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ORIGINAL RESEARCH ARTICLE

Crop Breeding & Genetics

From traits to typologies: Piloting new approaches to profiling trait preferences along the cassava value chain in Nigeria

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Abstract

Breeding programs are increasing efforts towards demand-led breeding approaches to ensure that cultivars released meet the needs of end users including processors, traders, and consumers, and that they are adopted by farmers. To effectively deploy these approaches, new tools are required to better understand and quantify the degree of preference differences among alternative trait changes competing for measurement and selection effort. The purpose of this study was to present a method of quantifying preferences and developing typologies according to breeding priorities by applying an online trait preference survey approach to cassava (*Manihot esculenta* Crantz). This paper presents a conjoint analysis based on Potentially All Pairwise RanKings of all possible Alternatives (PAPRIKA) to help guide breeding programs in understanding trait preferences across value chain roles and social contexts and set breeding priorities that represent diverse interests. Trait preferences were assessed using a comprehensive survey and analysis package incorporating a core adaptive conjoint method (1000minds, 2020). Trait selection was based on a trade-off of 11 cassava traits carried out with 792 cassava value chain actors in four geopolitical regions in Nigeria. Principal component and cluster analyses revealed three clusters (typologies) of respondents according to their trait preferences. The results demonstrate the usefulness of this methodology that innovates on previous trait preference approaches to address the expanding needs of plant breeding programs within smallholder contexts.

Abbreviations: CA, cluster analysis; FGD, focus group discussions; PAPRIKA, Potentially All Pairwise RanKings of all possible Alternatives; PC, principal component; PCA, principal component analysis.

1 | INTRODUCTION

Public sector breeding programs globally are shifting their focus to demand-led breeding approaches to increase their impact on development objectives, such as increased food security and decreased poverty through livelihoods (DLB, 2020; EiB, 2019). A process that starts with product design and develops breeding product profiles for the desired products necessitates capturing accurate and clear depictions of trait preferences from the prospective growers, processors, and consumers (end users) of the cultivars to be developed (Orr et al., 2021). More rigorous and systematic methods to capture trait preferences would enable breeding programs to make better informed and transparent decisions about the potential of new varieties (Ragot et al., 2018). This need for more rigorous methods in capturing trait preferences is acutely felt in public sector breeding programs in developing countries, where informal markets and seed systems create knowledge gaps that would underpin feedback loops from growers, processors, and consumers. In particular, breeding programs need methods that engage and elicit information from users along the value chain and help better define typologies (i.e., groupings based on trait preferences), and produce economic weights to guide breeding, for instance by guiding development of economic selection indexes.

This need for methodological innovation around trait preferences and for linking to typologies and economic weights builds on a history of methods used to elicit trait preferences. Previous approaches to understanding trait preferences have relied largely on direct ranking and choice experimentation. Direct rankings of varieties and traits have been used extensively in informing breeding decisions for several crops including beans (*Phaseolus vulgaris* L.) (Abeyasekera et al., 2002), maize (*Zea mays* L.) (Dao et al., 2015) and cassava (*Manihot esculenta* Crantz;) (Bentley et al., 2016; Teeken et al., 2021; Teeken et al., 2018). While scoring and ranking are simple, quick, and informative, they do not manage relativities (weightings) and may be difficult to translate to breeding values, or to representations of economic value or potential impact. Choice experiments (Louviere, 1988; Louviere & Woodworth, 1983) involve participants choosing their most preferred alternatives from a series of grouped options that relate to different hypothetical crop varieties and their end products. Choice experiments have been applied in preference studies for variety traits in several crops including cassava (Acheampong et al., 2018), bananas (*Musa* spp.) (Blazy et al., 2011), sorghum (*Sorghum bicolor* L.), teff (*Eragrostis tef* Zuccagni) (Asrat et al., 2010), sweet potatoes (*Ipomoea batatas* L.) (Naico & Lusk, 2010), and coffee (*Coffea arabica* L.) (Wale et al., 2005).

Although these studies and others have employed choice experiments to capture farmers' preferences, a bias could be created due to the burden of ranking several traits at a time;

Core Ideas

- Preference surveys can reflect economic importance of traits.
- Typologies of trait preferences give insights to understand heterogeneity of trait preferences.
- Typologies can guide breeding programs in exploring the needs of different market segments.

such biases may affect the quality of the choices when considering multiple traits at once (Nielsen & Amer, 2007). Another challenge in understanding trait preferences is the transferability of farmers' and other actors' descriptions of, and expressed preferences for, traits into quantitative terms that would allow them to be employed by plant breeders.

A new method aims to address these challenges within breeding. It incorporates a core survey, the 1000minds survey (1000minds, 2020), that employs conjoint analysis based on Potentially All Pairwise Rankings of all possible Alternatives (PAPRIKA) (Hansen & Ombler, 2008). This approach forces trait-by-trait trade-offs and adjusts which questions are asked based on responses to previous questions. Application of the 1000minds survey (1000minds, 2020) in combination with multivariate analyses yields typologies of traits and provides insights into segmentation of the population. The output from a 1000minds survey (1000minds, 2020) also informs derivation of economic values that can be employed by breeders in making selection decisions (Martin-Collado et al., 2015).

The 1000minds survey (1000minds, 2020) method has been applied in breeding applications of species including pasture plants (Smith & Fennessy, 2011; Smith & Fennessy, 2014), sheep (Byrne et al., 2012), and dairy cattle (Martin-Collado et al., 2015). These studies showed that preference survey tools can be applied in the derivation of economic values and provide insights into trait preference heterogeneity across value chains, guiding breeding programs to set accurate and impactful trait targets. However, they were not applied to inform public plant breeding programs in smallholder farmer contexts.

A salient example of trait heterogeneity across value chains is the case of cassava in Nigeria. Grown both as a subsistence and as a cash crop, cassava utilization and markets in Nigeria are shifting following national and regional policies to support diversification into new markets (AFDB, 2016). Most cassava produced is consumed fresh as boiled roots or transformed into multiple storable dry food products that are highly heterogenous across regions (Wossen et al., 2017). This diverse range of cassava products also influences interest in different traits and acceptance criteria, thus creating challenges for understanding trait preferences among breeders

(Acheampong, 2015; Bentley et al., 2016; Teeken et al., 2018; Wossen et al., 2017).

The objective of this study is to present the adaptation of the 1000minds survey (1000minds, 2020) to cassava breeding in a smallholder farmer setting. This context requires rethinking how to define and standardize units of traits and their economic values. Further, the tool must be adapted to capture data in remote settings using multiple languages. Focusing on Nigeria and gari, a fermented granular food product of cassava that accounts for about 74% of the marketed cassava in Nigeria (Sanni et al., 2007), we present typologies linked to value chain roles (i.e., farmers, processors, and marketers) and illustrate how using this approach can provide information on trait preferences to inform selection indices and product profile development for demand-driven cassava breeding programs.

2 | MATERIALS AND METHODS

2.1 | Sampling

We followed the sampling strategy of the Cassava Monitoring Survey that first stratified for the four geopolitical zones that contribute up to 80% of the total cassava production in Nigeria: north-central, south-east, south-south, and south-west (Wossen et al., 2017). Figure 1 is a map of the study area in Nigeria. Close to two-thirds (66%) of total production is in the southern part of the country, while about 30% is in the north-central and 4% in other parts of the north (FAO, 2021). Two states were randomly selected per zone. Across these eight states, six communities were purposefully selected as sites of a related research study to include a total of 50 participants. Ten additional communities were purposefully selected as major cassava-growing communities based on key informant interviews with Agricultural Development Program (ADP) officers who identified communities notable for cassava production and for seeking to add value to cassava by processing it into food products prior to sale. Participants for the focus group discussions (FGDs) were purposefully snowball sampled (Johnson, 2014), whereby leaders in each community were asked to refer potential FGD participants as those most familiar with the cassava and gari value chains. A list of individuals involved in the smallholder cassava value chain was compiled through the FGDs, which were stratified by value chain role. Survey participants were randomly selected proportionate to the strata of the sample frame. Nonfarmer value chain roles were predominantly represented by women, reflecting the observed gender composition of those positions. Farmers were mainly men.

2.2 | Presurvey focus group discussions

The study methods depended on community-driven information regarding local trait preferences and value chain mapping. Prior to the survey, FGDs were carried out in each of the 16 sampled communities. Three FGDs were held per community consisting of 20 smallholder value chain actors: female farmers (6), male farmers (6), and female processors and traders (gari sellers, fufu sellers, elubo sellers; 8). Women and men were met with separately. The FGDs focused on identifying value chain actors and understanding how they categorize traits with a focus on gari as a food product. Participants described the selected traits in terms of how they perceived and measured each trait. They also informed how the economic worth of a food product or fresh root would increase if a trait was improved. This feedback ensured that the trade-off units were presented in ways to which the survey respondents could relate and to avoid an abstract scoring system. These responses were then translated into trait levels to facilitate the comparison of trait improvement scenarios of equal economic value through the 1000minds survey (1000minds, 2020).

Responses also informed socio-demographic factors to consider in designing the survey. The FGDs also showed that many people were involved simultaneously in several value chain activities. Given this information, the survey was adapted to capture respondents' primary activity as well as their secondary activity relating to cassava. The primary activity was defined as the activity providing the most income and/or food to the household compared with other (secondary) activities. The survey questionnaire was pretested and revised accordingly.

2.3 | Survey implementation

The survey was carried out in February and March 2020. Survey participants were informed of the purpose of the study, and written consent was obtained from each participant before data were collected. Ethical approval to conduct the research was granted by the University of Otago Ethics Committee (19/174) and from the IITA Internal Review Board. The survey was administered via electronic tablets using the 1000minds and Alchemer software (Alchemer, 2020) (Figure 2). In addition to the 1000minds survey (1000minds, 2020), survey questions captured information on respondents' demographic information, planting material sources, and use of improved varieties. Participants were gathered in a central location in their communities where devices could be connected to the internet for the software to recalculate and present tradeoffs based on responses. A total of 792 respondents participated in the survey (310 men and 482 women). Of

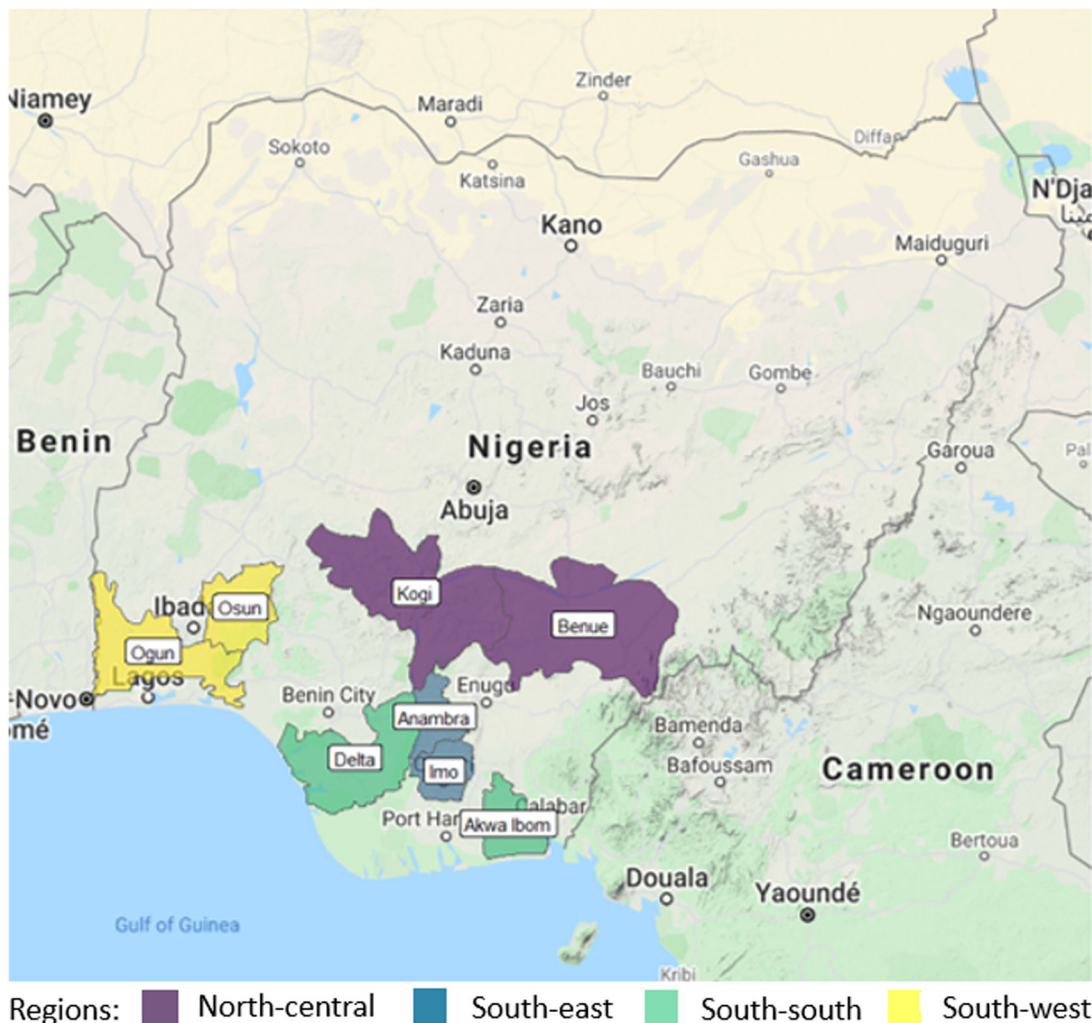


FIGURE 1 States and regions covered in the study. Map source: Google

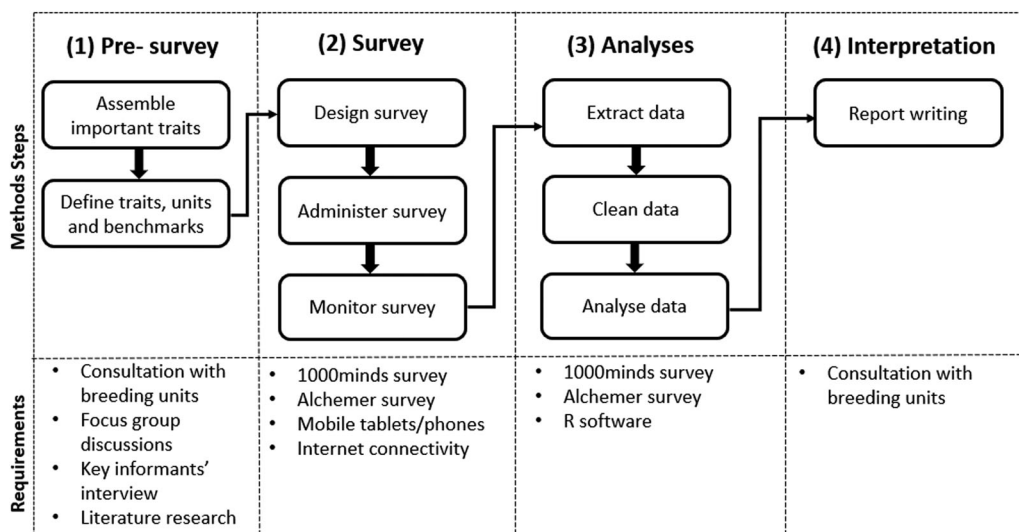


FIGURE 2 Research steps and methods used in the study

FIGURE 3 Example of a 1000minds survey traits trade-off question

QUESTION #4
Which of these 2 alternatives do you prefer?

1 less month to maturity of roots	4 more 100 kg bags of cassava per acre
THIS ONE	THIS ONE

THEY ARE EQUAL

the primary activities reported, respondents were 527 farmers, 173 processors, 60 gari sellers, 14 root traders, 11 fufu sellers, 4 stem multipliers, and 3 elubo sellers.

2.4 | Calculation of trait levels

Consultation with experts, outputs from ongoing projects (Bentley et al., 2016; Ndjouenkeu et al., 2021; Teeken et al., 2018 & 2021; Wossen et al., 2017), literature reviews (Awoyale et al., 2021), and FGD participants (Figure 2) formed the basis for identifying the traits to be included in the 1000minds survey (1000minds, 2020) (Table 1). This information further identified the parameters used to calculate trait levels presented to respondents in trade-off scenarios. Traits included agronomic and quality traits. Figure 3 shows an example of a 1000minds trade-off question. Hansen and Ombler (2008) provide a detailed description of the 1000minds survey (1000minds, 2020) algorithm. The traits and equivalence levels used to define alternatives in the 1000minds survey (1000minds, 2020) were considered with the intent to offer respondents alternative choices with similar average economic effect (i.e., economic equivalence). This means that all trait levels presented to survey participants were to be of similar average profit value. Economic equivalents were calculated as the economic effect of increment per unit change in each of the traits independently.

Calculation of similar average economic equivalence for all traits ensures that no individual trait is inadvertently excluded from preference choice through a trivial quantity being offered. Table 1 presents the units, valuation method, trait level change, the 1000minds survey (1000minds, 2020) wording, and the value of change in Nigerian naira (currency of Nigeria) per trait level change. Value for traits were considered independently of each other. The number of traits included in the survey were determined through consultation with breeding programs, FGDs, and survey testing. Eleven cassava traits, with the gari food product as focus case, were presented in the survey. This number was found to not overburden respondents with evaluating too many traits at a time, which could increase risks of respondents' fatigue and bias.

Having fewer traits also increases the power to accurately differentiate among trait preferences (Nielsen & Amer, 2007).

2.4.1 | Fresh root yield

Fresh root yield was utilized as a benchmark trait because yield is relatively easy to measure compared with other traits. However, many farmers did not calculate their total yield in weight units but made use of measures such as bags, ridges, baskets, tricycles, trucks, and lorries to estimate yield. Average yield was derived for all such measures identified in FGDs and converted to a standard unit of 4,000 kg (40 bags) acre^{-1} . This standard unit was then converted back to local measures when administering the survey. The price of cassava varies across Nigeria and across seasons. The price of a bag of cassava in Ibadan, Nigeria at the time of the survey was used as a base estimate of the total crop value per acre (100,000 naira ac^{-1} or 2,500 naira bag^{-1}). A reasonable increase in yield was set at 10% increase in yield per acre (10,000 naira or 4 bags). This economic equivalent of 10,000 naira was applied in the calculation of trait levels for all the other traits included in the survey.

2.4.2 | Maturity time

Focus group discussions identified that early maturity is important in all regions. Based on expert input, maturity at 6–9 mo was referred to as early and maturity at 12–18 mo as late maturity. For maturity, we used an average time to maturity of 9 mo after planting as reported by FGD participants; this was equivalent to 100,000 naira ac^{-1} . The 10,000 naira equivalent of improvement in maturity was then set to around 4 wk.

2.4.3 | In-ground storage

In-ground storability is important in cassava production as it is a crop that deteriorates quickly once harvested (Zainuddin

TABLE 1 Cassava traits evaluated, traits value, and interpretation

Trait	Unit expression	Trait level change	1000minds survey wording
Fresh root yield	number of 100-kg bags per acre	4 bags	4 more 100-kg bags of roots per acre
Maturity time	number of weeks to maturity	28 d	4 wk less to maturity of roots
In-ground storage	number of weeks of in-ground storage	35 d	5 more weeks of in-ground storage of roots
Root sizes	% of desired root sizes	25%	a quarter (25%) more roots are of desired sizes
Disease resistance	% resistance to diseases	10%	1 less plant in 10 is infected with disease (or 10% increase in resistance)
Dry matter content	% of gari yield	5%	5% increase in gari yield (1 more 100 kg bag of gari)
Root color	score of root color	1	1 more score in root color
Gari taste	score of gari taste	1	1 more score in taste
Gari texture	score of gari texture	1	1 more score in texture
Gari color	score of gari color	1	1 more score in color
Gari swelling	score of gari swelling	1	1 more score in swelling

et al., 2018). For in-ground storage, we set average in-ground storage time at 12 mo (Ingram & Humphries, 1972; Rickard & Coursey, 1981). The total crop value at 12 mo was set to 100,000 naira, with the 10,000 naira equivalent increase set to around 5 wk improvement of in-ground storage time.

2.4.4 | Root size

We derived a level for the increment in root size worth 10,000 naira (economic equivalent for 10% increment in fresh root yield). Focus group discussion results indicated that cassava buyers would be willing to pay up to 1,000 naira more per 100-kg bag as an upper limit for desired root sizes. We therefore set the price for change in root sizes at 1,000 naira. We then derived the amount of change in root sizes equivalent to 10,000 naira as a 25% change.

2.4.5 | Disease resistance

Most farmers reported that they could identify diseased crops using the following signs: drying of the stems, yellowing of the leaves, cobweb at the tip of the petioles, shrinking leaves, rotting roots, and lean (stunted) roots. However, disease is not considered common and would affect only a few stems when observed. Farmers would usually cut off and dispose of diseased stems. For disease resistance, we derived a 10% improvement valued at 10,000 naira for a total crop value of 100,000 naira ac^{-1} .

2.4.6 | Dry matter content (product yield)

Focus group participants described dry matter content in terms of gari/fufu yield from a certain amount of fresh root. Cassava varieties with high dry matter content are desired by farmers and processors because they have less water in them. High dry matter content here is defined as the weight of final product being about one third of fresh root weight. For dry matter content, the price of a bag of gari at the time of the survey was used to calculate the total cassava fresh root yield per acre. The 10,000 naira increment equivalent was calculated as 5% increment in gari yield from the same amount of fresh root.

2.4.7 | Food product quality traits

The food product quality traits presented more challenges in terms of quantifying economic equivalence. Focus group discussion results revealed that prices based on quality varied using informal scales. Given that cassava value chain actors in

rural communities tend to use informal scales to grade quality of products, a 1 to 5 scale was applied to the quality traits. Focus group discussion results indicated a premium of 1,000 bag⁻¹ for desired qualities (40,000 naira ac⁻¹), making the equivalency of 10,000 naira increase as one unit increase in scoring.

2.5 | Data analysis

Data analysis was carried out using R Software (R Core Team, 2018) following the survey analysis of the 1000minds survey (1000minds, 2020) output methodology described previously (Martin-Collado et al., 2015) using principal component analysis (PCA) and cluster analysis (CA). In this paper we adapt the Martin-Collado et al. (2015) methodology to cassava. The first step in the analysis was to determine the trait ranks for improvements calculated by the 1000minds survey (1000minds, 2020) algorithm. The result assigns each trait a ranking score of 1 to 11, highest to lowest, for each respondent. The relative ranking of each trait per respondent allows for exploration of differences among target end users and to identify potential market segmentations. The second step involved the use of the Kruskal-Wallis test (Kruskal & Wallis, 1952) to assess the differences in rankings and degree of variability of the 1000minds survey (1000minds, 2020) output for the 11 cassava traits. Subsequently, t-tests and the Kruskal-Wallis test (Kruskal & Wallis, 1952) were used to explore differences in trait rankings in participant subgroups (e.g., value chain role and geography).

Given the heterogeneity of the trait preferences, the dimensionality of the data was reduced to find meaningful patterns using PCA and CA and to detect hidden patterns of relationships in the data (Jackson, 1991; Jolliffe & Cadima, 2016). A multivariate analysis approach that combines PCA and CA using hierarchical clustering on principal components in the FactoMineR (Lê et al., 2008) package in R software was used to determine cluster groups (i.e., typologies). The decision on the relevant number of principal components is context-specific and depends on the application (Hartmann et al., 2018). We explored three methods to guide the final number of principal components in the study. The methods were: (1A) visual examination of the scree plot which is a line plot of the eigenvalues of principal components in an analysis, (2B) Variance of the data explained, and (3C) The Kaiser rule. Each method suggested a different number of principal components (PCs) ranging from 4–7 PCs. Five PCs were selected after investigating the PCA outputs in relation to the study context (i.e., how they can be applied in breeding programs). Five PCs showed clear variations in the data according to cassava trait preferences.

Hierarchical clustering on the PC was performed using Ward's criterion on the selected principal components. An

initial partitioning of respondents' trait preferences was performed by cutting the hierarchical tree. Each hierarchy level of clustering was investigated until a reasonable number of splits were obtained that reflect meaningful distribution of traits and respondents. K-means clustering was used to improve the initial partition obtained from hierarchical clustering and to determine the final number of clusters (Kassambara, 2017). Differences in trait rankings between the clusters were tested using ANOVA. The Chi-square test was used to test whether categorical variables on social demographic information or value chain roles weighted the attributes of the three identified typologies different. The null hypothesis was that the expected weight of the attributes was the same for each typology for all categorical variables. Where relevant, relationships were considered significant at $p < .05$.

3 | RESULTS

3.1 | Trait preference rankings

Following on the Martin-Collado et al. (2015) approach, the first output was the overall ranking of trait preferences for all 792 respondents provided by the 1000minds software. Overall ranking gives a meta-level analysis of trait preferences across all respondents, irrespective of value chain role or social demographic information. The next step was to test for differences between traits using the Kruskal-Wallis test (Kruskal & Wallis, 1952) (Figure 4). Fresh root yield was the most preferred trait for improvement, which was followed by in-ground storage time, while the least preferred trait for improvement was disease resistance. Differences in the relative importance of certain traits across value chain actors and geographies indicated heterogeneous preferences among respondents (unpublished data, 2019). Farmers ranked fresh root yield and in-ground storage time as their most preferred traits and ranked disease resistance as their least. Processors ranked fresh root yield and gari color as their most preferred traits while disease resistance was their least preferred trait for improvement. Gari sellers ranked gari taste and gari color as their most preferred traits while disease resistance was ranked as their least important trait for improvement. The south-south region had the highest rank for fresh root yield, whereas the south-east region had the highest rank for gari color, and the north-central region had the highest rank for root color.

3.2 | Principal component analysis and cluster analysis of population preferences for trait improvements

Principal component and cluster analysis of the trait ranking data underpins the next output of the Martin-Collado et al.

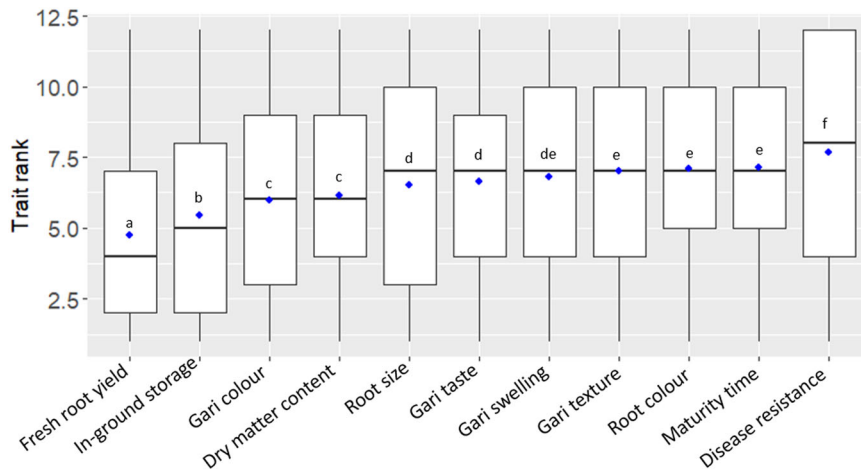


FIGURE 4 Ranking of cassava trait preferences for all respondents. Boxplots represent mean (blue dots), median (solid lines), first and third quartiles (contained in the boxes), and outliers (open points) of the distribution of the ranks of each trait improvement. Order of preferences for trait improvements is from most preferred (left) to least preferred (right). Different letters are outputs of the Kruskal-Wallis test and indicate statistical significance (P -value < .05) between the trait rankings

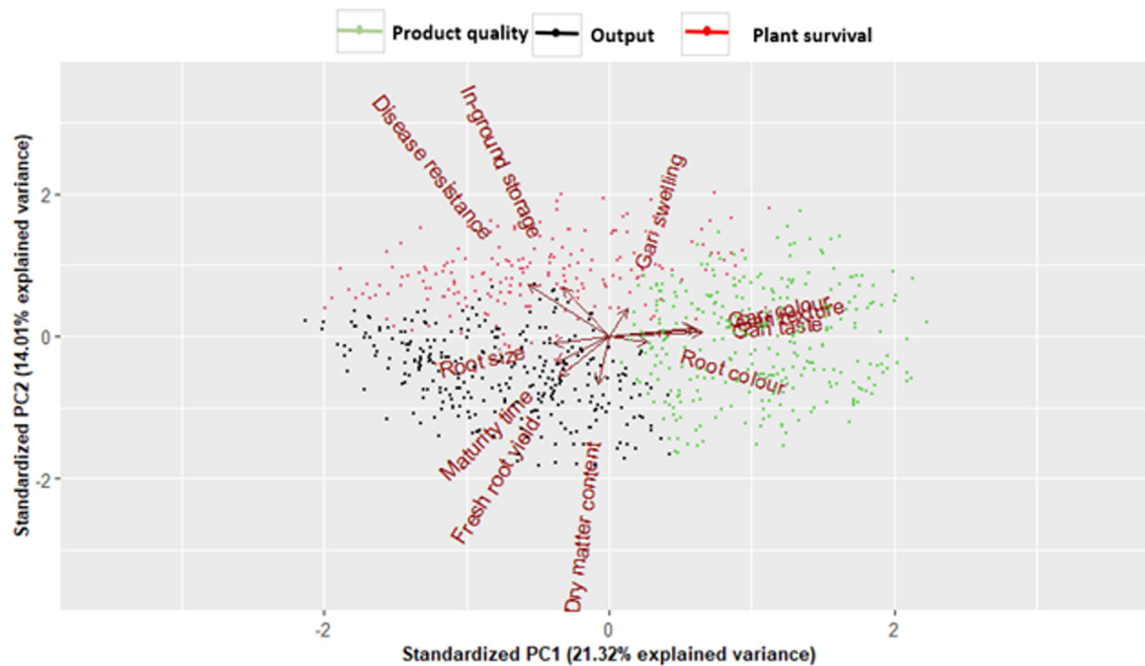


FIGURE 5 Principal components analysis of trait preference ranks comparing principal component 1 and 2. Each dot is a unique identifier of each respondent. Traits that are further apart in the axis represent the traits with the highest variation (length and direction of arrow) among respondents within the principal components, indicating differences in trait preferences among respondents

(2015) approach, which is the trait typologies. The first two PCs of cassava trait preferences for the study population are presented in Figure 5. These PCs accounted for >35% of total variation among respondents. In a large dataset with large variation in preferences such as this one, a PC accounting for 35% variation is enough to give a useful visual representation of the patterns of preferences. The analysis of five PCs generated three clusters among the respondents (Table 2). The three clusters represent typologies and have been named according to their pattern of preferences: product quality group ($n = 286$), output group ($n = 237$), and plant survival group ($n = 269$). In this respect, the traits that drive most of the variation in each group have significantly higher preference ranks

(lower rank means higher preference) relative to the ranks for the same trait in other groups. This was especially evident for gari color (mean of 3.7 compared with an overall mean of 6.5) in the product quality group, fresh root yield (2.9 and 4.8) in the output group, and disease resistance (3.4 and 7.7) in the survival group. The product quality group gave significantly higher preference for gari color, gari taste, gari texture, and root color. The output group of respondents gave significantly higher preferences for fresh root yield, dry matter content, and root size compared with other groups. This group also gave significantly higher preference rank for maturity time compared with the product quality group. However, this group did not differ significantly from the plant survival group in

TABLE 2 Average trait preference ranks by typologies

Traits	Overall mean	Typologies		
		Product quality	Output	Plant survival
Fresh root yield	4.8	6.6c	2.9a	4.5b
In-ground storage	5.4	6.2b	5.5b	4.4a
Gari color	6.0	3.7a	7.0b	7.8c
Dry matter content	6.2	6.7b	5.0a	6.6b
Gari taste	6.5	3.9a	8.0b	8.0b
Root size	6.7	8.3c	5.3a	6.1b
Gari swelling	6.8	6.4a	6.7ab	7.2b
Gari texture	7.0	4.5a	7.9b	8.9c
Root color	7.1	6.1a	7.5b	7.8b
Maturity time	7.1	8.8b	5.9a	6.5a
Disease resistance	7.7	9.3b	10.6c	3.4a

Note. Lower rank means the trait is more preferred; different letters indicate statistical significance (P -value < .05).

preference of maturity time. The plant survival group of respondents gave significantly higher trait preferences for in-ground storage time and disease resistance traits compared with other groups. This group also gave significantly higher preference for maturity time compared with the product quality group.

3.3 | Relationships for typologies with demographic factors

The last output of the Martin-Collado et al. (2015) approach centers around relating the typologies to demographic factors. The typologies were tested with demographic groups to assess the factors that might explain the differences between groups. The Chi-square test was used to compare frequency of distributions by gender, main value chain activity (occupation), age, regions, use of improved varieties, clientele, and source of planting material (Table 3). This analysis found differences between men and women in distribution among the typologies with more women represented in the product quality group than men. This difference was also observed with processors and gari sellers, mostly represented in the product quality group. However, women consisted of 94% of processors and 83% of sellers, which may have accounted for some of the similarities between gender and main value chain activity reporting.

We also found differences in the distribution of regions across the typologies with more of the respondents in the south-east region belonging to the product quality group and the south-west respondents in the plant survival group. Furthermore, respondents who made use of improved varieties were more highly represented in the plant survival group. We also found younger respondents (18–35 yr) more represented in the product quality group. In further analy-

sis of respondents that were primarily farmers, the south-west and north-central regions were more represented in the plant survival group while the south-east region was more represented in the product quality group. The south-south region had relatively uniform distribution of respondents across the typologies. No significant differences were observed in the distribution of respondents across typologies according to where planting materials were sourced. This may be due to few commercial stem markets in the selected study sites.

4 | DISCUSSION

4.1 | Piloting 1000minds survey as a new approach for profiling trait preferences

We present the adaptation of a methodology previously applied in dairy cattle (Martin-Collado et al., 2015) to cassava breeding. This methodology is suited for informal markets, such as the case of the cassava value chain of gari in Nigeria, where profit equations and bio-economic models may not be practical. The general practice of evaluating farmers' preferences in plant breeding such as scoring (Bentley et al., 2016; Ndjouenkeu et al., 2021; Teeken et al., 2021; Teeken et al., 2018) and choice experiments (Acheampong et al., 2018; Asrat et al., 2010; Blazy et al., 2011) are suitable when a quick assessment for understanding preferences is needed. However, they can be limited when breeding programs need to understand markets and tradeoffs or need to decide which plants to advance.

We reflect on several points that illustrate how this presents a powerful new approach for breeding programs to profile trait preferences. Firstly, previous methods of eliciting farmers' preferences in plant breeding lack trait cutoff levels for

TABLE 3 Frequencies of factors contributing to the differences between typologies. Differences between the participants in the different groups are tested for using the chi-square test

	N	Typologies			p-value
		Product quality	Output	Plant survival	
Expected weights	792	36	30	34	
A priori group					
Gender					<.01
Female	482	40	28	32	
Male	310	30	32	38	
Main value chain activity					<.02
Farmers (root producers)	531	32	32	36	
Gari sellers	60	50	27	23	
Processors	173	42	24	34	
Others (elubo, fufu, and root traders)	28	32	32	36	
Clientele					<.01
Local buyers and consumers	215	40	30	30	
Processors	193	26	36	38	
Retailers	234	43	22	35	
Wholesalers	106	30	36	34	
Others	23	30	36	36	
Age (yr)					<.01
18–35	165	44	30	26	
36–50	281	35	28	37	
51–65	249	32	29	39	
>65	97	36	40	24	
Regions					<.01
North-central	199	30	32	38	
South-east	202	49	26	26	
South-south	197	34	35	31	
South-west	194	32	27	41	
Users of improved varieties (Farmers only)	464	33	29	38	<.03
Source of planting material					.27
Stem multipliers	16	31	31	38	
Local markets	39	33	31	36	
Research institutes/Government/NGOs	86	34	31	35	
Neighbors	162	34	31	35	
Recycled	412	34	31	35	
Others	30	33	30	37	

comparison, which could result in biases when respondents are not considering the amount and unit of each trait being ranked. This is particularly common for output traits such as fresh root yield that are typically ranked as the most important trait for improvement (Teeken et al., 2018). Consistent high ranking of fresh root yield may be due to a lack of measurement unit for comparing fresh root yield and other traits and because traits are often not consciously compared in comparative scenarios with responding users because trait rankings are often based on the frequencies with which users men-

tion traits. This can result in users assuming that, for example, increased yield is automatically accompanied by increases in quality traits that are present in the varieties they currently prefer. Our results show that while fresh root yield is an important trait, certain traits may be preferred over increased yield when farmers are presented with equivalent economic incremental trait improvements of approximately equal economic value, as undertaken in our approach.

Secondly, the use of a trait-by-trait comparison rather than direct scoring is a simpler survey method because it allows

for more accurate prioritization of multiple traits with reduced risks of a respondent bias (Nielsen & Amer, 2007).

Thirdly, while this methodology allows for prioritization of a large number of traits, including only 11 traits in the survey ensured that respondents were not presented with complex decision-making processes that could also lead to biases from choice overload. This would increase the risks of poor selection decisions and loss of genetic progress (Martin-Collado et al., 2018). Increasing the number of traits to be evaluated by farmers also reduces statistical power of estimation of the relative importance of traits (Nielsen & Amer, 2007).

Fourthly, the ability to derive economic values presents the opportunity to consider economic gains in the development of breeding objectives, making this a more complete method compared with other approaches in understanding farmers' preferences.

Finally, the nature of the question is also a critical part of our methods. Respondents were not just asked to select their most preferred trait but instead were asked to select their most preferred trait for improvement. This is useful in deciding whether to continue to improve on a trait or not.

4.2 | Reflection on adaption of the 1000minds survey for use with smallholder Nigerian cassava farmers

Implementing this approach necessitated data collection in a situation where there were numerous practical challenges, and application to a food security crop has necessitated innovation around four key aspects building on previous experience of studies on livestock breeding: data capture; trait selection; trait level and unit definition; and representativeness.

4.2.1 | Data capture

A major adaptation of the survey deployment was to program the instrument onto tablets that enumerators could use to input verbal data provided by respondents. This contrasts with the common approach of using the 1000minds survey (1000minds, 2020) as an online tool, self-administered by respondents (Martin-Collado et al., 2015). Self-administration of the survey was not possible due to variable levels of internet access, smartphone and computer ownership, and literacy amongst participants in this research. Hence, these factors necessitated training of enumerators who were able to speak the different languages of the study region to ask the questions and enter responses from participants in group settings from central locations. Sampled respondents were requested to convene simultaneously in a location with data connectivity and of a reasonable distance from their communities. While in general this adaptation worked well, there

was a loss of data in some instances due to lack of data coverage in some regions, and respondents were asked to spend additional time in travel to participate. This study provides a precedent for the use of 1000minds survey (1000minds, 2020) in similar settings, where such limitations need to be considered.

4.2.2 | Trait selection

When applied to commercial commodities with defined markets and standards, 1000minds survey (1000minds, 2020) trait selection follows general industry standards, such as for sheep (Byrne et al., 2012), dairy cattle (Martin-Collado et al., 2015), and forage grasses (Smith & Fennessy, 2011; Smith & Fennessy, 2014). In the absence of industry standards, the 11 traits used in this study were identified by combining consultation with experts, outputs from ongoing projects (Bentley et al., 2016; Ndjouenkeu et al., 2021; Teeken et al., 2018 & 2021; Wossen et al., 2017), literature reviews (Awoyale et al., 2021), and the FGDs in the communities. This ensured a systematic approach that took into consideration different disciplinary perspectives (i.e., breeding, social science and gender research, agronomy, and economics) and research approaches (i.e., qualitative and quantitative social science research methods and field trials) with the expectation that these would be more inclusive and representative of the diversity of needs and users of cassava in Nigeria.

The intent, however, is difficult given the relatively low number of traits that ideally should be included in this approach and the level of trait definition that is possible. Some quality traits are still not well characterized including gari taste, texture, and swelling. While these characteristics have been identified previously to be important among cassava value chain actors (Ndjouenkeu et al., 2021; Teeken et al., 2018), they are variety dependent (Akely et al., 2020; Komolafe & Arawande, 2010; Sanoussi et al., 2015), related to measurable food science parameters (Awoyale et al., 2021; Teeken et al., 2021), and knowledge of their heritability, genetic architecture, or phenotyping is limited (Dufour et al., 2021). Another major challenge was the consolidation of several biotic stresses into one trait under disease resistance, which likely confounds how respondents understood and answered this question. This potentially raises questions around how it was ranked in the results presented. This potentially explains the large variability in the degree of priority given to disease resistance shown in Figure 4. An alternative explanation may be that cassava farmers in Nigeria do not perceive disease severity as a major issue (as per the FGDs indicating low disease pressures), or attribute disease symptoms to other nonbiological physical causes, hence the low rank for disease resistance despite breeders' recognition of its impact on yield and quality (Patil et al., 2015).

4.2.3 | Trait level and unit definition

Much like trait definition, unit definition and relevant increments around variation in previous applications of 1000minds survey (1000minds, 2020) for agriculture have been in settings with well-defined standards. Focus groups with a subset of socially diverse respondents provided the input to enable definition of appropriate units, trait levels, and increments. At the analysis stage, it was clear that some trait units, levels, and increments would need modification. Examples include the highly variable units of yield across sites, interpretation of dry matter content as product yield, and, most importantly, disease resistance. For disease resistance, it may be necessary to apply a threshold rather than increment, as the effects of diseases and pests may be tolerated to a certain level before being rejected for susceptibility. As such the increase in value may not be linear for all traits.

4.2.4 | Representativeness

In order to segment analysis along the value chain, sampling must account for the smallholder setting in food security crops where respondents often participate in multiple activities. This study had an overwhelming majority of respondents who identified as producers, and many played dual roles as producers and processors due mainly to the dominant village-level processing of cassava (Onyenwoke & Simonyan, 2014; Teeken et al., 2021). While we aimed to have a more balanced representation of the value chains, it is not uncommon to have these types of unbalanced representations due to the nature of the cassava value chain in Nigeria, especially in rural communities. It is difficult to achieve an equal representation and parse out the different value chain actors as a majority of the participants identify as farmers and many would fit into multiple other value chain roles. This might not be a challenge for other locations where value chain roles are clearly defined. Another reason for the unequal weighting of responses to compare across value chain roles was because population lists and sample frames are compiled through key informant interviews and were mainly informal.

A methodological adjustment would be to segment the survey to pose different sets of trade-offs and traits for groups of actors along the value chain, focusing on production traits for producers, processing traits for processors, and market value traits for traders, for example. Also, it should be mentioned that our survey focused on cassava in relation to gari, but many of the cassava users in this study also process other products such as wet fufu that are also sold or, importantly, used for household consumption as its processing is less strenuous. This dual purpose has to be taken into account in cassava breeding. Ndjouenkeu et al. (2021) show that the preference

for multi-purpose cassava cultivars is among the most important user criteria.

4.3 | Research results on typologies

Our study illustrates three typologies of preferences for cassava traits in Nigeria. These typologies are similar to those found when using similar methods in the livestock industry (Martin-Collado et al., 2015) and ongoing work with sweet potato in Uganda (unpublished data, 2019). Gari swelling and maturity time are two traits that do not seem to be driving variability of preferences in the dataset as indicated by similar letters (a) across two clusters (i.e., no statistical significance). The traits driving the most variability would be prioritized as driving market segments and also in the development of selection indexes.

4.3.1 | Output group

This group represents respondents focused on higher yields and other output traits and is driven by productivity of the roots rather than other aspects of cassava such as food product quality traits. Past breeding efforts have focused on improving output traits such as fresh root yield which has long been recognized as critical (Abdoulaye et al., 2014). The findings from this study indicate that when presented with a trade-off, increase in yield can be forgone for improvement of other traits. It has been emphasized that while improved crop cultivars may be high yielding, they may not be adopted unless they possess other specific traits that farmers consider important (Wale & Mburu, 2006). The key here is to balance quality, survival, and output traits in the final cultivar testing processes, while also keeping in mind that smallholders typically cultivate more than one type of cultivar (Iragaba et al., 2020).

4.3.2 | Product quality group

Cassava is a highly processed crop in Nigeria. Therefore, it is expected that preference for product quality would emerge as a major typology. More women were represented in this group as processors and marketers, as well as gari sellers and processors. This is in line with women being highly represented among processors and marketers (Curran et al., 2009; Ndjouenkeu et al., 2021; Teeken et al., 2021) and that women mention cooking and processing traits more often than men (Teeken et al., 2018). Youth (18–35 yr) were also more represented in this group, in line with prior studies emphasizing youth being responsible for gari quality (Bentley et al., 2016). Combining the demonstrated importance of quality traits, with documented varietal influence on gari quality (Akely

et al., 2020; Awoyale et al., 2021; Sanoussi et al., 2015), emphasizes the need for increased attention to these traits in cassava breeding programs.

4.3.3 | Plant survival group

Disease resistance traits may not always be indicated as important by users (Ragot et al., 2018). Diseases reduce yield and often quality, so disease resistance itself may not be important to the farmer but may be embedded in the importance of yield and/or quality. This study does highlight a group of respondents who prioritize disease and storage in line with prior studies (Acheampong et al., 2018) and whose perspective may be lost in other methodologies. Prolonged in-ground storage is particularly important in areas with a lengthy dry season during which farmers only harvest a few plants at a time leaving others stored in the field for later harvest (Hillocks et al., 1996). Long-storing cultivars are also grown for food security (Tumuhimbise et al., 2012). Kanju et al. (2019) demonstrated the possibility of breeding new cassava varieties that combine disease resistance (tolerance to cassava brown streak disease) and in-ground storability, emphasizing the need to focus on these traits in breeding priorities.

4.4 | Adding value to cassava breeding in Nigeria

Cassava breeding programs in Nigeria are shifting towards approaches based on product profiles, which requires that breeding programs develop clear objectives in terms of the type of cultivar (i.e., breeding ‘product’) (Cobb et al., 2019). A demand-led ‘stage gate’ breeding program starts with defining its customers (i.e., users) and the country–crop context. With the diversity of cassava uses and users in Nigeria, there is a need to better understand relationships between the traits that are preferred and demographics, location, and value chain roles. Typologies, as presented in this paper, can inform market segmentation and more detailed customer profiling to target social impact, product profiling, and by supporting development of economic selection indices that represent breeding objectives based on the different typologies. This is in line with Orr et al. (2018) and Ragot et al. (2018) who argue that while agronomic constraints are important, socioeconomic and demographic variability are critical factors in adoption. This approach also lends to additional analysis that promises a new frontier for cassava breeding. They can be applied in generating quantitative economic estimates of traits (Balogun et al., 2021) to model economic gains in the development of breeding objectives or reveal relationships between traits, and they can be employed in further analysis to reveal typologies with social identities, food security, and poverty

status (Teeken et al., 2021b). This represents an advancement in the methodology toolset for trait prioritization approaches in crop improvement and efforts to target smallholder value chain actors.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in the Harvard dataverse at <https://doi.org/10.7910/DVN/0KKXY9>

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AUTHOR CONTRIBUTIONS

Ireti Balogun: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Resources; Validation; Visualization; Writing – original draft; Writing – review & editing. Elisabeth Garner: Data curation; Formal analysis; Resources; Validation; Writing – review & editing. Peter Amer: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Resources; Supervision; Validation; Writing – review & editing. Peter Fennessy: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Resources; Supervision; Validation; Visualization; Writing – review & editing. Béla Teeken: Conceptualization; Investigation; Methodology; Resources; Writing – review & editing. Olamide Deborah Olaosebikan: Conceptualization; Investigation; Methodology; Resources; Writing – review & editing. Bello Abolore: Conceptualization; Investigation; Methodology; Resources; Writing – review & editing. Tessy Madu: Conceptualization; Investigation; Methodology; Resources; Writing – review & editing. Benjamin Okoye: Conceptualization; Investigation; Methodology; Resources; Writing – review & editing. Bruno Santos: Conceptualization; Formal analysis; Methodology; Resources; Validation; Visualization; Writing – review & editing. Tim Byrne: Conceptualization; Formal analysis; Methodology; Resources; Validation; Visualization; Writing – review & editing. Daniel Martin-Collado: Formal analysis; Methodology; Resources; Validation; Visualization;

Writing – review & editing. Chiedozi Egesi: Conceptualization; Data curation; Funding acquisition; Methodology; Project administration; Resources; Validation; Writing – review & editing. Peter Arthur Kulakow: Conceptualization; Data curation; Funding acquisition; Methodology; Project administration; Resources; Validation; Writing – review & editing. Hale Ann Tufan: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Supervision; Validation; Writing – review & editing.

CONFLICT OF INTEREST

The authors declare no conflict of interest in this work.

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