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Yam bean (*Pachyrhizus erosus*) tuber processing in Benin: production and evaluation of the quality of yam bean-*gari* and yam bean-fortified *gari*

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ABSTRACT

Yam bean (*Pachyrhyzus erosus*) tubers were processed singly and mixed with cassava into different types of *gari* (100% yam bean *gari*, 75% yam bean *gari*, 50% yam bean *gari* and 25% yam bean *gari*) following the traditional *gari* processing method. Conventional *gari* from cassava was processed following the same approach and used as control. Physical characteristics, proximate composition and sensory quality of the *garis* obtained were assessed. Results showed that low and medium (25% and 50%) yam bean fortified *gari* processing yielded better than 75% and 100% yam bean *gari* processing. Low and medium yam bean *gari* were the closest to conventional *gari* regarding the brown index (18.0 and 18.3 respectively), had good swelling capacity (≥ 3) and had higher relative bulk density (0.57 and 0.53 respectively). The proteins content of the processed yam bean *garis* increased with increasing incorporation rate of yam bean but, similarly, the crude fibres content increased going beyond the recommended level of 2% maximum. The processed *garis* were used to cook *èba* which were submitted to panellists' appreciation. Panellists scored better low and medium yam bean fortified *garis* and the resulting *èba*. Combining the results, the highest suggested incorporation rate was 50% yam bean tubers.

Keywords: Legume tuber-root crop, quality, physical characteristics, chemical composition, sensory evaluation.

INTRODUCTION

Tropical root crops such as cassava (*Manihot esculenta*, Euphorbiaceae), yams (*Dioscorea* spp, Dioscoreaceae), sweet potato (*Ipomoea batatas*, Convolvulaceae) and cocoyams (*Colocasia esculenta* and

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Xanthosoma spp., Araceae) are widely grown and consumed in the tropics. All these crops are characterized by high levels of carbohydrates (starch and/or sugars) with low amounts of protein. Cassava is one of the most widely consumed crops in Africa, with *gari* as its most popular processed product consumed by nearly 300 million people in West Africa (Oseni, 2012). Sanni et al. (2008) described *gari* as creamy-white, partially gelatinized roasted free flowing granular flour. The popularity of *gari* to urban consumers is due to its low cost, long shelf-life, low bulk (as compared to fresh cassava roots) and the ease of preparation for consumption especially the preparation of cooked stiff dough eg. *eba* (Oduro et al., 2000) or just suspended in water. To process *gari*, cassava tubers are peeled, washed, grated and the mash is often allowed to ferment for up to 3 days. The mash is pressed for de-watering, crumbled and heated by means of constant hand-turning over a heated steel pan until about 10–12% water content and finally sieved into different grades (Apea-Bah et al., 2009). Similarly to the raw material, a major drawback of *gari* as food is its low protein, minimal essential mineral and vitamin content, a deficit in essential amino acids and resulting poor protein quality (Sanni et al., 2002; Afoakwa et al., 2010).

Pachyrhizus erosus (jacatube or Mexican yam bean) and its closely related species *P. ahipa* and *P. tuberosus* produce tubers containing higher amounts of crude proteins: 11% - 18% (Kale, 2006; Zanklan et al., 2007) and relatively elevated iron contents of up to 130 mg kg^{-1} (Kale, 2006) than cassava. Previous works investigated the physicochemical characteristics of proteins and starch from *Pachyrhizus* sp. for potential agro-industrial uses (Forsyth and Shewry, 2002; Forsyth et al., 2002; López et al., 2010). However, studies on the possibility to process *Pachyrhizus* spp. into various foods products remain limited. Traditionally, the crisp and fruity fresh roots have been consumed raw as fruit or vegetable, providing calories, potassium and vitamin C to the diet (Sorensen et al., 1997; Zanklan et al., 2007). In previous studies, Zanklan et al. (2007) and Wassens (2011) demonstrated the suitability of *Pachyrhizus* spp. roots for West African *gari* processing. The present study aims to explore the possibility to process yam bean tubers into good quality *gari* and to evaluate the consumer acceptability of this food product in an area of major *gari* consumption in Benin.

MATERIALS AND METHODS

Origin of the yam bean tubers used for the study

Seeds of *Pachyrhizus erosus* accession EC-533 originating from Macao (Zanklan et al., 2007) were provided by the International Potato Centre of Lima (Peru) and grown at Niaouli (6° 12’ North, 2° 19’ East), Savè (8° 1’ North, 2° 29’ East) in the Central-Southern Guinea Savannah and Abomey-Calavi (6° 27’ North, 2° 21’ East), Coastal Savannah, Benin. Tubers were harvested 6–8 months after sowing and used for the processing experiments.

Yam bean tubers processing into *gari*

Processing into *gari* followed the traditional procedure described by Oduro et al. (2000). Roots were manually peeled, washed, grated with a mechanised grater, fermented for 2 days, pressed and dewatered using a manual screw-press, crumbled, sieved and roasted. For processing, only *P. erosus* tubers were used or combined with cassava roots (Figure 1). The following combinations were tested and compared with 0% yam bean *gari* (or 100% cassava *gari*) and 100% yam bean g*ari*:

- 25% yam bean + 75% cassava
- 50% yam bean + 50% cassava
- 75% yam bean + 25% cassava

The raw materials were mixed before the grating step. Processing was carried out in duplicates.

Physical characteristics of the processed g*ari*

Colour parameters

Colour characteristics were evaluated via the luminance (L*), the saturation index in yellow (b*) and the colour difference (ΔE) in relation to the white reference ceramic (D65 Y94.8 x .3150 y .3324), using the Minolta Chroma Meter CR-210b (Minolta Camera Co. Ltd, Osaka, Japan) . The brown index of *gari* was calculated as 100–L*.

Relative bulk density

Relative bulk density was determined following AOAC (1990) method. Twenty grams of g*ari* sample were filled in a 50 ml measuring cylinder. The cylinder was tapped during 15 minutes and the final volume of the *gari* in the cylinder recorded. Relative bulk density was calculated by dividing initial quantity of the *gari* sample by the final volume recorded after tapping.

Swelling capacity

Swelling capacity was assessed following the method of Ajibola et al (1987) modified by Bainbridge et al (1996). Ten millilitres of the *gari* were measured in a 50 ml glass cylinder and adjusted to 50 ml with distilled water at room temperature (about 28 °C). The cylinder was tightly covered, inverted for 2 minutes, inverted again and allowed to stand at room temperature during 3 minutes. The final volume of the *gari* in the cylinder was recorded and divided by the initial volume to obtain the swelling capacity.

Water absorption capacity

Water absorption capacity was assessed (AOAC 1990). A centrifuge tube was filled with 1 g g*ari* sample added with 20 ml distilled water. The suspension was thoroughly mixed and left to stand for 30 minutes at room temperature (about 28 °C). The tube was centrifuged at 500 rpm for 30 minutes and the volume of unabsorbed water measured. Water absorption capacity was calculated on the basis of quantity of water retained per gram of g*ari*.

Determination of the chemical composition of processed g*ari*

AOAC (1990) methods were used to determine water, proteins, fats and ash content of the processed g*ari*. Water content was determined by oven-drying 5 g g*ari* sample at 105 °C during 24 h, and calculating the evaporated water amount. Protein content was calculated by the Kjeldahl-Nitrogen analysis procedure, using 6.25 as conversion factor. Fat content was assessed through Soxhlet extraction using petroleum ether as solvent. Ash content was determined on the basis of a 5 g sample at 550 °C during 24 h. Total fibre content was determined as described by Osborne and Voogt (1978). The content of other carbohydrate was obtained by difference. Titratable acidity (TTA) of g*ari* was assessed following Nout et al. (1989) in a suspension of 10 g of g*ari* in 90 ml of distilled water.

Sensory evaluation procedures

Colour, flavour and taste of the processed g*ari* samples were evaluated using a hedonic test (Lawless and Heymann, 2010) with a panel of 32 *gari* consumers. Samples were scored on a five-point scale, 1 corresponding to very bad and 5 corresponding to very good. The g*ari* was reconstituted with boiling water to form a cooked stiff dough *èba* and submitted to 33 untrained panellists. A preference test (Lawless and Heymann, 2010) was used to appreciate *èba*. The most preferred *èba* was scored 5 and the less preferred one scored 1.

Statistical analysis

Data were analysed with SPSS 16.0 software (SPSS Inc., Chicago, Illinois, USA). Data of physical and chemical parameters were calculated in triplicates. All results were compared using one-way ANOVA followed by the Student-Newman-Keuls test.

RESULTS

Yield of garification during yam bean *gari* processing

Five types of g*ari* were obtained respectively from cassava roots, yam bean tubers and different combinations of yam bean tubers and cassava roots. Yields were calculated at the end of processing into *gari*. As shown by Figure 2, the yields decreased from 23.8% (cassava *gari*) to 3.55% (100% yam bean *gari*). The higher the percentage of yam bean tubers, the lower was the *gari* yield.

Physical characteristics of processed g*ari*

Colour

The luminance L* decreased and the resulting brown index (100–L*) increased significantly ($p < 0.05$) from 12.8 to 27.8 for 100% cassava g*ari* and 100% yam bean g*ari* respectively (Figure 3). This result showed that colour of g*ari* darkened as the percentage of incorporated yam bean increased.

Bulk density, swelling index and water absorption capacity

Relative bulk density decreased from 0.58 in 100% cassava *gari* to 0.50 for 100% yam bean *gari*. Similarly, swelling index decreased from 3.3 to 2.5 and water absorption capacity decreased from 5.95 to 3.49 (Figure 3). These results suggest that the higher the percentage of yam bean in the yam bean–cassava mixture, the lower the bulk density, the swelling index and the water absorption capacity of the resultant *gari*.

Chemical composition of the processed *garis*

Proximate composition revealed that the water content of g*aris* obtained from yam bean and cassava tubers ranged from 10.24% to 12.16% (Table 1). The titratable acidity increased significantly ($p < 0.05$) as the amount of yam bean tuber in the g*ari* increased from 0.91% to 2.50% lactic acid. For all types of g*ari*, fat and ash contents were low. Proteins and crude fibre content increased significantly ($p < 0.05$) from 1.83% to 5.09% and from 1.64% to 14.12% as the proportion of yam bean tubers used in processing increased.

Sensory evaluation

Cassava g*ari* was given the highest score by panellists and the scores attributed to taste, flavour and colour respectively decreased significantly as the percentage of yam bean tuber used to process g*ari* increased (Table 2). Student-Newman-Keuls test showed that 25%, 50% and 75% yam bean g*ari* were similar ($p \geq 0.05$) considering taste; and 25% and 50% yam bean g*ari* were considered similar in flavour and colour (results not shown). Thus, for all 3 sensorial quality parameters tested, good quality g*ari* i.e. mean scores close to 4 were obtained when the maximum of 50% yam bean tubers were mixed with cassava tubers during processing.

Similarly, *èba* cooked with cassava g*ari* was most preferred by panellists and the preference scores decreased significantly as g*ari* used to cook the *èba* contained more yam bean (Table 3). It appeared that panellists detected difference between the *èba* samples although 25% and 50% yam bean g*ari* were scored similar in taste, flavour and colour ($\alpha = 0.05$). Differences between the different *èba* types prepared from *gari* was mostly based on taste (55–79% of panellists) followed by its ability to be stretched or extensibility (52–76% of panellists) (results not shown).

Table 1: Composition of the *garis* obtained from yam bean and cassava tuber processing.

Sample	Water (%)	TTA* (% lactic acid)	Proteins (%db †)	Fat (% db)	Ash (% db)	Fibres (% db)	Other carbohydrates (% db)
Cassava *gari*	10.88 ± 0.35‡	0.91 ± 0.01	1.83 ± 0.05	0.28 ± 0.01	0.60 ± 0.02	1.64 ± 0.05	93.12
25% yam bean *gari*	12.16 ± 0.00	0.93 ± 0.01	2.06 ± 0.10	0.28 ± 0.00	0.92 ± 0.06	2.37 ± 0.02	94.37
50% yam bean *gari*	10.24 ± 0.47	1.27 ± 0.03	2.42 ± 0.10	0.41 ± 0,01	1.05 ± 0.01	5.62 ± 0.08	90.50
75% yam bean *gari*	10.90 ± 0.02	1.31 ± 0.03	3.08 ± 0.05	0.41 ± 0.01	0.89 ± 0.03	7.84 ± 0.01	87.78
100% yam bean *gari*	11.97 ± 0.20	2.50 ± 0.1	5.09 ± 0.05	0.21 ± 0.01	1.47 ± 0.28	14.12 ± 0.09	79.11

Table 2: Results of sensory evaluation of the different types of *gari* from yam bean and cassava tubers.

Type of *gari*	Scores recorded (n = 32 panellists)			Overall score
	Taste	Flavour	Colour	
Cassava *gari*	140§ (4.38) **	145 (4.53)	149 (4.66)	434
25% yam bean *gari*	123 (3.84)	122 (3.81)	128 (4.00)	373
50% yam bean *gari*	120 (3.75)	118 (3.69)	117 (3.66)	355
75% yam bean *gari*	113 (3.53)	105 (3.28)	103 (3.22)	321
100% yam bean *gari*	72 (2.25)	66 (2.06)	70 (2.19)	208

* Titratable acidity ; † Dry matter basis ; ‡ Results given as mean of triplicate determinations ± SD ; § Total score for all 32 panellists ; ** Mean score

Table 3: Results of sensory evaluation of *èba* cooked with different types of *gari* from yam bean and cassava tubers.

Type of *gari* used to cook the *èba*	**Panellists preference (n = 33)**					**Overall score**	**Mean score**
	1st	**2nd**	**3rd**	**4th**	**5th**		
Cassava *gari*	25 * (125) †	4 (16)	0 (0)	4 (8)	0 (0)	149	4.52
25% yam bean *gari*	6 (30)	18 (72)	9 (27)	0 (0)	0 (0)	129	3.91
50% yam bean *gari*	1 (5)	11 (44)	13 (39)	8 (18)	0 (0)	106	3.15
75% yam bean *gari*	3 (15)	1 (4)	11 (33)	18 (36)	0 (0)	88	2.67
100% yam bean *gari*	0 (0)	0 (0)	0 (0)	2 (4)	31 (31)	35	1.06

* Number of panellists for the choice
† Total score

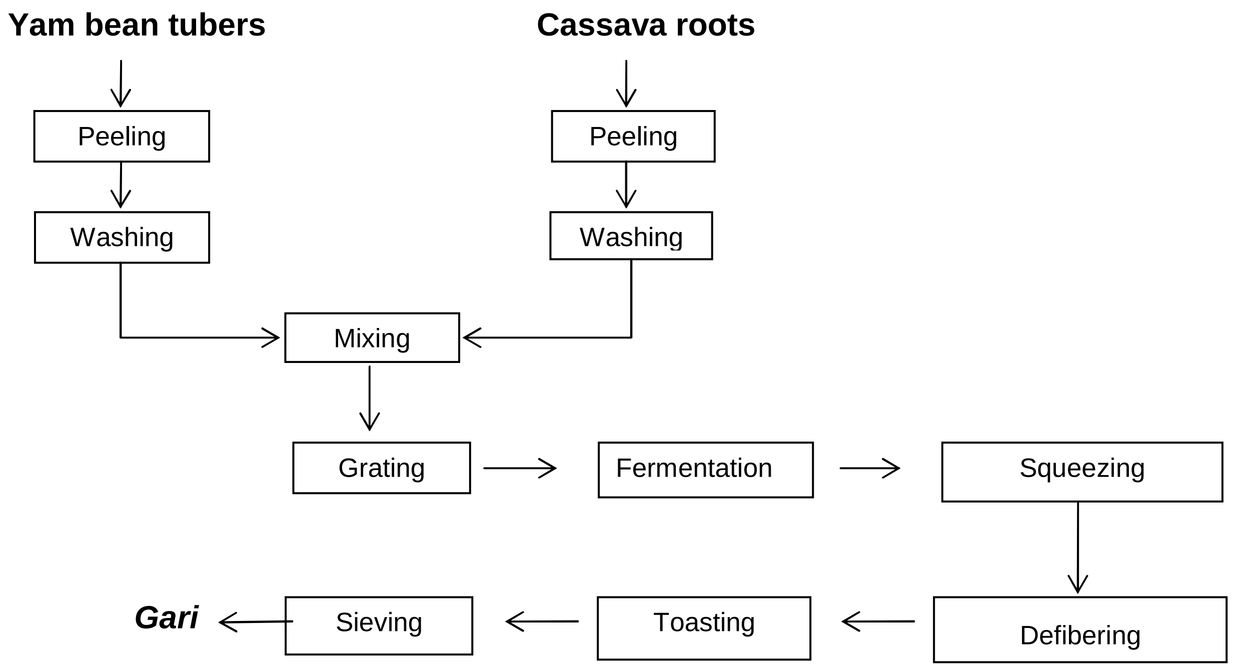

Figure 1: Flow diagram of mixed yam bean -cassava tubers processing into *gari*.

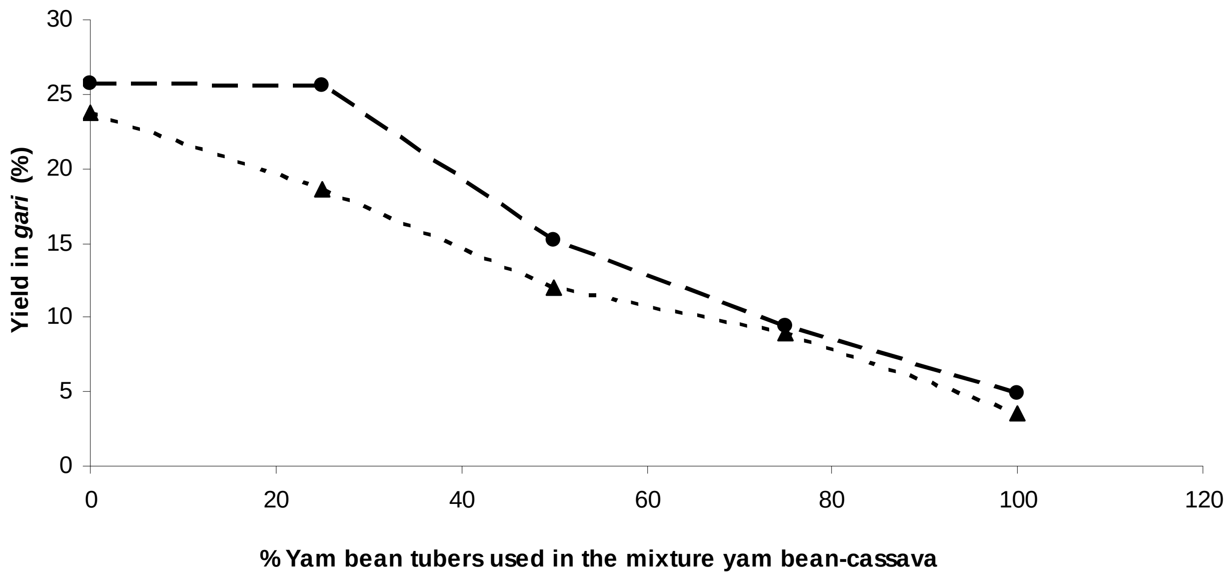

Figure 2: Evolution of the yields of garification when combining yam bean and cassava tubers for *gari* processing.
(······▲······): first trial; (— — ● — —): second trial.

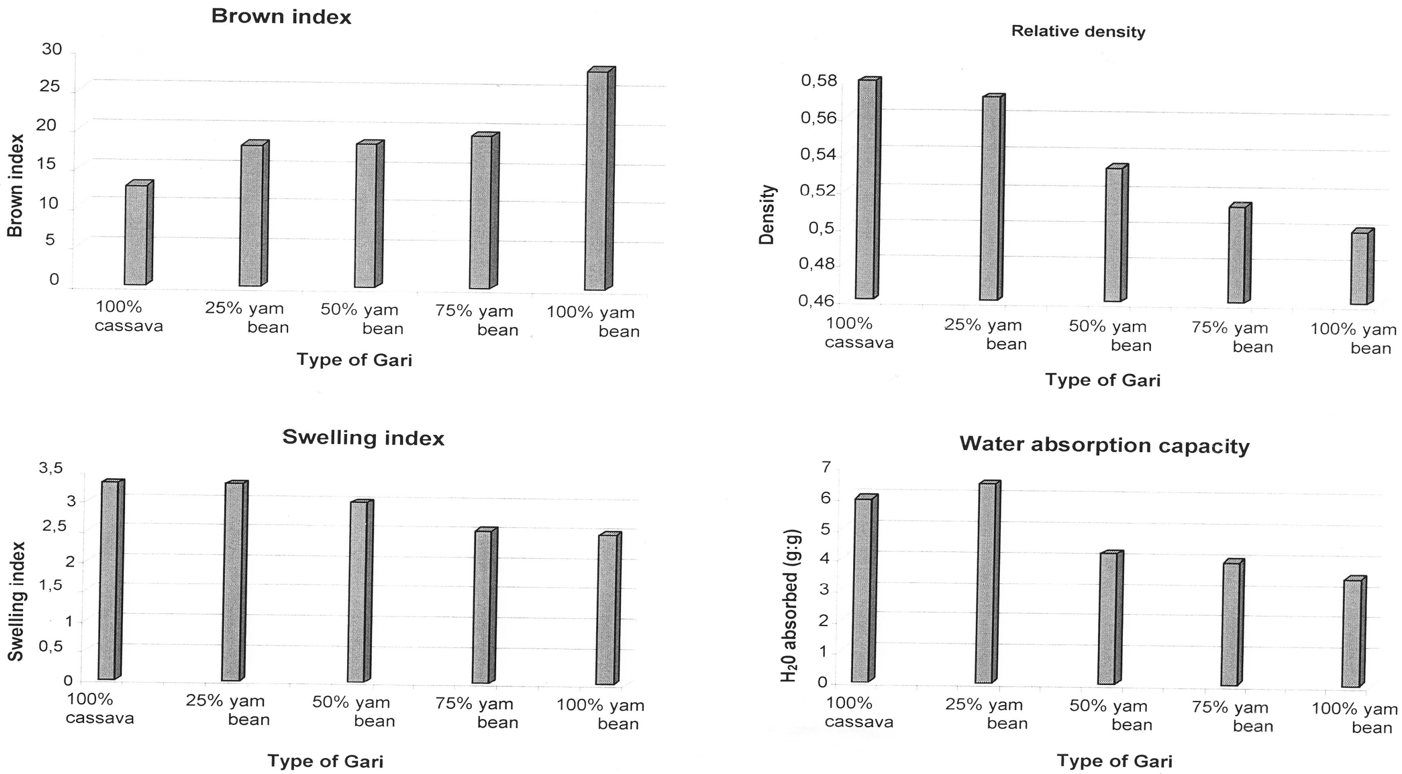

Figure 3: Physical characteristics of the *garis* processed from yam bean and cassava tubers.

DISCUSSION

Several researchers have previously worked on g*ari*; they all agreed that it is a low protein and carbohydrate dense food (Osho, 2003; Eke et al., 2008; Kolapo and Sanni, 2009). Thus, continuous consumption of g*ari* without supplementation with protein-rich sources would result in protein and minerals deficiency (Stephenson et al., 2010; Gegios et al., 2010). Studies have been carried out to improve the nutrient content of g*ari* through enrichment of cassava mash with protein and/or mineral-rich sources during the processing (Osho, 2003; Obadina et al., 2006; Eke et al., 2008; Kolapo and Sanni, 2009). Legume seeds such as soybeans (*Glycine max* [L.]) and derivatives were often used for this purpose. Yam beans (*Pachyrhizus* spp.) have leguminous seeds with high protein concentrations (Valesco et al., 2001; Zanklan et al., 2007); however these are not edible since they contain rotenone (Grüneberg et al., 2003).

The processing of yam bean tubers into the widely consumed g*ari* would make the introduction of this new crop into West-African cropping systems very interesting. This root crop showed good agronomic performance under West African conditions (Adjahossou, 2006; Zanklan et al., 2007). Zanklan et al. (2007) demonstrated that it is possible to prepare nutritionally improved g*ari* (about 5.5% proteins) from fresh yam bean tubers using traditional small-scale production methods. However, other quality attributes especially yield and organoleptic quality which determine consumers' acceptability were not tested. In the here presented study very low yields (4–5%) were observed when processing yam bean (*Pachyrhizus erosus* EC 533) tuber into g*ari* as compared with ~25% yield when cassava is processed into g*ari* (Karim and Fasasi, 2009). Similar levels have been observed by Wassens (2011). In fact, the yam bean *P. erosus* EC 533 is a low dry matter accession; its roots have high water content (80–90%) (Zanklan et al., 2007; Wassens, 2011) compared to 60–70% for cassava roots (Padonou et al., 2005). During processing the water content is reduced to 10–12% in the end product resulting in overall low yield. This makes *gari* processing from yam bean unattractive to African processors since they still need to put the same supplies and effort into producing *gari* with a lower yield.

The other factors which might reduce consumers' acceptability of g*ari* obtained from yam bean tubers is the observed high fibre content and the brownish colour. Wassens (2011) modified the traditional method for g*ari* processing by eliminating the fermentation step and by replacing the toasting by oven-drying at 50°C. She obtained a product with similar low yield. However, the resulting product unfermented and untoasted granules, is not in its pure sense g*ari*. In the present study it was shown that increasing incorporation of yam bean into cassava for *gari* processing modified significantly the composition of the end product. The water contents of all mix *gari* produced were in the range recommended by the Standard 151 of the joint FAO/WHO Commission of Codex Alimentarius (FAO/WHO, 2013), and levels of protein and fibres increased. The mixture of 50% cassava and 50% yam bean resulted in *gari* that was most appreciated by the consumers. The swelling capacity of the 50% yam bean *gari* was about 3, within the range required for good quality *gari* (Owuamanam et al., 2010). Mixing yam bean and cassava (50:50) resulted in increased of *gari* yields up to ~15%, while the crude fibre content decreased from 14.12% (100% yam bean g*ari*) to 5.62% and protein content increased by more than 30% when compared with cassava g*ari*. Yam bean/Cassava g*ari* (50:50) is whiter in colour and panellists scored it and its derived *èba* better than 100% yam bean g*ari*. With the purpose of improving the yield of garification, there is need to evaluate the potential to make *gari* from yam bean Chuin-type (*P. tuberosus*) with high dry matter content, combined with high protein content species (Grüneberg et al., 2003; Balbin et al., 2005; Zanklan et al., 2007). Thus, the yam bean Chuin-type should be tested for 100%

yam bean g*ari* production and consumers' acceptance evaluated.

Conclusion

Yam bean (*Pachyrhyzus* spp.) tubers were processed into g*ari*, the widespread cassava fermented food eaten in West Africa. The end-product had a better nutritional quality than traditional cassava based *gari*. However, regarding the low dry matter accessions tested during the present study, certain limitations were observed: the yield was too low and the consumer acceptability of the end product was low. The association yam bean–cassava tubers at levels of 50% - 50% for *gari* processing improved significantly the end product in terms of physical and nutritional qualities, and consumers' acceptance. There is need for further work on optimizing the yam bean *gari* processing conditions to make both the activity and the end-product more attractive. The profitability of processing yam beans into *gari* needs to be further evaluated.

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