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Varietal impact on women's labour, workload and related drudgery in processing root, tuber and banana crops. Focus on cassava in sub-Saharan Africa

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This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1002/jsfa.12936

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Abstract

Roots, tubers and cooking bananas are bulky and highly perishable. In Africa, except for yams, their consumption is mainly after transport, peeling and cooking in the form of boiled pieces or dough, a few days after harvest. To stabilize, better preserve the products and, in the case of cassava, release toxic cyanogenic glucosides, a range of intermediate products have been developed, mainly for cassava, related to fermentation and drying after numerous processing operations. This review highlights, for the first time, the impact of genotypes on labour requirements, productivity, and the associated drudgery in processing operations primarily carried out by women processors. Peeling, soaking/grinding/fermentation, dewatering, sieving, and toasting steps were evaluated on a wide range of new hybrids and traditional landraces. The review highlights case studies of gari production from cassava. Results show that, depending on the genotypes used, women's required labour can be more than doubled and even the sum of the weights transported along the process can be up to four times higher for the same quantity of end product. Productivity and loads carried between each processing operation are highly influenced by root shape, ease of peeling, dry matter content and/or fiber content. Productivity and the often related experienced drudgery are key factors to be considered for a better acceptance of new genotypes by actors in the value-addition chain, leading to enhanced adoption, and ultimately to improved livelihoods for women processors.

Keywords: Breeding pipeline, Gender, Varietal Adoption, Technological Characteristics, Food Product Profile, End-product Productivity, Value Chain, Market Segment.

Introduction

Drudgery in processing of root, tuber and banana crops (RTBs) has been recognized as a major, complex social, economic and health problem[1]. However, little attention has been paid to the influence of varietal differences on drudgery, and the potential to exploit breeding of appropriate varieties (genotypes) as a partial solution. Although it can have a significant impact on the livelihoods and wellbeing of women (who perform the majority of processing labour), addressing labour requirements, productivity and related drudgery in food processing is often ignored in the development of improved RTB genotypes. Throughout sub-Saharan Africa, women play a vitally important role in agriculture and post-harvest activities, 50% of agricultural work is done by women, with significant variations within and among regions and countries[2]. Agri-food processing at artisanal or small scale is mainly carried out by women with the help of family labour (often young and/or elderly people and neighbors). For processing of RTBs, these operations are often carried out entirely by women -- from the peeling to the elaboration of the end-products ready to be marketed or consumed at the household level[3,4,5,6,7]. The Collaborative Study of Cassava in Africa (COSCA), conducted in six African countries, showed that women lead in root transportation (68%) and processing operations (76%)[8]. On average, cassava processing was carried out mostly by women in about 75% of the surveyed villages, mostly by men in less than 5%, and by both equally in about 20%[1]. Women in sub-Saharan Africa have the highest average agricultural labour-force participation rates in the world[9].

Assessment of processing productivity and the drudgery associated with processing RTB-based foods is limited. Genotype acceptability and drudgery in processing appear to be strongly linked, i.e. women are more likely to prefer RTB varieties with traits that reduce the drudgery of processing [10,11,12,13]. Furthermore, cassava processing, for example, is associated with challenging working conditions and serious health hazards[14,15,16] which increase the likelihood that such operations are perceived as drudgery. Prolonged labour associated with all the operations significantly impinges on the productivity and wellbeing of the (mostly) women operators [17, 18]. Drudgery has been defined as the dissatisfactory experiences that constrain work performance in any activity[19] and is often related to time-consuming, repetitive and menial work. Physical and mental strain, agony, monotony and hardship have been linked to the drudgery often experienced in farm operations[20]

Whether a task is experienced as drudgery depends on many different factors which include specific working conditions (which include the quality and type of tools used), the extent of the task but also how the work is culturally validated and looked upon which in turn determines the type of meaning executers of the task attribute to the task[21].

RTBs have several important features of note in relation to labour input. They tend to be bulky and perishable, making them difficult to transport, and as a result most are often eaten fresh, after cooking, soon after harvest. Alternatively, RTBs are processed soon after harvest to convert them into less perishable and more easily transported products. Cassava, in particular, is extremely sensitive (3 to 5 days) to post-harvest deterioration[22]. Post-harvest handling and storage offer many challenges for RTBs, eliciting development of a wide variety of food products[23,24,25, 26].

Cassava is by far the most widely grown and consumed root in sub-Saharan Africa[27]. The starchy roots contain toxic cyanogenetic compounds at various levels[28,29]. Typically consumers perceive bitterness from cyanogens beyond a cyanogenic potential of about 80-100 ppm[30]. These toxic compounds are only very partially (20%) removed by boiling or frying[31] so genotypes below 50 ppm are recommended for consumption as boiled or fried pieces (genotypes above 100 ppm become toxic for mammals and must be detoxified to avoid health risks[32]. The detoxification is done mainly by grinding or rasping, often with fermentation before or after that process. Fermentation is done either by soaking the whole or peeled roots in containers (retting), or by resting the pulp in sacks or containers for several days. During these operations the volatile cyanogenic compounds are released[33]. These double-purpose operations of fermentation (detoxification and softening) of the roots in water are essential for the fiber removal and preparation of safe traditional staple foods in Africa: fufu, lafun, batôn, Chikwangue, agbelima, gari, attieke[34]. Varying the length of fermentation allows formulation of products according to the preferred tastes of consumers, which are very diversified for a range of products, are specific to production zones of origin, and may vary according to availability in the market[35,36].

The current study is an output of the project *Breeding RTB products for end user preferences* (RTBfoods https://rtbfoods.cirad.fr/). This project developed a new five-step methodology for developing food product profiles, through mobilizing a multidisciplinary team of breeders, social scientists, and food technologists to capture the preferred traits of farmers, end-users and consumers[37,38]. The data were produced following a standardized participatory processing diagnosis procedure common to all RTBs[39] and mainly published in 2021 as a special issue of the *International Journal of Food Science and Technology*: Consumers have their say: assessing preferred quality traits of roots, tubers and cooking bananas, and implications for breeding https://ifst.onlinelibrary.wiley.com/toc/13652621/2021/56/3.

The main objectives of the current study were ***i)*** to dissect the individual processing steps involved in different RTB food products; ***ii)*** to evaluate effects of genetic differences among varieties on processor workload, particularly comparing improved and traditional varieties; and ***iii)*** to guide breeders by highlighting the traits responsible for varietal differences in required labour inputs, which in turn influence acceptability of new varieties.

This review, therefore, does not directly evaluate the level of drudgery experienced based on different genotypes, but rather examines the impact of varieties on productivity and the associated labour requirements in processing operations. Regardless of how an operation is perceived, a decrease in productivity or an increase in labour requirements can potentially contribute to the drudgery experienced by processors. Therefore, this review examined the influence of different varieties on the productivity of processors individually for various processing operations. The study measured processing operator productivity by the amount of mass produced per unit of time per operator within each operation. Additionally, as a secondary measure related to productivity, we evaluated the weights of products that processors had to transport between operations. This assessment served as an indicator, albeit productivity-related, to quantify the labour involved in processing different varieties.

Materials and Methods

In rural or peri-urban areas of East and West Africa, RTB processing sites were selected according to a predefined sampling methodology. The processing trials were participatory and carried out with experienced *champion processors*. Both preferred (locally commonly used/popular varieties) and non-preferred genotypes (locally known as non-adequate for expected product profile) were included to provide a wide range of technological and physico-chemical characteristics (fixed effects from the statistical point of view). Processors provided feedback on the varieties before, during each step, and after processing to identify relevant characteristics of the crop and product. Processing parameters were measured at each step. The specific traits related to the processing ability were included in the different Food Product Profiles.

Proper and representative quantity of product was harvested from at least four genotypes (more if possible). Each processing step was conducted in duplicate (averages of two women, who collaborated by processing half of each batch of material for each genotype).

- Processors were invited to observe each raw genotype and give their views, as an operation unit, on its quality characteristics.
- Dry matter content (DMC) of all the collected samples was measured.
- The processing was carried out in real/normal conditions in processors' own communities.
- Each processor started with the first operation unit stage, processing one variety at a time.

For boiled or pounded products (cassava, plantain, yam), the process is relatively simple, including steps such as peeling, washing, boiling, steaming or frying, and (in some cases), mashing and pounding. The parameters measured were: peeling yield, duration of peeling, cooking (or pounding), and productivity of each operation unit. These products were processed by only 2-3 operation units.

Processing operations of fermented products, on the other hand, are more complex and involve more steps. To standardize the data collected in different countries and on different production lines, all the data were scaled to obtain 1000 kg of the end product. Each process was broken down into separate operation units.

- *Gari* (granulated product): peeling; grating; washing; fermentation & draining; mechanical dewatering; wet pulp sieving; mash toasting; and dry gari sieving[40].
- *Dry Fufu* (soaked cassava product: Couscous, Lafun): peeling; washing; soaking; fiber & non-softened material removal; draining in bags; sun drying; and dry fufu grinding[41].

A representative sample of approximately 20-50 kg of roots from each genotype were processed to perform the technological diagnosis, and used to measure the yield/productivity of each operation unit (The coding used for each genotype is available in supplementary table S1.). All trials were replicated twice. For each operation unit the average weight was measured before and after processing. The yields of each operation unit were thus calculated according to the genotypes studied and reported as ***Yield by operation unit (%).*** The time needed to perform each operation, on all the available material, was measured with a chronometer. ***Operator productivity by operation unit (kg/h/Operator)*** was calculated for each operation and per genotype studied. The calculation table allowed to visualize the incoming and outgoing quantities for each operation unit for 1000Kg of final product: ***Processed material by operation unit (kg /1000 kg final product); Operator time by operation (h)*** and ***Time distribution by operation unit (%)*** were thus obtained. Three global values allowed characterizing genotypes by:

- ***Gari Yield (%)*** expressed by weight of initial root/weight of finished product.
- ***Operator Time by kg of final product (h/kg)***, is the time needed to produce one kilogram of end product per genotype. It is calculated as the sum of the time spent to finalize each operation unit, reported to one kilogram of final product.
- ***Weight carried by operator per kg of final product (kg)*** calculated as the sum of all intermediate products carried or moved between each operation unit to obtain one kilogram of final product.

The methodology described above became a processing diagnostics and mass balances for the main RTBs consumed in subtropical Africa. Yam in Benin & Nigeria; Sweetpotato & Potato in Uganda, Plantain in Cameroon, Matooke in Uganda, Cassava in Benin, Cameroon, Nigeria, Uganda.

Results

Productivity and peeling yields of RTBs strongly influence the labour required from the processors. Specifically for cassava processing, multiple operation units and teamwork make it difficult to evaluate the labour required to produce one kilogram of end-product. New data on cassava, sweetpotato, yam, potato and cooking bananas (plantain and matooke) collected following Fliedel *et al.,* (2018) methodology were used[39]. The data collected allowed estimating the average productivity of each operation according to the genotypes used.

RTB peeling yield related to shape and ease of peeling.

Table 1 reports the RTB peeling data (available in open access) in each RTB processing diagnostic summary for the main product profiles. The flowsheet of each RTB final product has been established and are fully available in each crop report on Table 1 links.

The lowest yields were for bananas, with 55% yield measured for the matooke peeling operation and a productivity of 28 kg/h/operator. For plantains a yield of 50% was observed and a productivity of 43 kg/h/operator of pulp obtained after peeling. These results are in general agreement with previous reports[42,43], although yields were slightly lower. For potatoes 75% of peeling yield and 9 kg/h/operator were found for manual peeling in Uganda. In the industry, using steam peeling for potato, losses range from 6 to 10% of fresh weight[44, 45]. In Uganda, sweetpotato studies reported a peeling yield of 79% and a peeling productivity of 14 kg/h/operator. In India, losses ranged from 3 to 21% among 18 sweetpotato genotypes studied, with an average peel loss of 11%[46]. Yam peeling yield of 80% has been reported in Nigeria and Benin, with an average productivity of 34 kg/h/operator.

For cassava, where the largest number of trials were conducted, the average peeling yield was 74% and the productivity 57 kg/hour/operator. However, there was a high variability among locations and end products (Table 1). The physical characteristics of the peel could influence both peeling labour and the amount of product lost at the peeling stage. These differences in the properties of the peel can include variation in thickness, texture and strength of adhesion to the root flesh[47]. The peel consists of two basic components: the phelloderm, or the *bark*, is the thin, usually rough, outer layer; the cortex is the fibrous layer that attaches directly to the pulp. Low peel adhesion strength to cassava flesh allow easy removal of the external phelloderm by making an incision within the cortex with a knife, followed by pulling and removing the peel around the flesh or by rubbing it off in mechanized systems (figure 1). Cassava genotypes with easy peel removal reduced product waste and labour.

Table 1. Peeling yield and productivity and RTB shape reported on RTBfoods RTB processing diagnostic summary.

Product by institution and country	**Link to published flowsheets**	Average ± standard deviation					Number of genotypes		Age of plants at harvest (months)
		RTB Shape			Peeling yield (% w.b)	Productivity (kg/h/Operator)			
		Weight (g)	Girth (cm)	Length (cm)			Landraces	Improved	
Boiled Yam, UAC-FSA-Bénin **(48)**	http://agritrop.cirad.fr/602027/	1441±589	***	35±9	75 ± 11	39 ± 23	6	0	9
Boiled Yam, NRCRI-Nigéria **(49)**	https://agritrop.cirad.fr/602029/	***	***	***	87 ± 3	38 ± 9	0	4	***
Pounded Yam, Bowen Univ.-Nigeria **(50)**	https://agritrop.cirad.fr/602026/	978±340	31±6	36±5	79 ± 10	24 ± 11	10	***	***
Boiled sweetpotato, CIP-Uganda **(51)**	https://agritrop.cirad.fr/602026/	184±95	***	***	79 ± 5	14 ± 3	6	1	***
Boiled potato, NARL-CIP-Uganda **(52)**	https://agritrop.cirad.fr/602025/	68±42	***	***	75 ± 6	9 ± 4	4	2	***
Boiled plantain, CARBAP-Cameroon **(53)**	https://agritrop.cirad.fr/602023/	222±57	13,7±1,3	24,3±4,5	50 ± 5	43 ± 4	3	1	***
Matooke, NARL-Uganda **(25)**	https://agritrop.cirad.fr/602041/	26±9	13,7±1,4	19,3±1,4	55 ± 4	28 ± 5	3	3	4
Bâton, CIRAD/IITA-Cameroon **(54)**	https://agritrop.cirad.fr/595635/	875±482	21±6	27±4	70 ± 5	54 ± 13	0	8	13
Gari, CIRAD/UAC-FSA-Benin **(55)**	https://agritrop.cirad.fr/597596/	509±178	19±7	28±3	66 ± 3	66 ± 18	2	13	12
Dry Fufu, CIRAD/IITA-Cameroon **(56)**	https://agritrop.cirad.fr/597597/	***	***	***	73 ± 6	40 ± 10	3	18	13
Dry Fufu, CIRAD/UAC-FSA-Benin **(57)**	https://agritrop.cirad.fr/597594/	1068±707	23±6	34±11	73 ± 3	64± 13	3	13	12
Boiled cassava, NaCRRI-Uganda **(58)**	https://agritrop.cirad.fr/602019/	***	***	***	70 ± 8	60 ± 27	4	5	*
Boiled cassava, UAC-FSA-Bénin **(59)**	https://agritrop.cirad.fr/602013/	388±345	16±5	29±9	77 ± 6	16 ± 8	6	0	12
Water Fufu, IITA –Nigeria **(60)**	https://doi.org/10.1111/ijfs.14862	577±585	22±6	26±9	80 ± 3	54± 7	5	15	13
Gari/Eba, IITA-Nigeria **(60)**	https://doi.org/10.1111/ijfs.14862	581±453	25±9	21±8	78 ± 3	63 ± 12	5	15	13
Gari/Eba, NRCRI-Nigeria **(61)**	https://agritrop.cirad.fr/602035/	***	***	***	75 ± 3	***	***	***	***
Water Fufu, NRCRI-Nigeria **(62)**	https://agritrop.cirad.fr/602033/	***	***	***	83 ± 7	23 ± 4	1	3	12
Attieke, CNRA-Cote d'Ivoire **(63)**	https://agritrop.cirad.fr/603470/	1254±559	24±4	37±10	70±5	34±7	2	4	15

*** Not evaluated

Figure 1. Peeling cassava roots. **A.** Illustration of the occurrence of constrictions (left) and variation of root shape and size (right). **B.** Traditional peeling by slashing in Africa. **C.** Illustration of roots where the peel can be easily removed.

Roots of the majority of existing cassava genotypes in Africa can only be peeled (with current technologies) by slashing it off the flesh of the root with a sharp knife or machete, increasing enormously the losses and the women processor fatigue**[64]**. Some authors used a large number of cassava genotypes in Colombia**[65]**, Uganda**[66]** or India**[67]** for evaluating phelloderm and root cortex thickness: (0.79 to 5.14 mm in Colombia on 64 genotypes; 0.3–4.9 mm in East Africa on 825 genotypes; 0.2 to 0.5 mm in India on 10 genotypes, with cortex thickness at the proximal, middle, and distal varying from 1.2 to 3.1 mm). This large genetic variation in peel thickness is associated with the difficulty of peeling, which strongly affects peeling yields and productivity. Industrial or small-scale processors prefer genotypes that are easier to peel and for which labour and drudgery are reduced. For hand peeling, mainly in Africa, yield and productivity are also strongly related to the size and shape of the roots and the presence of constrictions**[68,69]**.

The data collected by the RTBfoods project teams allowed to visualize the peeling yield and productivity as a function of root girth, root weight and root length (Figure 2). Although there was a strong increase in peeling yields as a function of increasing root diameter, weight and length, the dispersion of the data highlights other factors such as irregular shape, peel thickness, and/or the presence of constrictions affecting peeling efficiency. Processors know how to predict accurately the ease of peeling. It is mainly the women processors who set the purchase prices of the genotypes to be processed and thereby contribute directly through their processing preferences to the varietal adoption by cassava farmers. These gendered decisions are primarily influenced by the labor-intensive nature of the tasks, particularly in relation to product yield, processing productivity, and the perceived level of drudgery.

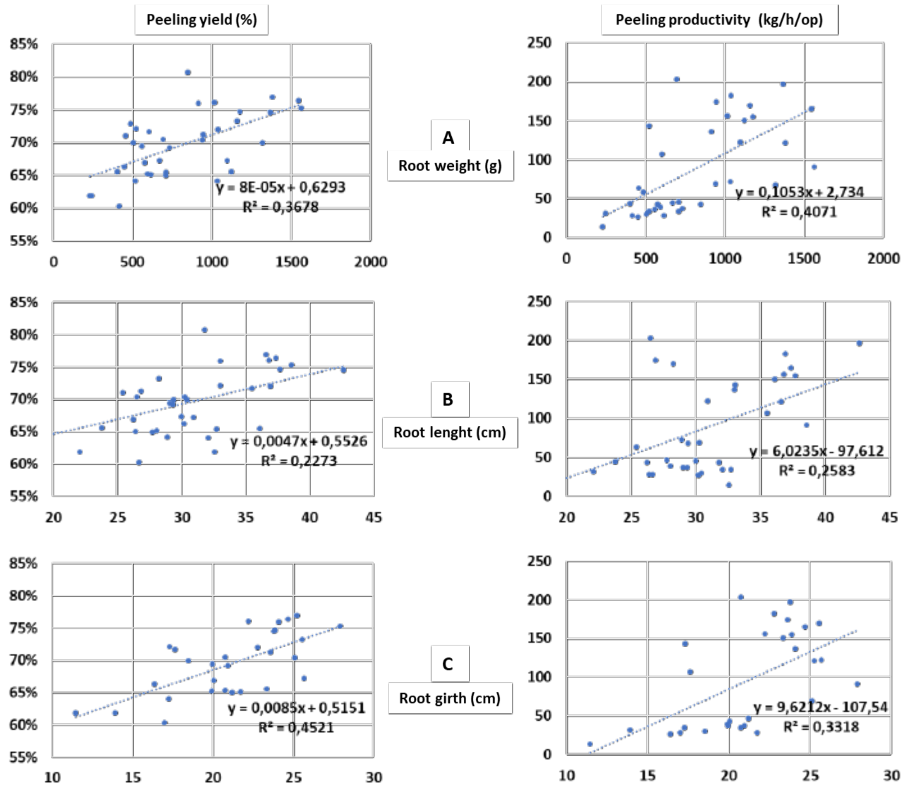

Figure 2. The impact of root morphology on peeling yield (%) and productivity (kg/h/operator) in cassava**. 1A)** Root weight (g); **1B)** Root length (cm); **1C)** Root girth (cm). Based on Gari UAC/FSA[55], Lafun UAC/FSA[57], and Bâton IITA-Cirad Cameroun[54] data.

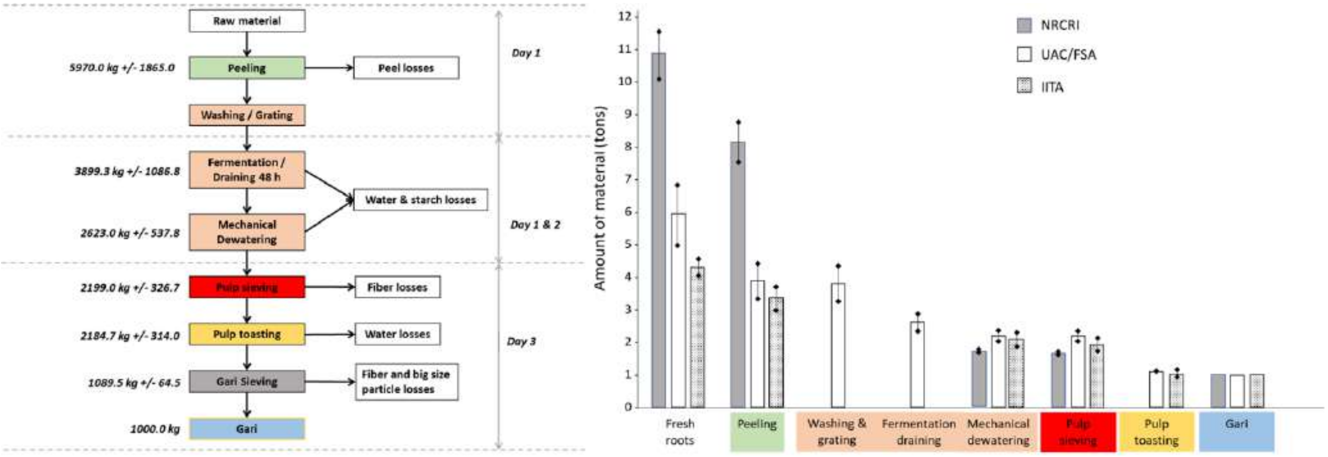

Figure 3. General description of the process to produce gari and average amounts of roots and intermediate products involved in the production of one ton of dry gari in three different regions of West Africa represented by the three different institutes that lead the work in the different regions. Lines on top of each rectangle represent the respective standard deviations.

Gari processing: diagnosis and genotype differences

Gari processing experiments were conducted by three different institutes in three different locations: Savalou, Colline, UAC/FSA, Benin (Supplementary Table S2), IITA, Osun State, Nigeria (Supplementary Table S3) and Umudike, Abia State, NRCRI, Nigeria (Supplementary Table S4). A varying number of genotypes was evaluated in each location (Supplementary Table S1). Only one genotypes (TME B419) was evaluated in the three locations.

Figure 3 illustrates the entire process to produce one ton of gari and the relative losses through the different stages. Yields were obtained for each operation unit on three different sites -- UAC/FSA in Benin, and NRCRI (Umudike) and IITA (Osun State) in Nigeria. There were large differences in the average tons of fresh roots required to produce one ton of gari: 12.9 (NRCRI), 7.0 (UAC/FSA) and 5.1 t (IITA). To a large extent, as illustrated later, the variation in the amounts of roots required was closely related to the average DMC of the genotypes processed in each location (31.4, 37.4 and 39.2%, respectively).

Root peeling is the first stage (operation unit) in gari processing. About 30-35% of the initial root weight is lost in the (manual) peeling. While shape and size of the roots play an important role in defining the losses during peeling (noted in previous section), this study did not characterize those parameters. As shown later in the article, there is also a remarkably variable required labour from the female processors, depending on each genotype and location. The average time to obtain 100Kg of peeled roots was 3.3±2.0 hours by operator, but the variation was very large ranging from 1.3 (easy to peel and high DMC) to 11.5 hours for the most difficult genotypes (small size, very adherent peel and/or low DMC).

A second stage in which weights are drastically reduced (by about 40%) is during the fermentation, draining and mechanical dewatering (Figure 3). The third important reduction in weights (around 50%) takes place during pulp toasting[70, 71,72].

For each processing site, the operators (mainly women) must carry fresh roots and the residual material after each operation unit in order to proceed to the next one. For the three trials, depending on the genotypes used, to obtain 1000kg of gari, a woman operator had to carry the accumulated weight of 25.7, 48.0 and 19.3 tons respectively in UAC/FSA, NRCRI and IITA.

Figure 3 presents the information for each location, dissecting for each genotype the losses through the individual processing operations in the gari production. The three graphs show a great influence of the location and edaphoclimatic parameters on the quantity of roots necessary to produce one ton of gari. There were large genetic differences in the losses at different stages of gari production by location. The DMCs of local varieties as well as the new hybrids tested in NRCRI were much lower than those observed in UAC/FSA or IITA (31.4%±2.3; 37.4%±5.9 and 39.2%±2.9 respectively).

The weight of discarded peel was much lower at IITA (954 kg) compared to NRCRI and UAC/FSA (2732 and 1879 kg, respectively). The low DMC of the trial at NRCRI would explain the important losses observed during the dewatering operation in that trial. In this region, locally grown genotypes (Agric, Nwacho and Mgboto) on the right of the plot, have a higher overall processing yield than the new hybrids evaluated. For the IITA and UAC/FSA trials, on the other hand, many of the new hybrids introduced showed higher gari yields than the locally grown landraces.

The standard deviations provided in Figure 4 demonstrate important differences among genotypes at the different stages of gari production. The coefficient of variation (σ/µ*100) can provide an insight into these stages during gari production where there is relatively more variation among genotypes regarding losses. (Supplementary Table S5)

Influence of root DMC on the amount of raw cassava roots required to produce 1000 kg of gari.

Figure 5 depicts the relationship between DMC of raw roots from 57 cassava genotypes and the respective amounts of raw roots required to produce one ton of gari. There was a clear negative correlation between DMC and the amount of fresh roots required *(tons of fresh roots = 26,078 – 0,525 * DMC ; R^2=0.674).* The red dots identify commercial checks often used to produce gari in the regions (Dale, Kati Kati, Salome, AGRIC, Nwageri, Chigazu, Durungwo, Nwocha, Mgboto Umuahia, Honourable 1 and 2, Omoh Local 1 and 2 and Akpu). Commercial checks are scattered from the top left down to the bottom right. TME B419 in green was processed in the three trials.

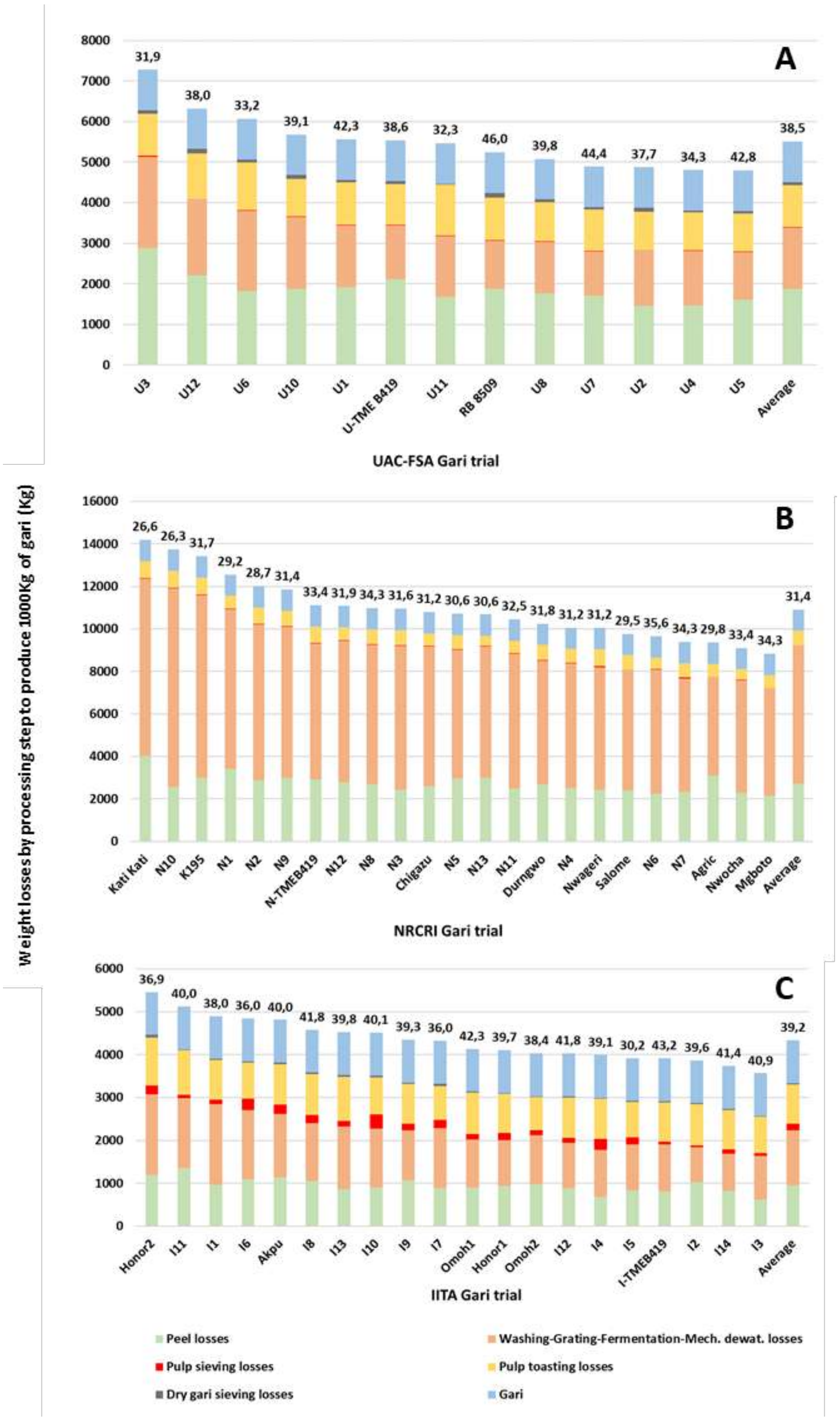

Figure 4: Individual losses through the different stages of gari production of several cassava genotypes evaluated at **A)** Savalou, Colline, (UAC/FSA) Benin; **B)** Umudike, Abia State, (NRCRI) Nigeria; and **C)** Osun state, (IITA) Nigeria. DMC values (%) are depicted on top of the respective bar.

Three groups of clones showing large deviation from the regression line (more than 2 tons difference between expected values based on the DMC and the actual amount of fresh roots required to produce 1 ton of gari) have been highlighted in Figure 5. Below the regression line there is a single group (within a green-doted triangle). This group included seven improved clones. On average, these genotypes required 5.27 tons of fresh roots to produce 1 ton of gari. However, based on the DMC, the model expected that these genotypes should have required up to 8.54 tons of roots. On average these seven genotypes had intermediate levels of DMC (average of 33.4%) and the contrast between their expected and observed performances would suggest that they were efficient gari producers.

There is a second group of six genotypes (within a red-dotted triangle), well above the regression line. This group included five bred clones and only one landrace check (Kati Kati). DMC in Kati Kati was very low (26.6%). The other five clones had intermediate DMC levels (average= 33.3%). The amounts of roots required to produce 1 ton of gari (11.87 t) for these clones were considerably higher than the expected (9.19 t) based on their DMC levels. Finally, within an oval, red-dotted figure (at the bottom right of Figure 5) there was a third group (two bred genotypes) that required 5.06 tons of fresh roots to produce 1 ton of gari. This is considerably more than the amount expected by the model (233 t). These last two groups are inefficient genotypes (above the regression line). They required considerably more fresh roots than expected based on the DMC regression model. These two groups differed considerably in their DMC averages.

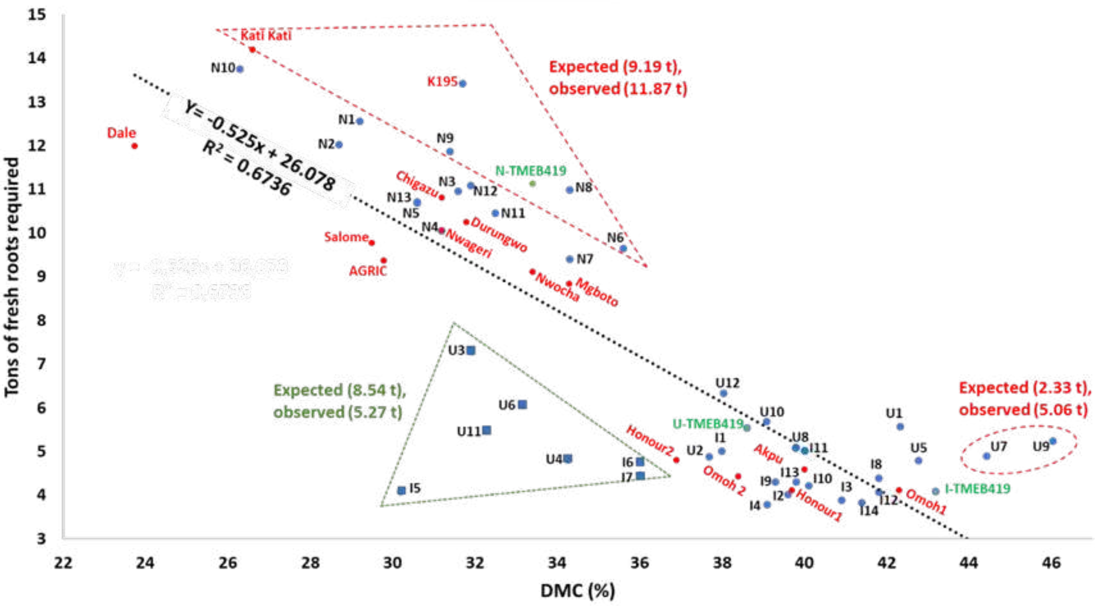

Figure 5. Relationship between dry matter content (%) of roots and the amounts of roots required to produce one ton of gari.

The efficiency of gari production is clearly related to DMC as illustrated by Figure 5. However, other characteristic (e.g., thin peel; easy to peel; reduced fiber content; less starch loss during the dewatering process; etc.) may explain the occurrence of large deviations from the expected values determined by the regression line.

Partitioning the total labour into the different activities

Figure 6 shows the data generated at Savalou, colline, UAC/FSA, Benin and Osun state, IITA Nigeria on the time required to complete each key step of the process for the gari production for 1000kg of final gari. By far the most time-demanding activities in the production of gari are pulp toasting (53.5%) and root peeling (31.0%). Other activities remained relatively minor in terms of labour demand (6% for pulp sieving, and root washing and dry gari sieving with about 3.7% each). The standard deviations indicate that there is considerable variation among genotypes in relation of their demand of labour to produce one ton of gari. The graph reveals that toasting was less efficient at IITA but, on the other hand, peeling was less time consuming there as compared with UAC/FSA (Figure 6A).

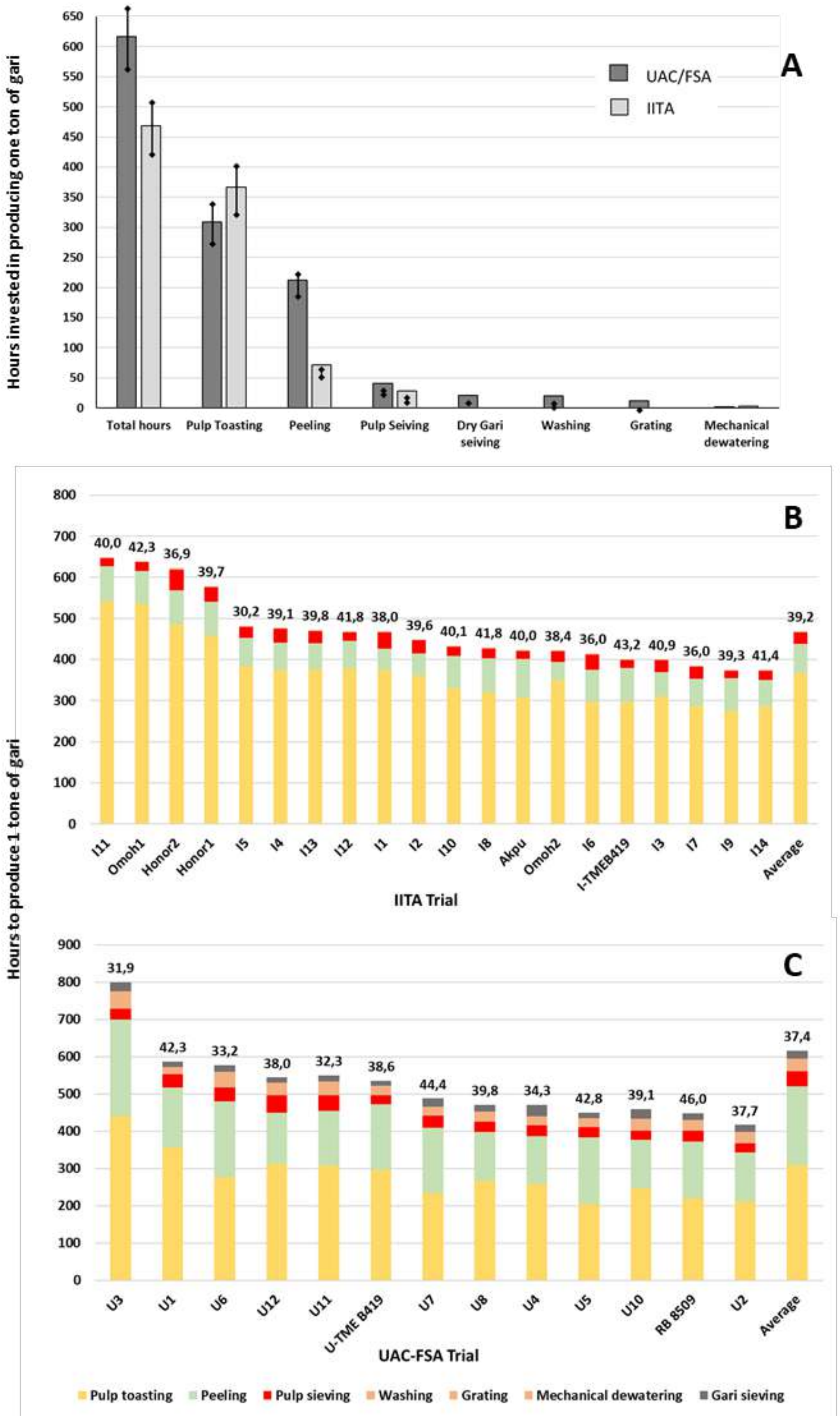

Figure 6. Time invested to produce one ton of gari. (**6A**) Partitioning the total labour required to produce one ton of gari into the different activities of the process.(**6B**) Time invested to produce one ton of gari in the UAC/FSA trial (6B) and IITA trial (**6C**) discriminated by genotypes and activities.

The variety Dale has been ignored in Figure 6 because of its outlying performance. As indicated, there were marked differences in the time invested for each operation among the genotypes evaluated, suggested by the standard deviations in Figure 6A. The plots of Figures 6B and 6C confirm large genetic variation for labour requirements to produce one ton of gari.

The coefficients of variation (CV=σ/μ*100) from UAC/SFA data, for the different operations, were: overall time (hours required to produce 1 ton of gari): 19.3%; peeling: 22.7%; washing: 33.2%; grating: 18.0%; dewatering: 6.8%; pulp sieving: 22.9%; pulp toasting: 23.6 % and dry gari sieving: 27.2% In the case of IITA trials CVs were: overall time: 16.0%; peeling= 15.6%; dewatering: 7.4%; pulp sieving: 27.3% and pulp toasting: 19.7 %

The CVs provide a general appreciation of where variation among genotypes is particularly important for a given activity and point out results that require further exploration. For example, in the IITA trial (Figure **6B**), root peeling was relatively more uniform (CV= 15.6%) than pulp sieving (CV = 27.3%). I1 and Honourable 2 required more than 40 hours in pulp sieving whereas Akpu and I9 required less than 20 hours. Understanding why these genotypes are so contrasting for pulp sieving would help breeders to use more efficient selection approaches.

Figures 6B and 6C also provide information on DMC for each genotype. U3 has low DMC and requires considerable labour input. RB 8509 (or U9) had the highest DMC and was second lowest clone in labour requirement (Figure 6C). There is some association between DMC and labour requirements. On the other hand, U2 with an intermediate DMC (37.7%), required considerably less labour than U1, which had excellent DMC (42.3%). This last clone required 80 more hours than the average of 523 hours (excluding Dale) for UAC/FSA.

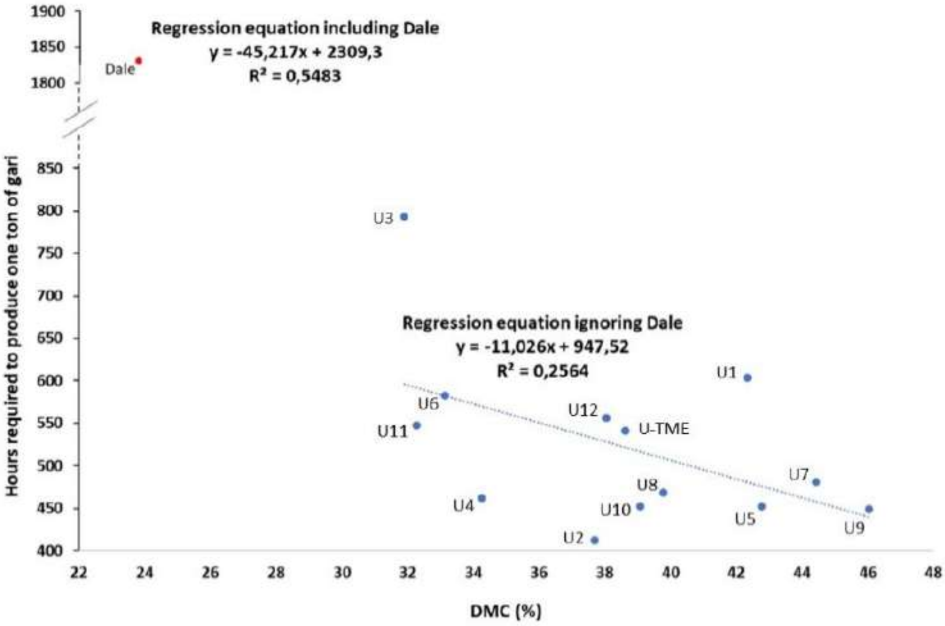

Figure 7. UAC/FSA trial Relationship between dry matter content of activities (Figure 6A). Therefore, the relationship between DMC and the time required to carry the roots and the total labour requirements to produce one ton of gari.

Influence of DMC on workload to process one ton of gari.

Labour hours required to produce one ton of gari versus DMC of raw roots (UAC/FSA data) was plotted in Figure 7. Dale is a locally grown variety in Benin with low DMC and small roots. If this genotype (clearly outlying) is included, the regression analysis comparing DMC and labour hours results in a $R^2 = 0.55$. However, when Dale was ignored the coefficient of determination was drastically reduced ($R^2 = 0.26$). The large range of time required to produce one ton of gari (ignoring Dale) goes from 400 to 800 hours. Relatively little of that variation is explained by DMC, as also indicated by data from Figures 6B and 6C. There are, therefore, other factors that influence the variation in the labour required for processing one ton of gari such as shape and size of roots, which has a huge impact on the peeling operation.

Root peeling, pulp sieving and pulp toasting are the most labour-demanding out these activities was further analyzed and depicted in Supplementary Figure S1. Data for this figure included trials at UAC/FSA and IITA. The most important influence of DMC was found to be for pulp sieving. However, there is a large dispersion of data (Supplementary Figure S1). The negligible influence of DMC on labour requirements for pulp toasting is not surprising. Most of the effect of DMC would be on stages prior to the toasting. When the material being processed reaches that stage, they already have a much more uniform (and increased) DMC because of the mechanical de-watering that takes place after fermentation.

Summary of the influence of DMC on gari production.

A summary of the relative importance of DMC in gari yield and labour requirements has been consolidated in Figure 8. In addition, this figure provides another important parameter related to the drudgery of gari production: the total amount of mass that women had to move throughout the entire process. The highest coefficient of determination was observed for the regression of kg of mass movement per kg of gari produced, on DMC ($R^2= 0.65$).

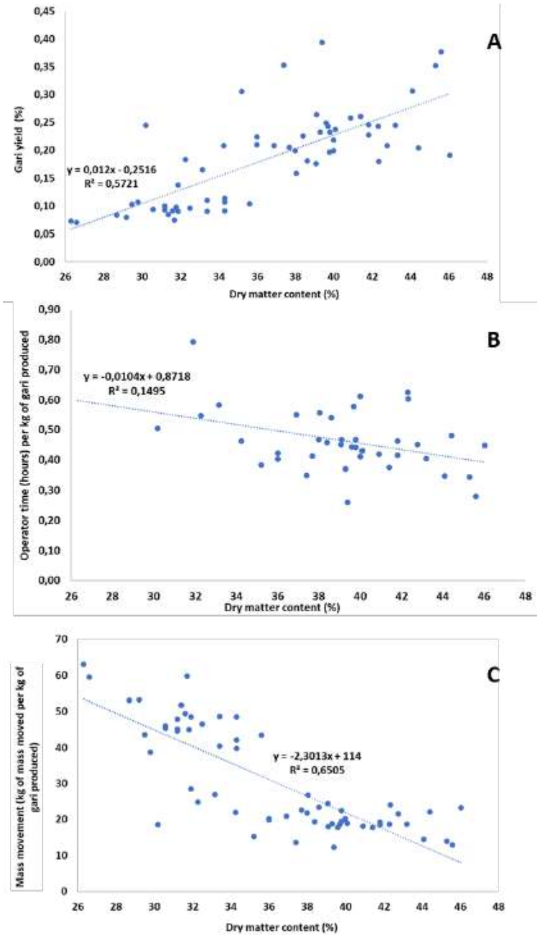

Figure 8: Impact of raw material dry matter content (%) on gari yield (8A), operator time (8B) and drudgery (8C)

Figure 8A shows a positive correlation between gari yield and the raw root dry matter content. However, the dry matter content doesn’t impact significatively the time spent for processing (Figure 8B). Other parameters may have to be considered for their impact on process productivity, such as: root peeling ability, draining behavior during fermentation, and draining, sieving ability linked to fiber content. A clear negative correlation can be observed between mass movement and dry matter content (Figure 8C). The dry matter content is thus an important trait to be considered in order to reduce labour requirements and thus the often related drudgery in gari processing.

Key findings and Conclusions

This review shows a strong genetic influence on processing yield, operators' efficiency, workload and fatigue of RTB processors (mainly women, young children and elderly). Processing yield depends not only on varieties but also on the level of complexity of the processes. Indeed, low processing yields are the result of complicated operations with many steps to reduce water content, enhance the shelf-life of products and, in the case of cassava, detoxify it if necessary.

Thus, more complex processes tend to increase the likelihood of perceived drudgery, reduce global processing yields but, on the other hand, lengthen the shelf life of food products. In that sense, complexity, and concomitantly some degree of drudgery, is the price to pay to increase the shelf life of the end-product coming from the same raw material.

Reduced processing yields do not only have a direct negative economic impact on the value addition, but also have an indirect (but strongly correlated) effect on the accumulated weight carried through the process. By combining all the data sets for the different food product profiles, Figure 9 illustrated the clear association between weights carried out and processing yields.

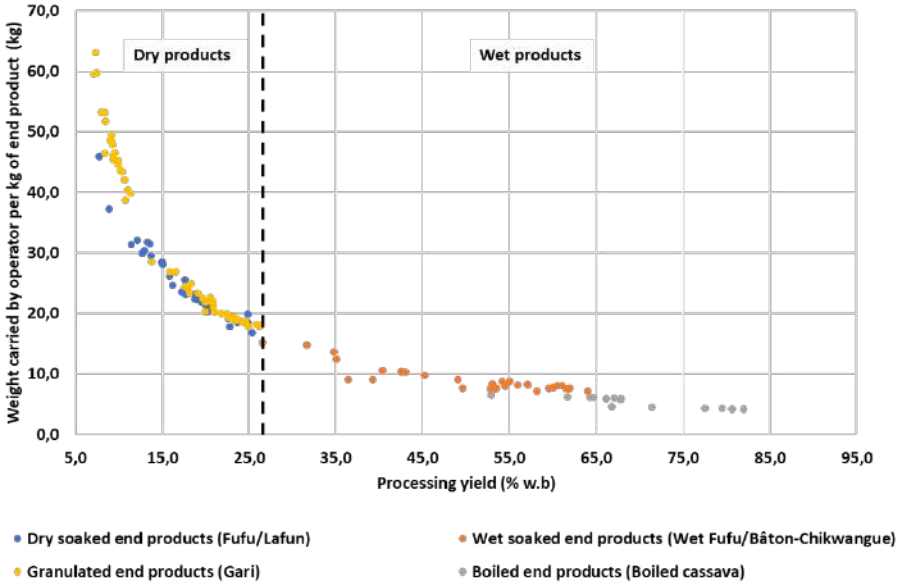

Figure 9: Weight (kg) carried out by operator per kg of end product according processing yield (% w.b). Based on Gari CIRAD/UAC-FSA[55], Gari IITA[60], Dry fufu CIRAD/UAC-FSA[57], Dry fufu CIRAD/IITA[56], Bâton CIRAD/IITA[54], Wet Fufu IITA[60] and Boiled cassava UAC/FSA[59] data.

Furthermore, this review addressed a clear gender dimension as processing work is often dominated by women because of existing norms that often push women into monotonous and drudgery related tasks. As social impact through social and gender inclusiveness is a particular outcome aimed by RTB breeding[73] and part of the sustainable development goals, increasing productivity and limiting perceived drudgery in RTB processing, is therefore crucial within the empowerment of women from below. Gender transformative approaches that aim to change gender roles are important but often slow and are not always able to address the concrete working conditions, livelihoods and their context (including the existing norms) that women are largely dependent on[74, 75] to make a living and increase their income and independence.

A special effort should be made by RTB breeders to evaluate the yields of the final product and the additional fatigue that could be brought by the introduction of new genotypes. This is particularly necessary for the more complex processed products, especially those from cassava, because of the additional need to detoxify them, reduce weight of the marketable product by removing water and the need to increase shelf live. Moreover, addressing labour requirements and associated drudgery related to processing is not enough because breeders must also consider consumer preferences as well. There is a large diversity of requirements for granulated and soaked products on one hand, and pasty and dough products such as pounded yam and matooke, on the other. All these products are obtained after complex processing steps[27,34,35,36].

The processing efficiency or productivity that determines the amount of labour required from processors and the related drudgery are key factors in the varietal adoption process. The processors, who are often the decision makers for the purchase of raw materials, strongly contribute to the creation of a market segment for new genotypes or to their rejection depending on the difficulty of processing and/or the food product yields obtained. The views of consumers, traders and growers have already been incorporated into the definition of breeding goals. This review highlights, however, the critical importance of processors in the final varietal adoption[76]. Their perception of each genotype provides relevant information that must be integrated upstream in the breeding pipeline to increase the chances of success of new varieties.

Acknowledgements

In memoriam of our colleague and friend Geneviève Fliedel, Ph.D., Food technologist at CIRAD who suggested and contributed to this work and for the passion and enthusiasm that characterised her work as a researcher.

The authors are grateful to the grant opportunity INV-008567 (formerly OPP1178942): Breeding RTB Products for End User Preferences (RTBfoods), to the French Agricultural Research Centre for International Development (CIRAD), Montpellier, France, by the Bill & Melinda Gates Foundation (BMGF): https://rtbfoods.cirad.fr.

The authors thank the various partner institutions of the RTBfoods project for allowing the sharing of additional data not contained in the diagnostic reports mentioned in the bibliographic list.

The final proofreading of the manuscripts by Clair Hershey improved greatly the quality of this manuscript.

Credit Authorship Contribution Statement

Conceptualization: AB, DD, TM, FKA, GF, LF, BT
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Formal Analysis: AB, DD, HC, AB, BT, BO, SN, LA
Investigation: AB, AB, BT, DOO, MO, SN, NO, LA, DD
Methodology: AB, GF, MT, LA, LF, DD
Supervision: AB, BT, TM, LA, GF, LF, DD
Writing: Original draft: AB, HC, DD
Writing reviewing and editing: AB, HC, DD, LF, BT
Project administration: DD

Editorial Policies and Ethical Considerations

The authors declare no conflict of interests. Authors have agreed to this publication. All funding has been acknowledged.

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