Research Article

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Genetic and environmental effects on processing productivity and food product yield: drudgery of women's work

Abolore Bello,[a] Afolabi Agbona,[a,b] Olamide Olaosebikan,[a] Gospel Edughaen,[a] Dominique Dufour,[c,d] Alexandre Bouniol,[e,f] Peter Iluebbey,[a] Robert Ndjouenkeu,[g] Ismail Rabbi[a] and Béla Teeken[a*]

Abstract

BACKGROUND: Cassava processing is a crucial source of livelihood for rural farmers and processors in Nigeria and Cameroon. This study investigated the varietal effect on the processing productivity of women farmer processors within their working environment and compared this with the food product quality as evaluated by the processors and the field yield. Field trials were established in Nigeria (Benue and Osun state) and Cameroon (Littoral region). Eight cassava genotypes were evaluated. These eight varieties included newly bred genotypes, commercial checks and varieties provided and preferred by the processors. The roots of these genotypes were harvested and processed into *gari* and *eba* by processors. The time of each processing step was recorded. Processors assessed the quality of the roots and food products using pairwise ranking.

RESULTS: In the field trials in Cameroon and Nigeria (Benue state), the newly bred genotypes showed superior performance in terms of dry matter content and fresh and dry yield. During processing, genotypes showed significant variation for most assessed parameters in both countries. Some newly bred varieties exhibited lower productivity that can make them more prone to drudgery than the local commercial checks and the varieties provided and preferred by the processors. Newly bred varieties were mostly ranked higher or equal to processors' preferred varieties concerning fresh root and food product quality. In the Cameroon location there were significant varietal differences in processing productivity and drudgery index which suggest that the particular processing methods there - such as pressing methods and fermentation time - cause these varietal differences to matter more.

CONCLUSIONS: The varieties that were tested were observed to differ in yield, product quality, processing productivity, and potential drudgery levels. Some breeders' germplasms displayed a combination of increased yields and good product quality and good processor productivity. Those varieties that showed low processor productivity should be avoided during selection to avoid increased labour burden and associated drudgery of women processors. Further research is recommended to enhance food product color, latent culinary qualities, and processing productivity of newly bred varieties to improve acceptability and reduce processing drudgery for women.

Supporting information may be found in the online version of this article.

Keywords: cassava processing; drudgery; breeding; *gari & eba*; acceptability; food product quality

* Correspondence to: B Teeken, International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. E-mail: b.teeken@cgiar.org

[Correction added after first online publication on 08 March 2024; The term Drudgery Index (DI) changed as Processing Productivity Index (PPI) throughout the article.]

a International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria

b Texas A & M University, College Station, USA

c CIRAD, UMR Qualisud, Montpellier, France

d QualiSud, Univ Montpellier, Avignon Université, CIRAD, Institut Agro, IRD, Université de La Réunion, Montpellier, France

e CIRAD, UMR Qualisud, Cotonou, Benin

f Laboratoire de Sciences des Aliments, Faculté des Sciences Agronomiques, Université d'Abomey-Calavi, Abomey-Calavi, Benin

g Department of Food Science and Nutrition, ENSAI, University of Ngaoundere, Ngaoundere, Cameroon

INTRODUCTION

Cassava is one of the most widely cultivated crops globally, ranking fourth after wheat, rice, and maize. Its importance lies in its consumption by nearly 1 billion people worldwide, particularly in tropical regions where more than 500 million people consume cassava-based food. A significant concentration of these people are in sub-Saharan Africa. The crop's adaptability to diverse agro-ecological environments and the absence of a clear maturity time facilitating year-round harvesting make it a crucial secure source of food for millions of people.[1,2]

Beyond its role as a staple food, there is growing interest in utilizing cassava for industrial purposes such as starch, syrup, chips, alcoholic beverages, and high-quality cassava flour, particularly in African countries like Nigeria and Ghana.[3] Cassava starch, in particular, stands out for its high purity, solubility, and lower retrogradation compared to starches from other sources like potato, rice, and corn.[4]

In Nigeria and Cameroon, cassava roots are mainly processed into granulated and paste products. Cassava processing methods involve various steps, including peeling, washing, grating, pressing, dewatering, fermenting, roasting, pounding, and frying, undertaken in different venues from cottages to households and on different scales ranging from microscale and medium scale (accounting for the largest number of cases), to large scale.[5,6] In Nigeria these traditional foods are mainly *gari*, *fufu*, *abacha*, and *lafun*, with processing being essential, enhancing shelf life, removing toxic cyanogenic glucosides, and improving palatability.[5] In Cameroon the major products from cassava are *gari*/tapioca, *kumkum/fufu/fonio/* couscous manioc/*rosettes de manioc, bâtons de manioc* (Bobolo and Miondo the first being the larger and the last being the smaller variant), *mitumba*, steamed cooked roots, starch, *fufu séché*, *tintin* (cassava doughnut), and water *fufu*.[7]

Agriculture plays a pivotal role in poverty alleviation and food security in Africa, and it is essential that the sector should be appealing for the millions of women who participate actively in various value-added activities such as processing and marketing. They often complement their husbands' efforts to meet the dietary and financial needs of their households. In Nigeria and Cameroon, women contribute significantly to the agricultural labor force, with Nigerian women providing 50% of the labor and Cameroonian women contributing 68%.[8] Women also dedicate 15 to 20% of their total labor hours to crop production[9] and account for 40% of the labor used in crop production across six other African countries: Malawi, Uganda, Tanzania, Nigeria, Ethiopia, and Niger.[10]

Women's involvement extends to the processing of cassava into different food products, and they dominate in both processing and marketing activities in Nigeria and Cameroon.[11,12] Furthermore, the feminization of agriculture has taken on new dimensions due to migration and new opportunities for men, potentially impacting women's roles in agricultural production and in adding value.[13]

Drudgery, defined as the unsatisfactory experiences that hinder work performance,[14] or as the physical and mental strain, agony, monotony, and hardship experienced,[15] is a significant challenge faced by the women who are involved in agriculture. Cassava production and processing in West Africa require a significant amount of manual labor, particularly for monotonous tasks such as peeling roots and toasting *gari*, with unsatisfactory experiences constraining work performance.[14] Women predominantly carry out these tasks.[11] Reduced productivity in these tasks increases the chance that these tasks are experienced as drudgery, even if we consider that specific repetitive work can be culturally valued more negatively or positively within local communities.[16] The productivity of cassava-related tasks can therefore be considered as a measure of the possible drudgery involved.

Mechanization and agro-processing have contributed to reducing drudgery in cassava production, for example through the production and dissemination of machines at subsidized rates to farmers in Nigeria, Zambia, and Uganda, to increase the productivity, income, and well-being of smallholder farmers. However, the equipment's impact has been limited as it was designed based on men's ergonomic characteristics[17] and is often still too expensive in use and often does not match the small- and medium-scale modes of processing. There is thus a need for labor-saving and drudgery-reducing technologies that cater specifically for women, thereby alleviating their drudgery, especially in processing activities.

Although research has recognized the importance of reducing drudgery in cassava production and in adding value,[17] there is limited information regarding the ways in which different cassava varieties influence processing productivity and thus drudgery, particularly among small-scale processors who play a major role in cassava processing in Nigeria.[18] This study therefore aimed to compare the productivity of processors when processing newly bred cassava varieties alongside commonly grown and processor-preferred varieties in Nigeria and Cameroon. Second, this research aimed to assess the field yield and food product yield (specifically *gari*) of these varieties. Third, this study engaged the experienced women processors in evaluating the quality of fresh roots, *gari*, and *eba* products to link their evaluations to processing productivity, food product yield, and field performance. This study is part of the RTB foods project (breeding roots, tubers, and banana products for end-user preferences: https://rtbfoods.cirad.fr).

MATERIALS AND METHODS

Trials composition

Three different classes of cassava varieties were evaluated (see Table 1):

Advanced newly bred clones. This category comprised recently released clones and advanced genotypes developed through genomic selection by the joint cassava breeding program of the International Institute of Tropical Agriculture (IITA) and the National Root Crops Research Institute (NRCRI).

Breeders' checks. This encompassed varieties used by breeders as checks in their experiments.

Local and regional checks included commercial checks which are popular commonly grown landraces in the chosen study locations (informed by the Cassava Monitoring Study that investigated the varieties cultivated by farmers in Nigeria including genetic fingerprinting of varieties as well as measurements of areas covered by each variety,[19]) as well as popular genotypes provided and preferred by champion processors in each study location (see Table 1). Advanced newly bred genotypes were developed for the product profile 'granulated and paste products' in Nigeria[20] which mainly encompasses *gari-eba* and *fufu* food products. The varieties were developed using feedback from cassava end users including participatory processing[21] and Tricot on-farm testing.[22]

Trial design and management

The selection of the trial sites was based on their proximity to communities actively involved in cassava production and processing.[12] The trial sites in Nigeria were established in two locations: NRCRI – Otobbi station (7°06'00.0"N 8°03'00.0"E) in Benue state and IITA – Agoowu station (7°15'00.0"N 4°19'12.0"E) in Osun state. These trials were established in 2020 and harvesting occurred in

Table 1. List of genotypes used for the study in Nigeria and Cameroon

Genotype		Status	ID	Nigeria		Cameroon
Original name	Variety name			Osun	Benue	Littoral
TMS13F1160P0004	Game Changer (Umucass47)	Released	TMS-1	x	x	x
TMS13F1307P0016		Advanced	TMS-2	x	x	x
TMS13F1343P0022	Obasanjo-2 (Umucass48)	Released	TMS-3	x	x	x
TMS13F1343P0044		Advanced	TMS-4	x	x	x
TMS14F1278P0003		Advanced	TMS-5	x	x	x
TMS30572	Nicass1	Released, Breeders check and commercial check–Nigeria	BC	x	x	
TMS920326		Released, Breeders' Check and popular poundable variety (commercial check), Cameroon	BC-1			x
TMEB1		Popular variety (commercial check) in Osun (CMS study[19])	PV-Osun	x		
TMEB2		Popular variety (commercial check) in Benue (CMS study[19])	PV-Benue		x	
TMEB3		Variety provided and preferred by champion processors in Osun state, Nigeria	LV-Osun	x		
Akpu		Variety provided and preferred by champion processors in Benue state, Nigeria	LV-Benue		x	
Madame		Variety provided and preferred by Champion processors in Littoral region, Cameroon	LV-Madame			x
Sape		Variety provided and preferred by Champion processors in Littoral region, Cameroon	LV-Sape			x

2021. The Cameroon trial was established in the research station of l'Institut de Recherche Agricole pour le Développement (IRAD) (4°34'59.1"N 9°38'36.2"E) in Njombé, Littoral region in 2021, and harvesting occurred in 2022.

The IITA fields were prepared carefully for planting and to produce cassava stem cuttings. The stem cuttings underwent phytosanitary evaluation before being sent from Nigeria to the IRAD research station in Cameroon. Documentation for the cross-border exchange of agricultural materials was obtained from the Nigeria Agricultural Quarantine Service.

The Nigerian trials were established with three replications, utilizing a plot size of 5 m × 6 m. In Cameroon, the trial had two replications with a plot size of 10 m × 10 m. All the trials were established using 1 m × 1 m spacing. A randomized block design was adopted for all trials. Hoe weeding was carried out two to three times before harvest and no fertilizers were applied. The Nigerian trials were harvested and processed 12 months after planting, in two batches of five varieties, each with commercial checks included in both batches. The Cameroon trial was harvested and processed 11 months and 2 weeks to mitigate root rot issues prevalent in the region.

Selection of champion processors, measurements during processing, and evaluation of roots, *gari*, and *eba* quality with the processors

Champion processors were chosen from specific locations in Nigeria and Cameroon, primarily based on their prior involvement in the RTBFoods project, during which quality traits important for processors were determined and prioritized.[7,12,23] Processing took place within communities using the processor's traditional setup. In Souza, Cameroon, processors added palm oil during the toasting of *gari*, reflecting the common practice. The amount of oil added was not standardized but was left to the expertise of the processors. With regard to the root, *gari*, and *eba* evaluations by the champion processors, comparative assessments were conducted on fresh roots, the intermediate product *gari*, and the final food product *eba* following a method described by Teeken *et al.*[21] A method described by Ngoh Newilah *et al.*[24] was followed with regard to the the measurements taken during the processing (processing diagnostics). Processors carried out pairwise comparisons and provided explanations for their choices, drawing upon indigenous expertise and experience. In Nigeria, processing and pairwise ranking was carried out in two batches; each batch included a part of the five newly bred varieties as well as the varieties Local 1 and 2 (commercial checks and varieties provided and preferred by processors) appeared in both batches (Tables 4–6).

Data collection

Agronomic and yield data were collected at harvest, and data on the different processing stages were documented during the processing diagnostics. The fresh roots ranking for root quality (Rtqlty) was calculated by aggregating the ranks of root size, ease of peeling, and dry matter content.

Processing productivity was determined by dividing product weight at specific processing steps by the time expended by processors to complete those steps. For example *peeling productivity = peeled root weight/peeling time.*

Processing time (Proc_t) encompassed the cumulative time spent on major processing stages, including peeling, sieving, and toasting.

The processing productivity index (PPI) was formulated as the final food product yield (*gari* yield in kg) divided by the total processing time in minutes.

The fresh roots and food products, *gari* and *eba*, were appraised based on the pairwise ranking by the processors on processing color and textural attributes. The root quality rank was calculated as the sum of root size, ease of peeling, and dry matter content (water content). *Gari* quality (Gariqlty) rank was calculated as the sum of *gari* color, heaviness, and smoothness ranks while the *eba* quality (Ebaqlty) rank is the sum of *eba* color, stretchability, and moldability ranks.

Table 2. Field performance of eight cassava genotypes evaluated in Nigeria (Benue and Osun states) and Cameroon (Souza) for dry matter content (DM), dry root yield (DYLD), and fresh root yield (FYLD)

	Cameroon			Nigeria (Osun)			Nigeria (Benue)		
Genotypes	DM (%)	DYLD (t ha^{-1})	FYLD (t ha^{-1})	DM (%)	DYLD (t ha^{-1})	FYLD (t ha^{-1})	DM (%)	DYLD (t ha^{-1})	FYLD (t ha^{-1})
TMS-1	39.4a	10.0ab	25.4ab	43.7a	11.8ab	27.1ab	44.4a	9.1b	20.4b
TMS-2	33.5 cd	11.0ab	33.0a	40.8a	14.3a	34.9a	41.9ab	10.6ab	25.1ab
TMS-3	40.1a	13.0ab	32.5a	36.1a	12.7a	35.4a	44.0a	15.9a	36.3a
TMS-4	37.1ab	15.6a	42.0a	36.5a	10.8ab	29.7a	42.9ab	13.4ab	31.3ab
TMS-5	37.7ab	15.2a	40.5a	38.5a	10.3ab	26.8a	42.3ab	12.1ab	28.8ab
BC	33.0 cd	8.6bc	25.7ab	39.8a	7.8b	19.7b	41.5ab	10.8ab	26.0ab
Local1	32.2d	3.0c	9.7b	38.3a	13.7a	35.8a	40.8ab	9.2b	22.4b
Local2	35.4bc	3.4c	9.6b	40.1a	14.4a	35.8a	35.9b	10.3b	28.8ab
Average	36.0	10.0	27.3	39.2	12.0	30.6	41.7	11.4	27.4
SE	2.1	1.1	3.0	1.5	1.2	2.6	1.4	1.1	2.4
Min	32.2	3.0	9.6	36.1	7.8	19.7	35.9	9.1	20.4
Max	40.1	15.6	42.0	43.7	14.4	35.8	44.4	15.9	36.3
σ^2_G	8.7	22.0	143.9	3.6	4.0	27.2	4.9	4.1	19.5
σ^2_e	0.6	2.5	20.6	6.6	3.7	18.7	6.3	3.6	18.2
H^2	1.0	1.0	0.9	0.6	0.8	0.8	0.7	0.8	0.8
GCV	8.2	47.1	44.0	4.8	16.8	17.0	5.3	17.8	16.1
PCV	8.3	48.4	45.5	6.1	19.2	18.9	6.3	20.2	18.5
LSD	1.8	3.7	9.8	9.8	3.6	8.0	4.3	3.2	7.1
CV (%)	2.4	2.2	15.7	15.6	13.7	12.0	4.9	13.2	12.2
$P(\geq 0.05)$	***	**	***	ns	***	***	*	**	**

σ^2_G: Genotypic variance; σ^2_e: Error variance; H2: Heritability; PCV: Phenotypic coefficient of variation: GVC: Genotypic coefficient of variation; LSD: Least significant difference.
Significance levels indicate the probability that the trait is significantly different from 0: ns: not significant.
Cameroon: Local1 = LV-Madame, Local2 = LV-Sape; Nigeria (Osun): Local1 = PV-Osun, Local2 = LV-Osun; Nigeria (Benue): Local1 = PV-Benue, Local2 = LV-Benue.
*$P < 0.05$.
** $P < 0.010$.
*** $P < 0.001$.

Data analysis

R version 4.2.1 and Statistical Analysis Software (SAS) version 9.4 were used to analyze the field and processing performance of the genotypes, to identify processing productivity and the Processing Productivity Index (PPI).[25] A linear mixed model was fitted to the individual field trials using the 'Proc Mixed' procedure of SAS to estimate the genetic variance components and the fixed effects for each genotype.

The model is described as follows:

$$y = \mu + X\beta + Zb + \varepsilon$$

where y is a list of phenotypic observations for each cassava genotype; μ is the grand mean; β is the fixed effect of the genotypes under evaluation with its associated incidence matrix X; b is the random effect of the replications with its associated incidence matrix Z; ε denotes the random error term, which is assumed to follow a Gaussian distribution.

A similar linear model was fitted using the 'lm' function in the 'stats' library in R to evaluate the processing performance of the genotypes; however, all the effects (genotype and processor) were considered fixed.

Pairwise ranks underwent Bradley Terry model analysis to estimate the probability of a genotype winning from another for each trait of interest, in SAS using the 'Proc Logistic' procedure. The ensuing estimates facilitated the ranking in SAS as described by Bradley[26] and Van Etten[27] by using the individual pairwise ranks to obtain estimates that were subsequently used to rank varieties (see Appendix 2). Varieties with higher estimates rank higher. For Nigeria we estimated the overall rank based on the sum of the ranks of the individual traits while for Cameroon the overall rank was directly assessed with the champion processors (see Appendix 1).

RESULTS

Performance of the field trials

The root dry matter content (DM), dry root yield (DYLD), and fresh root yield (FYLD) were analyzed for the field trials conducted in Cameroon and Nigeria (Table 2). In Cameroon, genotypic variances for DM, DYLD, and FYLD were higher than the error variances, indicating significant genetic differences among the genotypes. In Nigeria, only DYLD and FYLD showed high genotypic variances. The phenotypic coefficient of variation (PCV) exceeded the genotypic coefficient of variation (GCV) for all traits in Nigeria, except for DM, which had the lowest PCV (6.13%), while DYLD recorded the highest (48.36%).

In Cameroon, newly bred varieties outperformed preferred local commercial check and processor preferred varieties for DYLD and FYLD. However, breeders' checks showed poor performance for DYLD both in Cameroon and Nigeria (Osun state) when compared with newly bred cassava varieties.

Table 3. Mean squares for the genotypes and processors' source of variation in the analysis of variance for relevant processing traits

Source of variation	df	Peelrtwt	Pulpwt	Gariyld	Peeling_t	Toasting_t	Sieving_t
			Cameroon (Littoral region)				
Genotype	7	3.9***	7.1***	2706.4***	120.8***	220.4***	22.8*
Processor	2	1.5*	0.39^{ns}	221.9^{ns}	626.4***	156.2**	75.1***
R^2		0.8	0.9	0.9	0.9	0.9	0.7
CV		2.4	5.2	5.3	13.6	7.7	17.9
			Nigeria (Benue)				
	df	Peelrtwt	Pulpwt	Gariyld	Peeling_t	Toasting_t	Sieving_t
Genotypes	7	5.9***	9.3***	2976.8*	233.2*	189.4^{ns}	
Processor	2	0.9^{ns}	0.8^{ns}	490.7^{ns}	674.2***	226.5^{ns}	
R^2		0.7	0.8	0.6	0.8	0.4	
CV		3.9	6.8	12.7	15.6	27.9	
			Nigeria (Osun)				
	df	Peelrtwt	Pulpwt	Gariyld	Peeling_t	Toasting_t	Sieving_t
Genotype	7	1.3^{ns}	3.0***	475.9^{ns}	120.8***	126.9***	
Processor	2	0.8^{ns}	0.4^{ns}	155.9^{ns}	626.4***	258.5***	
R^2		0.6	0.7	0.53	0.65	0.78	
CV		2.5	4.4	5.93	22.6	10.6	

A total of eight cassava genotypes were evaluated by three champion processors in Nigeria (two locations) and Cameroon (one location).
Significance levels indicate the probability that the trait is significantly different from 0: ns: not significant; R2: coefficient of determination.
Peelrtwt: Peeled root weight; Pulpwt: Pulp weight; Gariyld: *Gari* yield; Peeling-t: Peeling time; Toasting_t: Toasting time; Sieving_t: Sieving time.
*$P < 0.05$.
** $P < 0.010$.
*** $P < 0.001$.

Processing diagnostics and evaluation by the processors

Analysis of variance (ANOVA) was conducted on the genotypes evaluated by champion processors in Nigeria and Cameroon. It showed that genotypes and processors both had an impact on most of the processing traits. The study had acceptable coefficient of variation (CV) values, which indicated precise data collection (Table 3).

In Cameroon (Littoral region) genotypes and processors both had significant effects on processing traits, except for *gari* yield and pulp weight. In Nigeria, genotypic effects were significant for most processing traits, except for peeled root weight and *gari* yield (Osun state), and toasting time (Benue state), and processor effects were significant for peeling time and toasting time in Cameroon and Nigeria (Osun state).

The productivity, PPI, and appreciation of food products by champion processors varied. Tables 4–6 show the processing diagnostics by processing step, productivity, and processors' perception of roots and food products developed from the clones evaluated from each of the three locations, respectively. Differences were observed in the time spent on root peeling and toasting of the grated pulp in Cameroon and Nigeria. In Nigeria, varietal differences affected toasting productivity, total processing time, and PPI in Osun state, while genotype performance significantly influenced the processing time, productivity, and PPI in Cameroon (Tables 4–6).

The processors' pairwise ranking of the eight cassava clones for fresh roots and food products revealed preferences for newly bred varieties in Nigeria (Osun and Benue states) in comparison with processors' preferred checks. In Cameroon, the processor preferred variety LV-Sape was evaluated best for gari and eba food quality while TMS-1, a newly bred variety, was appreciated for its *gari* qualities when compared with processors' preferred checks, although it had the highest PPI in Osun state but it was comparable in this respect with local and regional checks in Benue and Cameroon.

Based on the Processing Productivity Index (PPI), fresh root yield, and *gari* yield, the cassava genotypes in Nigeria (Osun state) were classified as having medium potential for fresh root and *gari* yield, with medium processing productivity. In Benue state, the genotypes showed high fresh root and *gari* yield potential with low to medium processing productivity. In Cameroon (Souza), the cassava genotypes and especially the recently bred ones exhibited high fresh root yield, high *gari* yields and relatively higher processing productivity (Fig. 1).

Popular commercial check varieties as determined by the CMS study[19] in Nigeria and breeder checks (BC and BC-1) had relatively low PPI scores whereas TMS-1, LV-Benue, and TMS-2 had relatively high PPI scores. Cassava with high PPI scores had relatively medium and high fresh cassava yield, high *gari* yield, and slightly low products rank (for *gari* and *eba*).

In Nigeria (Osun state) and Cameroon, there were significant varietal difference for peeling productivity and PPI. In the batch 1 and 2 evaluations in Benue, BC, TMS-1, TMS-5, PV-Benue, and LV-Benue had high food product quality, low peeling and toasting productivity with low and slightly high PPI scores. In Osun state batch 1 and 2 evaluation, LV-Osun, TMS-3, TMS-5, BC and TMS-4 had significantly lower peeling productivity and processing productivity index and high food product quality rank. In Cameroon, LV-Sape, TMS-1 and TMS-3 had significantly lower peeling productivity, slightly higher toasting productivity and lower PPI, with high food product appreciation scores.

Table 4. Processing productivity, Processing Productivity Index (PPI), and products appreciation of eight cassava genotypes evaluated by three champion processors at Station–Iwo, Osun state, Nigeria

	Processing time, productivity and Processing Productivity Index										Food product appreciation rank			
Genotypes	PEEL RT (kg)	PULP WT (kg)	GARI WT (kg)	GYLD (kg /1 ton of fresh roots)	PTIME (min)	TTIME (min)	P_prd	T_prd	Proc_t (min)	PPI	Genotypes	Rootqlty rank	Gariqlty rank	Ebaqlty rank
													Batch 1	
PV-Osun	29.0a	17.4a	9.1a	228.3a	36.2a	45.7ab	0.9ab	0.2a	81.8a	2.8b	TMS-5	3 (1)	11 (4)	9 (2)
LV-Osun	29.5a	19.2a	10.3a	258.2a	36.6a	59.7a	0.9ab	0.2a	96.3a	2.7b	PV-Osun	7 (2)	13 (5)	11 (4)
TMS-1	30.3a	19.5a	10.4a	260.3a	23.0a	43.8b	1.4a	0.2a	66.9a	3.9a	LV-Osun	11 (4)	6 (2)	3 (1)
TMS-2	30.6a	19.4a	10.7a	268.5a	28.9a	55.2ab	1.2ab	0.2a	84.1a	3.3ab	TMS-3	10 (3)	5 (1)	9 (2)
TMS-3	30.3a	20.3a	10.2a	255.7a	34.3a	58.5ab	0.9ab	0.2a	92.8a	2.9ab	TMS-1	14 (5)	10 (3)	13 (5)
TMS-4	30.4a	19.1a	10.6a	263.9a	46.3a	48.2ab	0.7b	0.2a	94.5a	2.9ab			Batch 2	
TMS-5	28.9a	19.4a	10.1a	251.1a	42.4a	46.4ab	0.7b	0.2a	88.8a	2.8ab	TMS-2	7 (1)	10 (5)	9 (3)
BC	29.6a	17.6a	9.8a	245.4a	44.1a	44.4ab	0.7b	0.2a	88.5a	2.8b	PV-Osun	13 (5)	9 (2)	9 (3)
Average	29.8	19.0	10.2	253.9	36.5	50.2	0.9	0.2	86.7	3.0	LV-Osun	9 (3)	9 (2)	8 (2)
CV	2.0	3.5	4.8	4.8	18.4	8.8	22.3	12.7	12.2	12.6	TMS-4	7 (1)	9 (2)	3 (1)
SE	0.4	0.5	0.3	8.5	5.4	4.4					BC	9 (3)	7 (1)	8 (2)
min	28.9	17.4	9.1	228.3	23.0	43.8								
max	30.6	20.3	10.7	268.5	46.3	59.7								
LSD	1.3	1.4	1.0	25.6	14.4	9.5								
P (≥ 0.05)	ns	*	ns	ns	*	***	**	ns	**	*				

Note: Significance levels indicate the probability that the trait is significantly different from 0: ns: not significant.
Rtqlty Rank: Root quality Rank (comprises of root size, ease of peeling, and dry matter content); Gariqlty Rank: *Gari* quality Rank (comprises of *gari* color, *gari* heaviness, *gari* smoothness), Ebaqlty Rank: Eba quality (comprises of eba color, eba stretchability, eba mouldability). Numbers in front of the numbers in parentheses are the aggregate sum ranks of traits considered under Rtqlty Rank, Gariqlt Rank, and Ebaqlty Rank. The numbers in parentheses are the final appreciation rank of the genotype. PV-Osun = Popular variety in Osun in CMS study, LV-Osun = Osun champion processors identified the best variety.
Abbreviations: BC: Breeding check; CV: Coefficient of variation; GARI WT: Gari Weight; GYLD: Gari yield; PEEL RT: Peeled root weight; PPI: Processing Productivity Index; P_prd: Peeling productivity; Proc_t: Total processing time; PTIME: Peeling time; PULP WT: Grated pulp weight; TTIME: Toasting time; T_prd: Toasting productivity.
*$P < 0.05$.
** $P < 0.010$.
*** $P < 0.001$.

Table 5. Processing productivity, Processing Productivity Index (PPI), and products appreciation of eight cassava genotypes evaluated by three champion processors at Otukpo, Benue state, Nigeria

	Processing time, productivity, and Processing Productivity Index										Food product appreciation Rank			
Genotypes	PEEL RT (kg)	PULP WT (kg)	GARI WT (kg)	GYLD (kg /1 ton of fresh roots)	PTIME (min)	TTIME (min)	P_prd	T_prd	Proc_t (min)	PPI	Genotypes	Rtqlty rank	Gariqlty rank	Ebaqlty rank
											Batch 1			
PV-Benue	28.9ab	18.4b	11.1a	277.8a	60.2ab	58.5a	0.5a	0.2a	118.7a	2.4a	PV-Benue	10 (3)	3 (1)	9 (4)
LV-Benue	27.2b	16.4b	12.0a	299.9a	49.1ab	44.7a	0.6a	0.3a	94.4ab	3.2a	LV-Benue	10 (3)	6 (2)	9 (4)
TMS-1	31.1a	22.4a	11.6a	290.4a	54.6ab	57.4a	0.6a	0.2a	112.0ab	2.6a	BC	6 (1)	8 (3)	8 (2)
TMS-2	27.7b	18.2b	11.4a	284.7a	50.0ab	46.4a	0.6a	0.3a	96.4ab	3.0a	TMS-2	11 (5)	10 (4)	4 (1)
TMS-3	28.6ab	19.0ab	11.1a	276.4a	60.1ab	52.7a	0.5a	0.2a	112.8ab	2.5a	TMS-3	8 (2)	14 (5)	8 (2)
TMS-4	26.7ab	18.3b	8.5a	213.5a	42.4ab	36.2a	0.6a	0.2a	78.5ab	2.8a	Batch 2			
TMS-5	27.1ab	18.0b	9.0a	225.2a	37.1b	39.7a	0.8a	0.2a	76.8b	3.0a	TMS-1	8 (2)	8 (1)	6 (1)
BC	28.0ab	17.3b	10.1a	252.6a	60.9a	48.3a	0.5a	0.2a	109.2ab	2.4a	TMS-5	5 (1)	7 (2)	7 (2)
Average	28.2	18.5	10.6	265.1	51.9	48.0	0.6	0.2	99.9	2.7	PV-Benue	12 (5)	9 (3)	8 (3)
CV	3.2	5.4	10.0	10.0	12.7	22.7	18.3	21.7	14.1	13.7	LV-Benue	9 (3)	9 (3)	12 (5)
SE	0.6	0.7	0.8	18.7	6.9	7.9					TMS-4	10 (4)	12 (5)	11 (4)
min	26.7	16.4	8.5	213.5	37.1	36.2								
max	31.1	22.4	12.0	299.9	60.9	58.5								
LSD	1.9	2.1	2.2	56.0	14.2	23.4								
P (≥ 0.05)	***	***	ns	ns	*	ns	ns	ns	**	ns				

Significance levels indicate the probability that the trait is significantly different from 0: ns: not significant.
Rtqlty Rank: Root quality Rank (comprises of root size, ease of peeling, and dry matter content); Gariqlty Rank: *Gari* quality Rank (comprises of *gari* color, *gari* heaviness, *gari* smoothness), Ebaqlty Rank: *Eba* quality (comprises of *eba* color, *eba* stretchability, *eba* mouldability). The number in front of the number in parentheses is the aggregate sum rank of traits considered under Rtqlty Rank, *Gari*qltRank, and Ebaqlty Rank. The numbers in parentheses are the final appreciation ranks of the genotype, PV-Benue = Popular variety in Benue in CMS study, LV-Benue = Benue champion processors identified the best variety.
Abbreviations: BC: Breeding check; CV: Coefficient of variation; GARI WT: Gari Weight; GYLD: Gari yield; PEEL RT: Peeled root weight; PPI: Processing Productivity Index; P_prd: Peeling productivity; Proc_t: Total processing time; PTIME: Peeling time; PULP WT: Grated pulp weight; TTIME: Toasting time; T_prd: Toasting productivity.
*$P < 0.05$.
** $P < 0.010$.
*** $P < 0.001$.

Table 6. Processing productivity, Processing Productivity Index (PPI) of eight cassava genotypes evaluated by three champion processors at Souza, Cameroon

	Processing time, productivity, and Processing Productivity Index												Food product appreciation rank		
Genotype	PEEL RT (kg)	PULP WT (kg)	*GARI* WT (kg)	GYLD (kg /1 ton of fresh roots)	STIME (min)	PTIME (min)	TTIME (min)	P_prd	T_prd	S_prd	Proc_t	PPI	ROA rank	GOA rank	EOA rank
LV-Madame	21.4d	11.7 cd	6.9bc	228.3bc	16.3ab	32.7ab	47.6b	0.7bc	0.14ab	0.72bc	80.4abc	2.9bc	7^{**}	4^{ns}	4^{***}
LV-Sape	22.2bc	13.4abc	7.8ab	261.4ab	14.4ab	28.4ab	51.9b	0.9abc	0.15ab	0.99abc	80.3abc	3.3ab	1^{**}	2^{***}	1^{ns}
TMS-1	22.3bcd	14.3ab	8.9a	295.4a	12.5b	37.1ab	50.5b	0.6bc	0.18a	1.18a	87.5ab	3.4ab	4^{ns}	1^{***}	3^{***}
TMS-2	23.1bc	12.7bcd	7.8ab	260.5ab	15.1ab	24.8b	44.9b	1.0ab	0.18a	0.85abc	69.6c	3.8a	5^{ns}	8^{ns}	8^{ns}
TMS-3	23.2bc	14.9a	8.7a	289.4a	16.4ab	29.3ab	54.1ab	0.9abc	0.16ab	0.94abc	83.4ab	3.5ab	3^{**}	3^{**}	4^{***}
TMS-4	23.5ab	13.7abc	8.5a	283.2a	12.9ab	28.7ab	48.5b	0.8abc	0.18a	1.12ab	77.2bc	3.7a	6^{ns}	4^{***}	6^{***}
TMS-5	25.0a	15.3a	8.2a	274.0a	21.0a	23.0b	69.5a	1.11a	0.12b	0.79abc	92.6a	3.0bc	2^{**}	7^{ns}	2^{***}
BC-1	21.9 cd	10.8d	6.3c	209.8c	17.7ab	42.2a	40.7b	0.6c	0.15ab	0.63c	82.9ab	2.6c	8^{*}	4^{*}	7^{ns}
Grand mean	22.8	13.3	7.9	262.7	15.8	30.8	51.0	0.8	0.17	0.91		3.3			
CV	2.4	5.2	5.3	5.3	17.9	13.6	7.7	14.4	12.22	16.53		6.9			
SE															
mim	21.4	15.3	8.9	228.3	12.5	23.0	40.7								
max	25.0	10.8	6.3	295.4	21.0	42.2	69.5								
CV															
R^2	0.9	0.9	0.9	0.9	0.7	0.9	0.9								
P(≥ 0.05)	***	***	***	***	*	***	***	***	*	**	***	***			

Note: Significance levels indicate the probability that the trait is significantly different from 0: ns: not significant.
Abbreviations: ROA: Root overall acceptability; GOA: *Gari* overall acceptability, EOA: *Eba* overall acceptability, LV-Madame = Champion processors identified best variety in Littoral LV-Sape = Champion processors' identified best variety in Littoral. GARI WT: Gari Weight; GYLD: Gari yield; PEEL RT: Peeled root weight; PPI: Processing Productivity Index; P_prd: Peeling productivity; Proc_t: Total processing time; PTIME: Peeling time; PULP WT: Grated pulp weight; TTIME: Toasting time; T_prd: Toasting productivity.
*$P < 0.05$.
** $P < 0.010$.
*** $P < 0.001$.

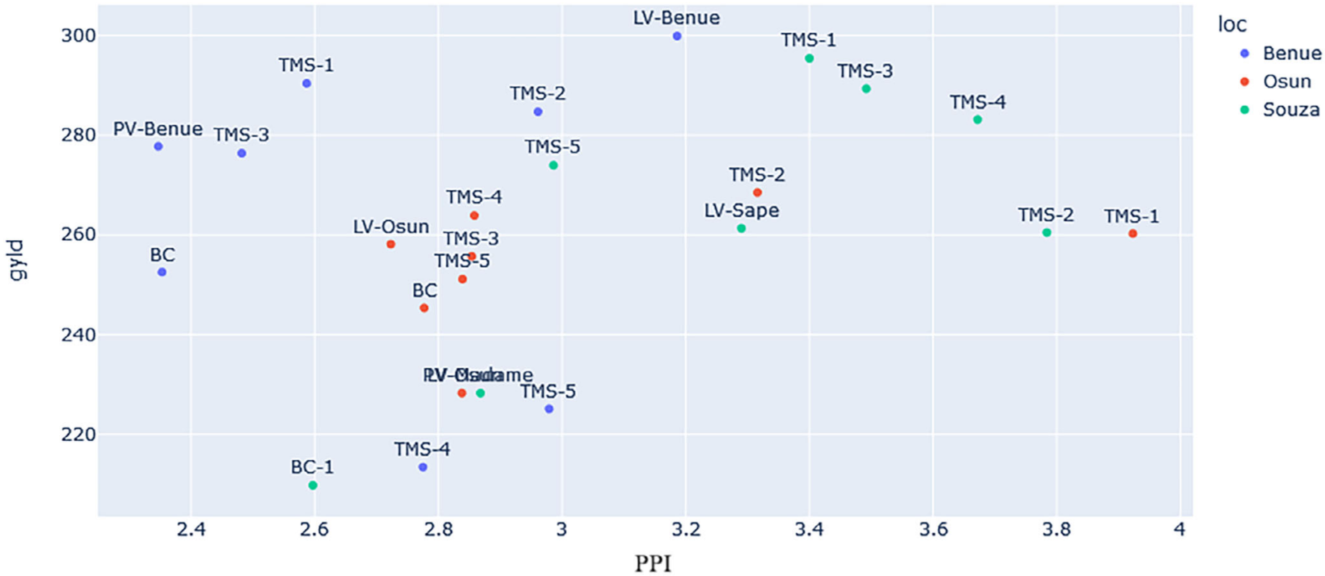

Figure 1. Grouping of eight cassava genotypes in Nigeria (Benue and Osun states) and Cameroon (Littoral region, Souza) based on the Processing productivity index (PPI), *gari* yield (gyld).

DISCUSSION

Genetic effects were probably overestimated due to the diverse sources from which genotypes were obtained.[28] There was clear and substantial evidence of significant genetic variability among the field data of the genotypes that were evaluated (Table 2). A significant proportion of the observed phenotypic variance could be attributed to genetic influences, as indicated by the high broad-sense heritability (H_2). The relatively lower genotypic variance in DM within the two Nigerian locations compared to the error variance suggested the strong influence of environmental conditions on this trait in those regions. Similar trends have been reported for yam and cassava,[29] pointing toward considerable potential for the genetic recombination and enhancement of these traits. The minimal discrepancies between GCV and PCV implied that the observed variation was predominantly due to genetic effects.[30]

In Osun state, there were no significant differences between locally preferred check varieties and newly bred clones for dry matter content, dry yield, and fresh yield. Conversely, in Benue state and Cameroon, local commercial checks generally exhibited inferior performance in comparison with several of the evaluated newly bred genotypes. This broadly underscores the successful development of enhanced germplasm with increased productivity by breeders.

Significant variations were observed among genotypes for all the variables that were assessed during processing across the three locations, except for peeled root weight in Osun state and toasting time in Benue state (Table 3). This is important for an understanding of the laborious aspects of cassava processing. Nweke[31] recognised the laboriousness and thus drudgery in various cassava-processing stages. Our investigation demonstrated that differences between varieties contributed to the difference in processing productivity and thus to the possible drudgery experienced. This underscores the clear varietal differences in processing productivity observed by Bouniol et al.[32], who evaluated the processing productivity of processors and the loads carried from one processing step to the other on a larger and more contrasting set of cassava varieties in three locations across Nigeria and Benin (Bouniol et al[32]). The observed genotypic influence on how champion processors evaluated the food product quality, also underscore that genotypes play a role in determining food product qualities. This aligns with Olaosebikan et al.,[33] in which the products made by processors were evaluated with consumers, as well as with Teeken et al.,[21] Awoyale et al.,[34] and Semiu et al.,[35] who observed that varietal effects influence the quality of *gari-eba* and cassava-wheat composite bread in a separate study.

The absence of significant variance attributed to processors' techniques, within each location, for peeled root weight, pulp weight, and *gari* yield suggests that processors largely adopted similar processing approaches, or that variations in techniques did not affect product quality significantly (Table 3). This is possibly due to robust local traditions, extensive experience, and mastery of processing activities among processors. This concurs with the assertions of Bakut[36] and Ezeocha[37] highlighting that experienced processors demonstrate high levels of work mastery. However, significant differences were evident among processors for peeling time across the three locations, toasting time across Cameroon and Osun state, and sieving time in Cameroon. This substantiates the findings of Onabowale,[38] who noted differences in *gari* processing methods based on countries, regions, food culture, environmental factors, cassava types, and processing equipment. Notably, significant variations in key processing steps like peeling and toasting indicate their pivotal role in *gari* production and their significant contribution to productivity and thus drudgery.[30,39] Streamlining these steps could alleviate time constraints and reduce drudgery, aligning with the view that reducing the relative cassava processing time enhances *gari* processing efficiency and productivity.[31] The processor influence on peeling time, toasting, and sieving time. Underscores the possible impact of processing on the quantity and quality of cassava food products. This assertion is consistent with the findings of Ekwu[40] and Udoro[41] regarding the effect of processing steps on cassava flour quality.

The factors that influence the quality of *gari* and *eba* are in line with quality descriptors suggested earlier by Kegah[7] and by Ekwu.[40,41] These descriptors include visual characteristics such

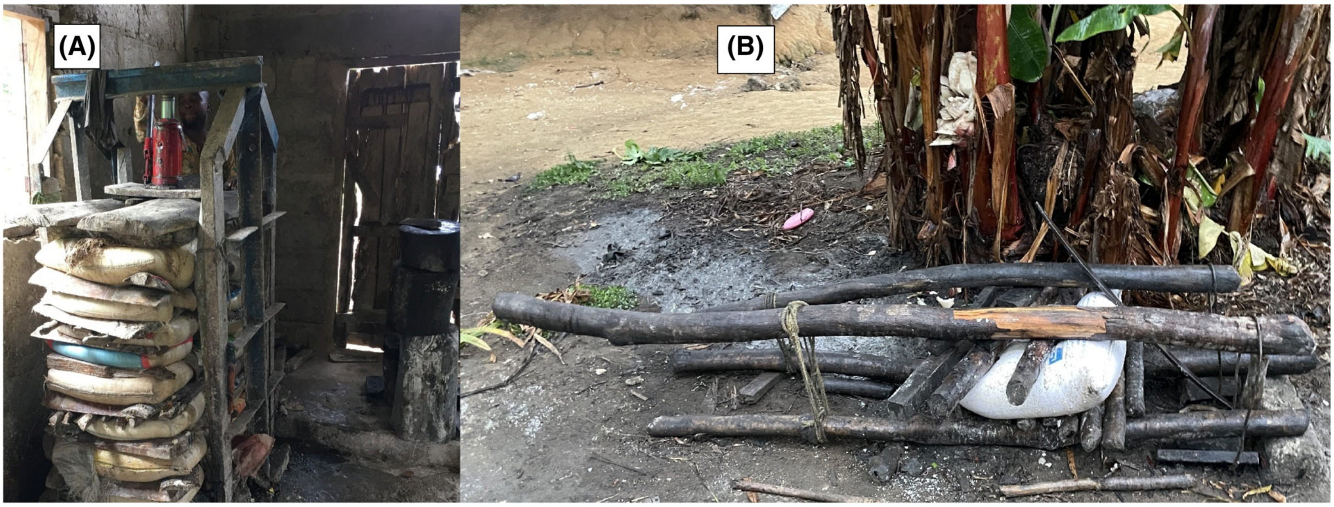

Figure 2. Grated pulp dewatering methods adopted in Nigeria (A) and Cameroon (B).

as color, and textural properties like smoothness, mouldability, and stretchability.[21] The quality attributes of the roots that were examined correspond to the properties identified by processors that contribute to excellent food products.[41] These properties include physiological characteristics of the raw roots, processing attributes such as ease of peeling, and physiochemical traits like dry matter or starch content.

With regard to quality, newly bred varieties were found to be equally or more appreciated than locally preferred varieties typically grown for high-quality fresh roots, *gari*, and *eba* exept for LV-Osun and LV-Sape that showed better food product quality in Osun and Littoral zone Cameroon. This supports the findings of Awoyale et al.[34] who noted the similarity in performance between newly bred cassava varieties and regional processor-favored varieties concerning physical and textural attributes of *gari* and *eba*, as well as consumer acceptability.

Gari from newly bred varieties was equally appreciated compared to *gari* from popular and processors' identified cassava in the tested locations.

In Benue state, Nigeria, there was no significant difference in the processing productivity and PPI of the tested genotypes but a significant difference was observed in the PPI of tested genotypes in Osun state, where TMS-1 had a significantly higher PPI than the local and popular varieties and the breeders check, although no difference in the processing productivity of the individual operations was observed. Genotypes with high dry matter content have a higher *gari* yield in all locations, in line with Bouniol et al.[32]

In Cameroon there were significant differences in processing productivity and PPI among the tested genotypes as well as the processing productivity of the different processing steps. This implies that varietal effects clearly contributed more to processing productivity and thus the PPI than in the other two locations. This could be ascribed to the difference in processing procedure and methods used. First, in Cameroon there is much less fermentation before pressing than in the other two locations. Fermentation times in Benue and Osun are 3 and 4 days respectively whereas in Cameroon fermentation time is only 2 days[33] (same issue). Furthermore, traditional presses are used in Cameroon whereas in Nigeria car jacks and iron frames are used (Fig. 2), which exert greater pressure on the grated and fermented mash, possibly removing relatively more water. So it is possible that, where less fermentation is practiced, varietal effects are larger, or that where traditional presses are used (which exercise relatively less pressure) varietal effects are larger. More research is needed to see the effect of each of these influences and any interactions between them.

CONCLUSIONS

This study identified the effect of varieties on the yield of both fresh roots and processed food products, processing productivity as well as food product quality. These traits can be integrated by breeders into the selection index to advance candidate varieties for release. The research emphasized the importance and laboriousness of specific processing steps in cassava processing productivity, such as peeling and toasting. These steps demand high levels of skill to ensure high-quality food products, and they are time consuming and labor intensive. It is thus important to make them as efficient and productive as possible.

Given that many processors, especially women, rely on cassava processing as a means of livelihood, it is essential to breed cassava varieties that do not reduce processing productivity and ideally increase it. This would help to alleviate constraints faced by processors and make their efforts more rewarding, improving their working conditions. The findings align with research by Bouniol,[32] Teeken,[21] Polar,[42] Donovan,[43] and Forsythe (same issue)[44] which emphasizes the objective of public breeding to create social impact and promote a more demand-driven, socially and gender-responsive breeding strategy.

The newly bred varieties displayed high yields of fresh roots and *gari*, albeit with slightly lower productivity for some varieties and moderate to good product quality. This shows the successful screening for quality traits based on evaluations mentioned earlier such as participatory processing,[21] consumer testing,[33] and Tricot on-farm testing, which included processing and food product-quality evaluation. On the other hand, processors preferred LV-Osun, LV-Sape, which showed outstanding quality in *gari* and *eba* products, along with moderate field and food product yields. These varieties showed slightly higher processing productivity and thus lower potential drudgery, which indicates that higher processing productivity and excellent food product quality can be combined in the same variety. The varieties TMS-1 (released as Game Changer)

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and the advanced clone TMS-5 (TMS14F1278P0003) have comparable PPI scores as the local varieties in Cameroon, where varietal effect on processing productivity and thus potential drudgery was the most outstanding. Importantly TMS-1 (Game Changer), had a significantly higher PPI in Osun, which is a promising illustration how field yield as well as processing productivity have been improved (and possible drudgery thus reduced) while also maintaining food product quality because the released variety game changer and the advanced TMS14F1278P0003 also displayed comparable or better food product quality than the local and regional checks. This is in line with a consumer-testing study carried out with the products produced by the processors in this study.[33] The varieties TMS-4 and TMS-2 performed poorly in this consumer testing study. This partly aligns with the quality assessment in this study and especially in Cameroon, where these varieties were both ranked low by the processors, and TMS-4 was also ranked low in Benue state. This indicates that the processor quality assessment of *eba* is partly aligning with those of consumers.

We observed clearer significant differences in processing productivity and the PPI in Cameroon, where the least fermentation takes place and traditional presses are still used, which exert relatively less pressure during dewatering. This means that people with fewer resources using cheaper material might be more affected by varietal differences. This highlights the need to inquire into the reasons behind this difference observed between Nigeria and Cameroon.

To enhance utilization, acceptability, and adoption of varieties released in the tested areas, it is recommended that breeders should focus on screening for, and possibly improving, processing productivity and thus reducing possible drudgery. This can be further enhanced by further focus by the breeding program on assuring food quality at a threshold level or even improving the food quality (e.g., color), and culinary attributes of new genotypes. Such improvements will contribute to the overall success of breeding efforts and benefit farmers, processors and consumers in the cassava value chain.

AUTHOR CONTRIBUTIONS

Conceptualization: AbB, AA, OO, GE, BT, DD, ABo, PI, RN, IR. Data curation: AB, OO, PI, BT, AA, GE. Formal analysis: AB, AA, BT, OO, DD. Investigation: AB, OO, BT, BA, AA, DD. Methodology: AB, OO, BT, DD, ABo, RN, IR, PI. Supervision: AB, OO, BT, RN, PI, DD, ABo. Writing—original draft: AB, OO, BT, AA, DD. Writing—review and editing: AB, OO, BT, AA, DD. Project administration: AB, OO, BT, AA, PI, IR, DD, RN.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

ETHICS STATEMENT

The research described in this manuscript has the approval of the International Institute of Tropical Agriculture ethical review board committee and RTBFoods Project. IITA has the mandate to carry out research in both of the countries (Nigeria and Cameroon) where this research took place. Written informed consent was obtained from all study participants. All participating processors were financially compensated for the processing work through fair negiotiation with the processors following the local charges for this type of work.

DATA AVAILABILITY STATEMENT

The data on which this study is based are openly avaiable from the IITA CKAN repository: https://doi.org/10.25502/b8f0-4t77/d.

SUPPORTING INFORMATION

Supporting information may be found in the online version of this article.

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