24.4	6.1	1.8	1.2	0.07	1.3
Standard deviation[a]	3.6	0.7	1.7	14.2	5.1	2.0	0.6	0.08	1.7
Yakarango[b]	18.7	2.4	9.3	24.5	8.2	2.7	0.9	0.07	0.3
Omoya[b]	19.6	1.8	12.2	7.4	6.8	2.8	1.4	0.04	ND[c]
Gnidou[b]	20.9	1.6	9.8	24.3	3.5	1.5	1.3	0.09	2.3
Florido[b]	18.6	2.1	9.1	47.7	5.6	2.2	1.8	0.22	3.2
LSD[d]	6.3	1.2	3.2	12.1	6.8	4.3	1.2	0.2	3.0

[a]23 samples.
[b]Mean values for three treatments.
[c]Not detected.
[d]Least significant difference ($P = 0.05$) between cultivars.

Table 2. Color and sensory results of amala

	100-L*	a*	b*	Sweetness	Bitterness	Acidity	Fermented taste	Roasted taste
Mean value[a]	53.2	3.8	7.9	2.0	1.7	1.6	1.5	1.1
Standard deviation[a]	4.8	1.2	2.2	1.2	1.2	1.3	0.9	1.0
Yakarango[b]	51.1	5.4	9.4	1.9	1.7	1.5	1.4	0.6
Omoya[b]	55.7	4.4	9.5	0.9	2.8	1.8	1.7	2.1
Gnidou[b]	53.9	3.5	7.0	2.0	1.8	1.1	1.3	1.3
Florido[b]	52.6	3.9	6.3	3.2	0.7	1.6	1.8	0.8
LSD[c]	7.9	1.0	3.0	1.3	2.0	1.1	0.9	1.7
Ideal amala	58.9	4.4	7.8	0.7	3.4	2.2	2.0	1.8

[a]23 samples.
[b]Mean values for three treatments.
[c]Least significant difference ($P = 0.05$) between cultivars.

values (50–1000 μM O_2 min^{-1} per 100-g fresh *D. alata* or *D. rotundata* yams) obtained by Ozo and Caygill [29]. No residual peroxidase activity could be detected in yam flours whereas it ranged between 60 and 600 units/g (db) for freeze-dried fresh yams. By comparison, Ikediobi et al. [15] reported a peroxidase activity close to 1000 units/g fresh tissue in *D. rotundata* yam. The lack of activity for high-temperature (75 °C) precooked yam flours was in accordance with the results of Ikediobi and Obasuyi [30], who observed that purified yam PPO activity dropped sharply after few minutes beyond 60 °C. In the case of flours obtained from yams steeped at 30 °C before drying, the lack of PPO activity should indicate that an inactivation also proceed during drying at 45 °C. Accordingly, Omidiji and Okzupor [16] observed a total inactivation of PPO for yam slices stored at or above 40 °C for several hours.

Sensorial Analysis and Color Characteristics of Amala

For each attribute, the sensory score range was large covering the whole scale for sweetness, bitterness, and acidity (Table 2). Color parameters of amala were in the range observed for commercial products [3] but with greater variability. This was expected as the processing conditions used in this study were designed to enhance sensorial and appearance differences between samples. The cultivar significantly influenced the red index (a*), Yakarango giving the reddest amala. Proceeding conditions also influenced significantly amala color: samples prepared with addition of ogi liquor during blanching gave clearest but more colored amala (with higher a* and b* indexes). Florido gave the significantly sweetest amala whereas Omoya gave the least one. As expected, the use of fermented ogi liquor during blanching significantly increased acidity and fermented score of the amala. Indeed, ogi liquor which can be used traditionally for parboiling yams is the liquid surrounding fermenting maize mash and has an average pH of 3.4 and a titratable acidity of 13.8-mg lactic acid g^{-1} (db) [31].

Fermented and acid tastes were highly correlated (R = 0.94) as were bitter and roasted tastes ($R = 0.81$). Bitterness was negatively correlated with sweetness ($R = -0.68$) as expected as these two tastes are in competition for their perception. In addition, the brown index (100-L*) was highly correlated with roasted and bitter tastes, with R of 0.83 and 0.74, respectively, indicating that the darker the amala the bitter and roasted taste it has.

Among the seven amala tested by the hedonic method, one had hedonic scores close to 0 for the five sensorial attributes (○ sample on Figure 1) and a global note of 16.6 over 20. It can thus be considered as the ideal amala. This was a quite dark and reddish amala, moderately bitter but very slightly sugary and slightly acidic, fermented, and roasted (Table 2). It should be noticed that the ideal product was obtained from a kokoro-type yam with the standard procedure (intense peeling and parboiling at 65 °C) but for yam ships stored for several months. The variation between the seven tested amala (Figure 1) was mainly due to three attributes (color, bitterness, and roasted taste) that were all intercorrelated as shown above. The color hedonic score was in particular highly correlated with measured brown index ($r = 0.82$) but not with red and yellow indexes ($r = 0.16$

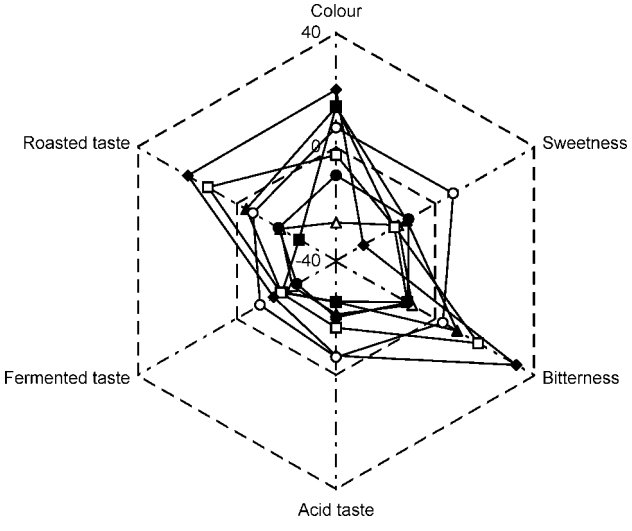

Figure 1. Hedonic scores of the seven amala.

Table 3. Correlation matrix between sensorial quality of amala and physicochemical properties of flours

	Flour characteristics						
Amala quality	100-L*	a*	b*	Glucose–fructose	Citrate	Lactate	Phenols
100-L*	0.80**	0.35	0.59*	−0.13	−0.22	−0.17	0.72**
a*	0.10	0.78**	0.36	−0.18	0.30	0.46	−0.08
b*	−0.09	0.28	0.43	−0.38	0.52	0.36	−0.34
Sweetness	−0.39	−0.30	−0.63*	0.80**	0.18	−0.19	0.02
Bitterness	0.62*	0.45	0.81**	−0.49	0.14	0.18	0.34
Acidity	−0.54	−0.15	−0.13	−0.04	0.42	0.52	−0.45
Fermented taste	−0.57*	−0.13	−0.21	0.05	0.33	0.58*	−0.44
Roasted taste	0.65*	0.33	0.71*	−0.37	−0.03	−0.23	0.61*

*Significant at 1% level.
**Significant at 1 P 1000 level.

and 0.05, respectively). This should mean that consumers were mainly influenced by the darkness of amala but not by its color.

Relationship Between Sensory Quality of Amala and Instrumental Analysis of Yam Flour

The brown index of amala was highly correlated with the brown index of yam flour (Table 3) and both were highly correlated with total phenol content of yam flour. Indeed, fresh yam discoloration is generally attributed to polyphenols generated by enzymatic and/or chemical oxidation [32]. In the case of yam flour also, Almenteros and Del Rosario [8] found that phenolic rich yams gave darker flours whereas Izundu [17] evidenced the role of peroxidase on flour yam paste discoloration. The very low peroxidase and PPO activity recovered in flours in our experiments indicated that enzymatic discoloration of flour during storage and cooking is very unlikely to appear; these enzymes may however be active in the beginning of the yam processing into flour. Nonenzymatic browning caused by Maillard reaction between free sugars and amino acids could also play a role in paste darkening during cooking as proposed by Achi and Akubor [24]. Multiple regression models show however that glucose and fructose flour content was negatively correlated with amala brown index (Table 4) which means that flours with low sugar level gave darker amala. This indicated that sugars are not involved in amala darkening during pasting. The red indexes of yam paste and flour were highly correlated but no tight relationship was found with physicochemical characteristics of flours (Table 3); amala red index was only slightly (5% level) and positively correlated with lactic acid content. On the contrary, Achi and Akubor [24] recently evidenced that lactic-fermented yam tubers gave lighter amala. This contradiction may be due to our experience design that mixed the effects of addition of ogi liquor and of *Tectona grandis* leaves, the latter contributing to the reddish color of the steeping water and of yam surface. There was no correlation between yellow index of amala and of yam flour, neither with any of measured biochemical characteristics.

Flour glucose and fructose content was highly positively correlated with amala sweetness and negatively correlated (at 5% level) with its bitterness. This confirmed the opposition of these two tastes. In addition, multiple regression models confirmed the antagonist role of sweet and bitter molecules as phenol and proanthocyanin contents were positively and negatively correlated with bitterness and sweetness, respectively. Indeed, the bitter impact of polyphenols and particularly of proanthocyanins, has been already demonstrated for fresh yams [12, 13]. In addition, Onayemi and Idowu [12] found that aroma and flavor of fresh yam was improved after storage for several months and they attributed this improvement to an increase of yam sugar content despite of a parallel polyphenol increase. Our results thus evidenced that the bitter taste of yam paste has the same origin as for fresh yam.

In addition, a positive partial correlation was found with flour oxalate content. Finally, models obtained by multiple regression gave a quite good representation of measured sweetness and bitterness (Figure 2a and b). Roasted taste gave a quite similar pattern as bitterness (Table 4): it increases with phenol content and decreases with sugar content. These two attributes were indeed highly correlated;

Table 4. Multiple regression models of amala sensory quality based on chemical composition of yam flour

Amala variable	Model[a]	R^2
Brown index	47.7 + 6.98 [Phenols] −0.13 [Glucose–fructose]	0.63
Sweetness	0.26 + 0.094 [Glucose–fructose] −7.14 [Proanthocyanins]	0.76
Bitterness	1.12 + 1.18 [Phenols] −0.054 [Glucose–fructose] + 1.35 [oxalate]	0.62
Acidity	0.49 + 0.30 [lactate] + 0.091 [Citrate]	0.41
Roasted taste	0.43 4 + 1.41 [Phenols] −0.048 [Glucose–Fructose]	0.74

[a][Metabolite] (mg g^{-1} db); [Phenolic compound] (μM g^{-1} db).

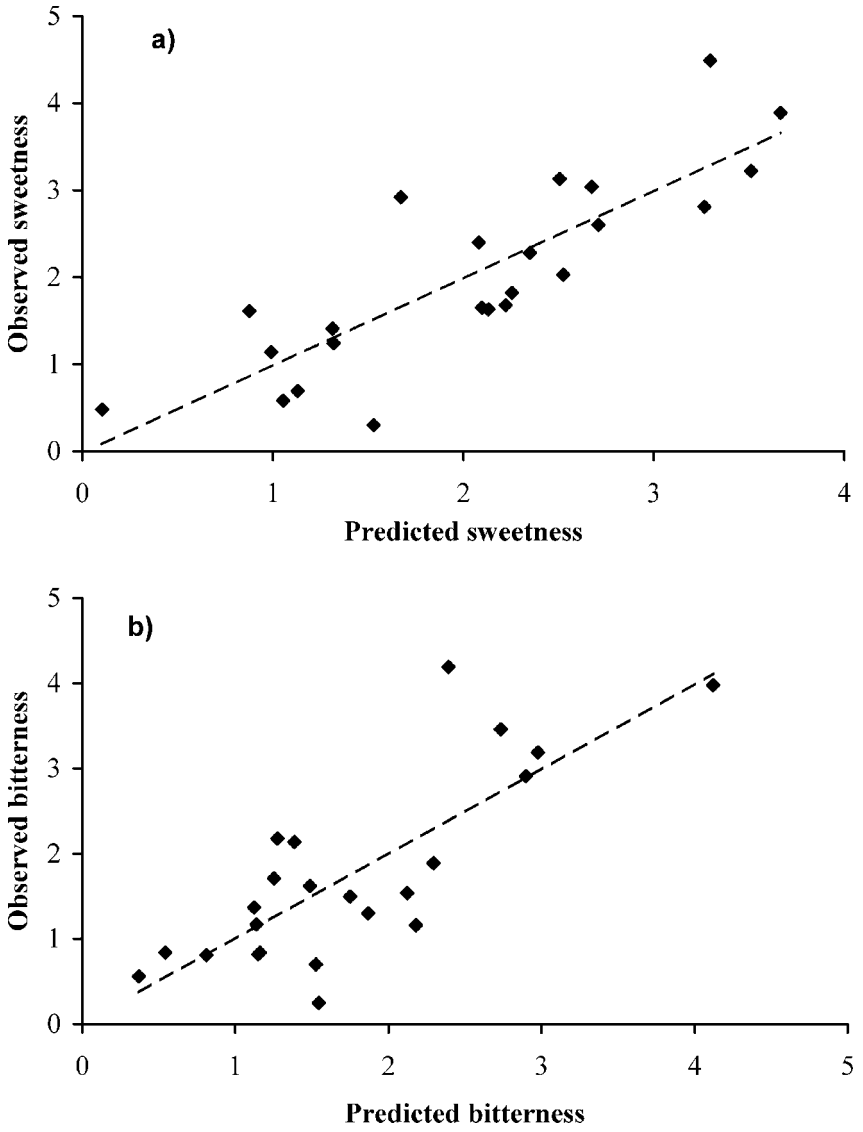

Figure 2. Plot of observed versus predicted values obtained by multiple regression analysis: (a) sweetness, (b) bitterness.

they appeared complementary and might be, partly, linked to Maillard and/or quinone reaction with sugars during precooking and/or drying.

The acidic taste was positively correlated with the main organic acid content of yam flours (citrate and lactate) that could explain 41% of this taste. It should be noticed that panellists were able to distinguish acid and fermented tastes as the latter was only correlated with lactic acid content (Table 3).

Conclusion

Five main taste and aroma attributes were identified for amala. These attributes and color parameters can be efficiently predicted from flour biochemical characteristics. Polyphenols appear in particular at the origin of three major attributes of amala: darkness, bitterness, and roasted taste. However, PPO and peroxidase that can be suspected to be involved in polyphenols synthesis were inhibited during yam processing into dried flours and their specific role on polyphenol content of yam flour needs to be investigated. This preliminary study also showed significant effects of variety and processing factors on, in particular, amala sweetness and darkness, respectively. This will be more studied in following papers.

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References

1. Mozie O (1988) Effect of storage temperature on storage weight losses in white yam (Dioscorea rotundata Poir) tubers. Trop Sci 28: 273–276.
2. Girardin O, Nindjin C, Farah Z, Escher F, Stamp P, Otokoré D (1998) Use of gibberellic acid to prolong dormancy and reduce losses during traditional storage of yams. J Sci Food Agric 77: 172–178.
3. Akissoé N, Hounhouigan DJ, Bricas N, Vernier P, Nago CM, Olorunda A (2001) Physical, chemical and sensory evaluation of dried yam (Dioscorea rotundata) tubers, flour, and "amala" a flour-derived product. Trop Sci 41: 151–155.
4. Chilaka FC, Eze S, Anyadiegwu C, Uvere P (2002) Browning in processed yams: Peroxidase or polyphenol oxidase? J Sci Food Agric 82: 899–903.
5. Vernier P, Dossou RA, Letourmy P (1999) Processing yam chips from Dioscorea alata: Effect of the variety and chip size on drying, storage ability and sensorial properties. Afr J Root Tuber Crops 3: 62–68.
6. Bricas N, Vernier P, Ategbo E, Hounhouigan J, Mitchikpe E, N'kpenu KE, Orkwor G (1997) The expansion of yam chip food subsector in West Africa. Cah recherche Dév 44: 100–114.
7. Osagie AU, Opoku AR (1984) Enzymatic browning of yams (Dioscorea species). Niger J Biochem 25–29.
8. Almenteros VP, Del Rosario RR (1985) Phenolic content and polyphenoloxidase activity related to browning in yam (Dioscorea alata Linn.). Philipp Agric 68: 449–452.
9. Rasper V, Coursey DG (1967) Anthocyanins of Dioscorea alata L. Experientia 23: 611–612.
10. Imbert MP, Seaforth C (1968) Anthocyanins in Dioscorea alata L. Experientia 24: 447–449.
11. Ozo ON, Caygill JC, Coursey DG (1984) Phenolics of five yam (Dioscorea) species. Phytochemistry 23: 329–331.
12. Onayemi O, Idowu A (1988) Physical and chemical changes in traditionally stored yam tubers (Dioscorea rotundata Poir and Dioscorea cayenensis Lam). J Sci Food Agric 36: 588–591.
13. Martin FW, Ruberté R (1975) Bitterness of Dioscorea Cayenensis. J Agric Food Chem 23: 1218–1219.
14. Adamson I, Abigor R (1980) Transformation associated with catecholase in Dioscorea alata during storage. Phytochemistry 19: 1593–1595.
15. Ikediobi CO, Chelvaran RL, Ukoha AI (1989) Biochemical aspects of wound healing in yams (Dioscorea spp). J Sci Food Agric 48: 131–139.
16. Omidiji O, Okzupor J (1996) Time course of PPO-related browning. J Sci Food Agric 70: 190–196.
17. Izundu AI (1995) Peroxidase activity and inhibition of browning reaction in Dioscorea dumetorum tubers. J Root Crops 21: 12–16.
18. Rousset S, Pons B, Pilandon C (1995) Sensory texture profile, grain physico-chemical characteristics and instrumental measurements of cooked rice. J Texture Stud 26: 119–135.
19. Rousset S, Pons B, Martin J-M (1999) Identifying objective characteristics that predict clusters produced by sensory attributes in cooked rice. J Texture Stud 30: 50–532.
20. Issanchou S (1990) The profile of ideal product. In: Sztrygler F (ed), Evaluation sensorielle: Manuel méthodologique. Paris: Lavoisier, pp 195–205.
21. Hounhouigan DJ, Nout MJR, Nago CM, Houben JH, Rombouts FM (1993) Composition and microbiological attributes of mawè, a fermented maize dough from Benin. Int J Food Sci Technol 28: 513–517.
22. Nago M, Tétégan E, Matencio F, Mestres C (1998) Effects of maize type and fermentation conditions on the quality of Beninese traditional ogi, a fermented maize slurry. J Cereal Sci 28: 215–222.
23. Swain T, Hillis WE (1959) The phenolics constituents of prunus domestica. I: The quantitative analysis of phenolic compounds. J Sci Food Agric 10: 63–68.
24. Achi OK, Akubor PI (2000) Microbiological characterization of yam fermentation for "Elubo" (yam flour) production. World J Microbiol Biotechnol 16: 3–7.
25. Wanasundera JPD, Ravindran G (1994) Nutritional assessment of yam (Dioscorea alata) tubers. Plant Food Hum Nutr 46: 33–39.
26. Wanasundera JPD, Ravindran G (1992) Effects of cooking on the nutrient and antinutrient contents of yam tubers (Dioscorea alata and Dioscorea esculenta). Food Chem 45: 247–250.
27. Asemota HN, Wellington MA, Odutuga AA, Ahmad MH (1992) Effect of short-term storage on phenolic content, *o*-diphenolase and peroxidase activities of cut yam tubers (Dioscorea sp). J Sci Food Agric 60: 309–312.
28. Muzac-Tucker I, Asemota HN, Ahmad MH (1993) Biochemical composition and storage of Jamaican yams (Dioscorea sp). J Sci Food Agric 62: 219–224.
29. Ozo ON, Caygill JC (1985) Some characteristics and a comparison of the activities of *o*-dihydroxyphenoloxidase from five yam (Dioscorea spp.) species. J Sci Food Agric 36: 973–979.
30. Ikediobi CO, Obasuyi HN (1982) Purification and properties of *o*-diphenolase from white yam tubers. Phytochemistry 21: 2815–2820.
31. Nago M, Hounhouigan J, Akissoë N, Zanou E, Mestres C (1998) Characterization of the Beninese traditional ogi, a fermented maize slurry: Physico-chemical and microbiological aspects. Int J Food Sci Technol 33: 307–315.
32. Martin FW, Ruberte R (1976) The polyphenol of dioscorea alata (Yam) tubers associated with oxidative browning. J Agric Food Chem 24: 67–70.