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Participatory Evaluation of Sorghum Processing and Sensory Attributes in Mali: Methodology for Improving Food Security Outcomes from Variety Development Efforts

Krista Isaacs [1,*], Marjolein Smit [2], Bakary Samaké [3], Fred Rattunde [4], Fatimata Cissé [5], Abdoulaye Diallo [6], Mamourou Sidibe [7] and Eva Weltzien [4]

1 Department of Plant, Soil, and Microbial Sciences, Michigan State University, East Lansing, MI 48824, USA
2 Independent Researcher, 1290 Geneva, Switzerland
3 Center for Biodiversity and Agrosilvopastoral Initiatives, Bougouni BP 68, Mali
4 Agronomy Department, University of Wisconsin-Madison, Madison, WI 53706, USA
5 Laboratoire de Technologie Alimentaire, Institut d'Economie Rurale, Bamako BP 258, Mali
6 Programme Sorgho, Institut d'Economie Rurale, Bamako BP 258, Mali
7 International Crops Research Institute for the Semi-Arid Tropics, Bamako 320, Mali
* Correspondence: isaacskr@msu.edu

Abstract: A requirement for the successful development of new sorghum varieties in Mali is effective evaluation of grain qualities, since sorghum is a staple food crop on which farmers rely for food security. The diversity of grain quality and social aspects that determine varietal acceptability for processing and cooking, however, make this a challenging task. As the processors of sorghum grain in households, women's knowledge of grain quality traits can contribute to this work. Our objective is to understand opportunities to use grain quality traits to identify experimental varieties that may contribute to food security. Culinary evaluations were conducted in nine villages across two sorghum production zones. Three teams of women, one per replicate, processed, cooked and evaluated five test varieties in each village. Sensory evaluations were conducted by 25 taste testers per village. The major varietal differences observed included the decortication losses, women's appreciation for ease of processing, and consistency of the prepared food. The participatory evaluation of the quality testing results led to the development of the concept of 'food yield'. Discussion of these results focuses on designing cost-efficient grain and food quality evaluations that rely on women's expertise as processors and strengthens their role in the variety development process.

Keywords: sorghum; traits; culinary tests; organoleptic; processing; gender; participatory plant breeding

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1. Introduction

Sorghum, an indigenous staple cereal in West Africa, is grown first and foremost for food [1]. The ability of sorghum to reliably produce in unpredictable and stressful conditions contributes to its important role in West African farming systems [1]. Not only is demand for sorghum in West Africa primarily driven by home consumption [2], but food security considerations are paramount, as indicated by the criteria used by farmers in choosing which varieties to cultivate [3]. This is true for nearly all West African farmers, as there are basically no large-scale, primarily market-oriented farmers. West African sorghum breeding programs seek to develop new varieties for smallholder farmers that offer improved agronomic characteristics, such as higher yield, stover quality and yield stability through disease and pest resistances [1]. The grain qualities of these new varieties for home processing and consumption, although they have received some attention, have been the target of fewer systematic efforts. Adoption rates of improved varieties of sorghum in West Africa were reported to be low due to problems with grain quality for local food use [4].

Participatory plant breeding (PPB) offers an approach to more effectively develop varieties that are adapted to the farmers' environments and that respond to their needs and criteria [5–7]. Evidence from Mali indicates that intensity of participation in the testing of different varieties increased adoption rates in farmers' fields [8]. In-depth participatory engagement to understand how cultural, social and traditional knowledge influences trait preferences can help guide the breeding of new varieties [9].

Several assessments of the acceptability of various sorghum food products in laboratory settings have been published. For example, sensory evaluations conducted by employees or students have been reported from studies in Niger [10,11] and South Africa [12]. Experimental designs and data collection tools are needed to identify quality traits of importance and increase the gender-responsivity of breeding programs [13].

Culinary testing of experimental sorghum varieties is conducted annually as part of participatory variety development activities in Mali [14]. These culinary tests involve evaluating numerous varieties for grain aspects prior to processing, the relative ease and yields of various grain processing activities and organoleptic qualities of the cooked food product [15]. However, to date, no detailed description of the methodology used for these culinary tests has been published, nor have assessments of the effectiveness of discriminating among varieties for the different observed traits.

The objectives of this study are to i. describe, in detail, the methodology used for the participatory culinary testing of sorghum varieties in Mali; ii. assess the feasibility of effectively discriminating among varieties for the various observed traits; and iii. understand trait relationships pertinent for designing procedures to develop varieties that are adoptable by smallholder farmers and contribute to their food security.

2. Materials and Methods

The culinary tests conducted annually by International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), the Institut d'Economie Rurale (IER), and collaborating farmer organizations, typically involved each village choosing four varieties out of that year's participatory on-farm sorghum variety trials for post-harvest evaluation [14]. One common check variety from those trials was included in all culinary tests as the fifth test entry to facilitate comparisons between trials in different villages. The culinary tests in 2006, in contrast, involved testing the same five varieties in every village in order to better understand the repeatability and effectiveness of the various trait observations for discrimination among varieties for post-harvest quality. We, therefore, use the 2006 culinary tests for this paper.

Sorghum is used to prepare various dishes in Mali, including porridges, pastes and beverages. The initial culinary testing, starting in 2003, evaluated the acceptability of various dishes based on the participants' interests. Testing in subsequent years focused on evaluating only tô, a thick paste that is the most common preparation for meals. This decision was based on both the importance of this dish and the greater complexity of factors determining its acceptability. These factors include taste, color, consistency, whether it sticks too much to fingers and teeth and the ability to maintain a consistent texture as leftover food the following morning.

2.1. Study Area and Participants

The culinary tests took place in two regions of Southern Mali, the zone of Mandé and the zone of Dioila. Both areas have similar agroecological conditions, with 4–5 months of rainfall (primarily June through October) and annual precipitation means between 700 and 1000 mm. However, there are great differences between the regions in terms of market orientation, mechanization and organizational development. Dioila is one of the longest-established cotton production areas of Mali, and has higher levels of market orientation mechanisms and use of external inputs than the zone of Mandé, where cotton is less important as a crop and farmers have less access to loans and equipment. Sorghum is the main staple crop in both zones, but maize, millet and rice are also cultivated.

The culinary tests were organized in villages where ICRISAT and IER conducted PPB trials. The varieties developed through the plant breeding programs at ICRISAT and IER were tested on farmer fields in different villages and evaluated in the field by men and women for their agronomic characteristics. Each year, 32 varieties were evaluated. In normal years, farmers identified key varieties for agronomic qualities and these varieties were tested for culinary attributes.

For this study, we used results from the culinary tests conducted in 2006 in 4 villages in Mandé and 5 villages in Dioila that collaborated in participatory sorghum variety evaluations. A total of 225 farmers participated, of which 101 were women and 124 were men (Table 1).

Table 1. The villages, number of participants and sorghum varieties used in the preparation and sensory evaluations of tô in the Diolia and Mandé zones of Mali in 2006.

Zone and Village		Participants		Local Variety	Experimental Varieties Tested in All Villages
		Women	Men		
Mandé	Kenièro	15	10	Segetana	Kalaban (00 KO-F5DT-19) Guana (GP00*IS15401_K4) Weli (GPN01 S01 267-9-1) Tieblé (CSM335)
	Teneya	10	15	Niobleni	
	Siranikoro	6	19	Keleyabomousso	
	Siby	15	10	Troukani	
Dioila	Kafla	10	15	Niobleni	
	Magnambougou	10	15	Bandokablen	
	Tonga	12	13	Niobleni	
	Seyla	12	13	Segetana	
	Seribila	11	14	Kassorokoro	
225 Total Participants		101	124		

2.2. Sorghum Varieties

A total of 3 experimental varieties, as well as the long-term check variety (Tieble), were chosen from the 32 varieties tested in participatory field evaluations for culinary testing in 2006 (Table 1). These varieties were chosen to represent the range of plant types and genetic (racial) backgrounds (Table 2) among the experimental varieties under test, and to exhibit desirable field performance. In addition, each village chose one of its own local cultivars (Local) to compare with the experimental varieties.

Table 2. Pedigree, racial genetic background, plant type and yield expectations of sorghum varieties used in the culinary tests in 2006.

Name	Pedigree	Race	Panicle Type	Plant Pigmentation	Plant Height	Mean Yield in Trial Villages (2005 and 2006) (t/ha)
Kalaban	00 KO-F5DT-19	Caudatum	semi-compact	Tan	intermediate	1.7 t/ha
Guana	GP00*IS15401_K4	Interracial	semi-compact	Pigmented	tall	1.4 t/ha
Weli	GPN01 S01 267-9-1	Interracial	semi-lax	Pigmented	intermediate	1.5 t/ha
Tieble	CSM335	Guinea	lax	Pigmented	tall	1.4 t/ha
Local *	Local Varieties	Guinea	lax	Pigmented	tall	1.3 t/ha

* Local indicates the average of the local cultivars chosen by each village to compare with the experimental varieties.

2.3. Team

The field team conducting the culinary trials consisted of one supervisor from ICRISAT, two local interviewers from the farmer organization, two staff members from IER sorghum program and one person from the Laboratoire de Techonologie Alimentaire (LTA) at IER. All interviewers for this study had participated in data collection in the culinary tests from years prior, and, therefore, had adequate experience.

Female farmers, as the sole processors of sorghum at the household level, evaluated the grain aspects and characteristics during the milling and preparation processes. These women were from households that conducted the on-farm variety trials where the grain for testing was produced. The evaluation of the quality of the finished product, tô, in contrast, was carried out by both women and men.

2.4. Culinary Test Design

Grain from plots of each test variety from the villages' on-farm variety trials was used for the three replicates of the culinary tests, with grain from different plots used for each replicate. In cases of shortages of grains for a certain variety, grain from the fourth plot was added to make up the three samples of 1500 g for each replicate. The varieties were randomly assigned to 5 different-colored bowls, separately and randomly for each replication, such that no variety was associated with a specific bowl color.

Women conducted all stages of the culinary test and evaluated the results, while both men and women evaluated the final cooked product, tô, for organoleptic qualities. An earlier inquiry in the region showed that the most important quality criteria of tô, listed in order of importance, were taste, color, texture and overnight keeping quality, or conservation. Each replication was evaluated by one group of two to three women from one of the households that conducted the field experiment. Each group of women worked with one female observer, who noted the women's observations and scores, as well as the weights of samples. For most observations, the women provided a score of 1 (problematic), 2 (good) or 3 (very good). During the process and after each step, qualitative observations made by the female processors were noted by the interviewer. In addition, quantitative observations were made, such as weight of the decorticated grains, the weight of tô, the duration of decortication, the amount of potassium used and the cooking time.

2.5. Stages of Evaluation

There were 6 stages of evaluation in the culinary test, and at each stage, the processors evaluated multiple characteristics (Appendix A). These stages included grain characteristics, decortication, factors related to milling the grain into flour, the preparation of tô, sensory evaluations and, finally, an evaluation of how well the leftover tô conserved the next day.

First, women in each group evaluated the grains for external characteristics such as color, grain size, presence of glumes, broken grains, smut and insect damage. Corresponding laboratory tests were conducted to compare these evaluations with lab-based measurements.

Second, the grains were placed in a wooden mortar and decorticated with a pestle. Grain decortication refers to the removal of the outer envelope or encasing of the seed. Water was added to facilitate the decortication process; the exact amount was measured by the observer. The women decided when to end the decortication by evaluating the grains visually and with their hands. The bran of the decorticated grains was removed by winnowing and followed by washing the grains. Once the grains of a certain variety were put to dry in the sun, the women were asked for their opinion about the ease of decortication and color of the decorticated grain.

Third, after all the decorticated varieties were dried, the grain and bran were weighed to assess the decortication yield. Then, the women ground the grains to flour using the same wooden mortar and pestle. The ground flour was sieved three times in order to obtain fine flour suitable for the preparation of tô. The two types of flour, fine and grits, were weighed. Each variety was evaluated for the ease of grinding and the quality of the obtained flour.

Fourth, the flour was used to prepare tô in aluminum pots on wood fires. The women added a free amount of potash during the cooking process, which was measured and recorded. During the preparation of tô, the women were asked their opinion on the ease of cooking the tô.

Fifth, the tô was taste tested by a panel of 25 persons (women and men) in each village. These testers received a filling meal along with all others attending the evaluations before

the taste testing started. They evaluated the tô for acceptability by rating the taste, color and consistency and then assigning a "global appreciation" score. All participants blindly tasted the 3 replications of tô of all varieties. The tô was prepared without any sauce and taken with their hands, without using a fork or spoon, the common method of eating tô. This sensory testing took place individually in a secluded place. The scores used ranged from 1, for problematic, to 3, for very good. The interviewers noted when they doubted the ability of a participant to effectively evaluate the quality. A general discussion and feedback session, in which notes were taken, was conducted once all participants had finished their evaluations. The basins with tô were presented and de-randomized so that the participants could see the tô from each test variety across the three replicates; then, the preference scores for each variety were announced. The meaning and relevance of the results were discussed by both female and male farmer participants.

Finally, the women were asked to preserve the tô to evaluate the next morning. The acceptability of tô that is conserved overnight is an important quality criterion, especially because tô leftovers from dinner are often reheated and eaten for breakfast [16]. On the second day of the culinary test, this "left-over tô", was, therefore, evaluated for its ability to be conserved by the member of the family that had prepared it. This evaluation was, therefore, conducted by a single person per repetition.

2.6. Laboratory Grain Analysis

A corresponding laboratory analysis of the grain was also conducted. This included scores for vitreosity, 100-grain weight, percentage of discolored and broken grains and mechanical decortication. The grains were scored for their vitreosity using a score of 1–10, with 10 being fully vitreous, without floury endosperm, and 1 having a full floury endosperm (average of 6 grains). The 100-grain weight was determined by weighing 100 grains on a precision scale (0.001) (duplicated). The percentages of discolored grains and broken grains were visually estimated. Grain hardness was assessed mechanically. The grains were mechanically decorticated using a Tangential Abrasive Dehulling Device (TADD) for 4 min (duplicate) to determine the losses during mechanical decortication.

2.7. Statistical Analysis

The categorical results were transformed into a numerical rating (referred to as preference score) by multiplying the number of answers in each answer category by a corresponding value for that score (poor = 0, good = 0.5 and very good = 1) on a village/variety level, summing these products and dividing by the total number of respondents to obtain the final rating of each category [17]. The data were analyzed using GenStat for Windows version 14.0 (SPSS Inc., Chicago, IL, USA) and R (Core Team, 2021). All data were checked for normality using the Kolmogorov–Smirnov test. One-way ANOVA was used to test varietal difference in normally distributed data. Varietal differences in non-parametric data were tested using the Kruskall–Wallis one-way analysis of variance by ranks. Stepwise linear regression was used to examine the extent to which grain characteristics influenced the overall grain appreciation. An ordinal regression model was used to assess whether other factors besides taste, consistency and color contributed to the global appreciation score. The global score was the response variable, predicted from the other variables using the most complex model (all combinations of the 3 levels), with the mean of the Local varieties as the baseline. The Pearson and Spearman tests were used to calculate the correlation coefficients of normal and nonparametric data, respectively.

3. Results

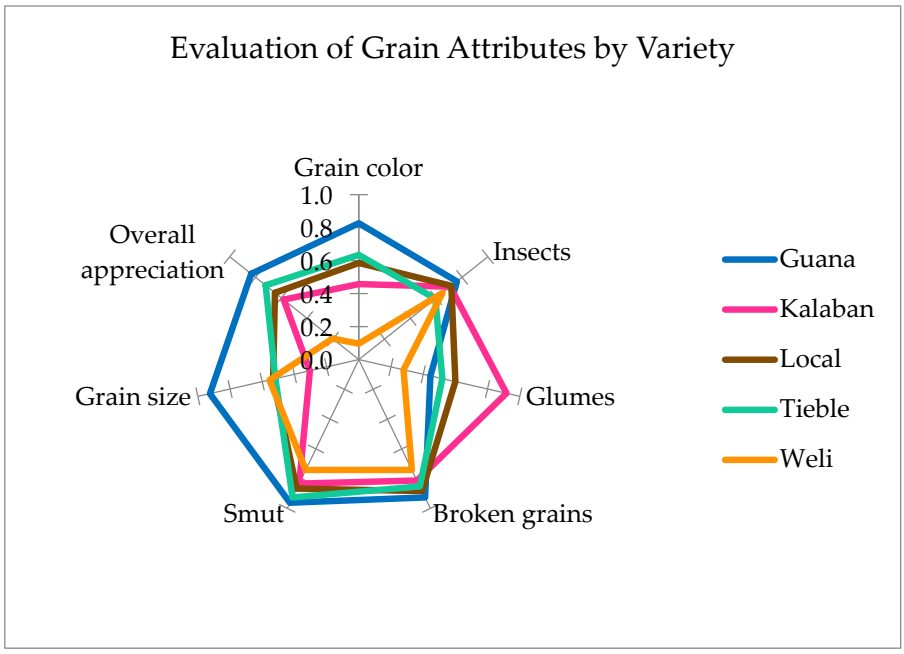
3.1. Participation

The average number of men participating in the sensory study was slightly higher than the number of women (Table 1), with the percentage of men ranging from 40% in Keniero and Siby to 68% in Siranikoro. Overall, the sex ratio (number of men/number of

women) was 1.2:1. The overall age distribution showed that 14% of the participants were younger than 25 years, 53% were between 25 and 45 and 33% were older than 45 years.

3.2. Grain Attributes

There were significant varietal differences in the appreciation of grain color, presence of glumes, grain size and overall appreciation. However, only the color ($p < 0.001$) significantly influenced the overall grain appreciation. The Guana variety had the highest overall appreciation scores (Figure 1), while Weli received the lowest. This was mainly due to the discoloration of the grain, with red and brown spots, and the presence of glumes due to the poor opening of the glumes at or after harvest, which makes threshing more difficult (Figure 1). The check variety chosen by the researchers (Tieble) and the means of the local varieties chosen by each village received very similar appreciation scores for all traits.



Final rating of global grain appreciation	Guana	Kalaban	Local	Tieble	Weli
	0.83	0.58	0.65	0.72	0.20

Figure 1. Appreciation scores of key grain attributes (higher is better) from visual evaluations by the women conducting the culinary testing in 9 villages in Mali. Local indicates the average of the local cultivars chosen by each village to compare with the experimental varieties.

3.3. Decortication Yield

Step two of the culinary test was the decortication of grain. Sorghum processing in Mali commonly involves decortication to remove the unpalatable bran of the grain. Traditionally, decortication has been carried out manually, using a pestle and mortar, and the majority of the women in the study zones still decorticate their grain manually. The manual decortication yields differed significantly amongst varieties, with varietal means ranging from 67.9% for Weli to 81.7% for Tieble (Figure 2). Kalaban's and Weli's decortication yields were the lowest, below 70%. The varietal decortication yields and scores for ease of decortication showed no correlation (data not presented). The varietal ranks for decortication yields were the same for both the manual method with a mortar and pestle and using the TADD machine (Figure 2).

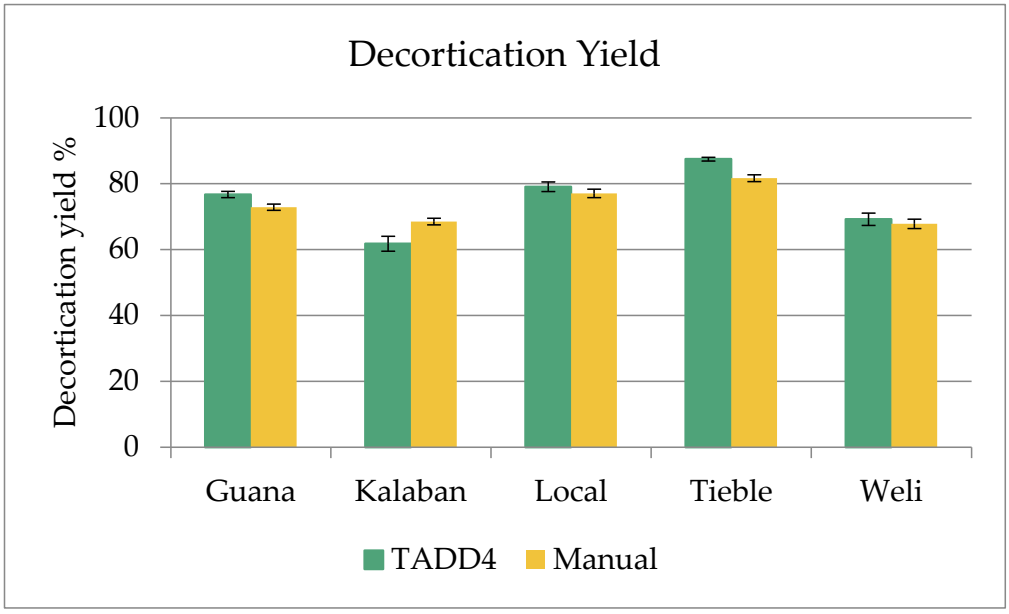


Figure 2. Decortication yield, as a percent of total grits and flour relative to total grain weight by variety, using a TADD4 machine in the laboratory and manually in mortar and pestle by women in 9 villages in Mandé and Dioila, Mali. Local indicates the average of the local cultivars chosen by each village to compare with the experimental varieties.

3.4. Evaluations by Women during Grain Processing, Tô Preparation and Conservation

Significant varietal differences ($p < 0.01$) were observed by the women during processing and cooking activities in the ease of decortication, color of the flour, the ease of grinding and the preparation of tô. Significant varietal differences ($p < 0.01$) were also observed for the conservation of tô on the day after it was prepared.

The overall appreciation of tô, as indicated by the women, was mainly influenced by the color of the tô, while the variety, village, economy of the meal (flour utilization relative to total weight) and the texture did not have a significant impact on overall appreciation (Table 3). Weli was less appreciated than the other varieties for overall grain, grinding, tô texture and conservation appreciation, while Tieble was one of the best varieties for grain preparation characteristics.

Table 3. Mean preference score of different preparation activities and observations of tô, as observed by the women preparing the to, and assessing the conservation quality the next day.

	Mean Preference Scores by Processors				
Variety	**Grain Score ***	**Decortication Ease**	**Grinding Ease**	**Ease of Tô Preparation**	**Tô Conservation**
Guana	0.83	0.80	0.74	0.65	0.67
Kalaban	0.54	0.37	0.80	0.76	0.83
Tieble	0.72	0.44	0.80	0.83	0.72
Weli	0.20	0.63	0.24	0.24	0.39
Local **	0.69	0.48	0.70	0.65	0.67

* Grain score is the overall appreciation of the visual characteristics of the grain. ** Local indicates the average of the local varieties used in each village.

3.5. Village Sensory Evaluations

A darker tô color was generally less appreciated (Figure 3). While the yellow and tan grains of Kalaban were not appreciated, its yellow/olive green tô color was highly appreciated (Table 4) in all villages. The tan grain color of Kalaban is due the lack of pigmentation in the whole plant, which is a very rare trait in local West African varieties and is unfamiliar to farmers. In contrast, the grain color of Guana was most appreciated,

but its tô color was only moderately appreciated. Thus, good grain color did not necessarily lead to an appreciated tô color. Weli was disliked for both the color of the grain and its dark tô (Table 4).

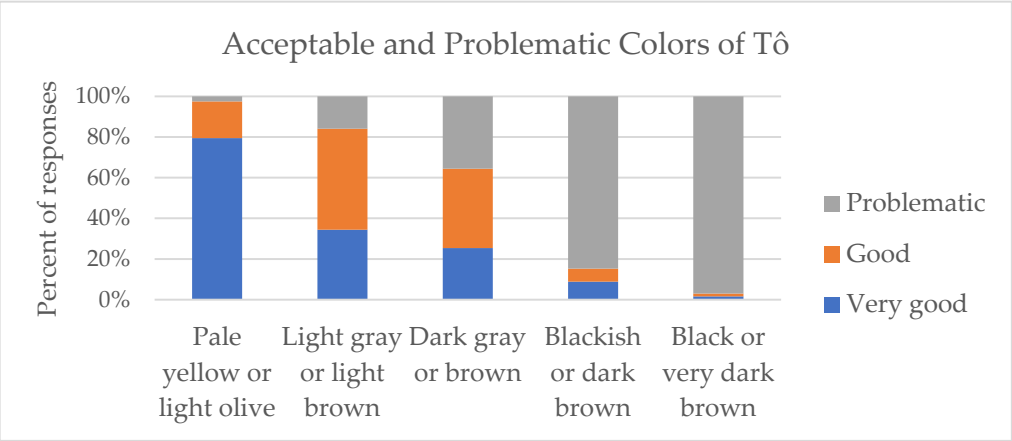


Figure 3. Preferences for tô colors, as observed by 225 men and women in 9 villages in Mandé and Dioila, Mali.

Table 4. Grain and tô color appreciation scores for individual varieties evaluated by the women during the preparation process in 9 villages in Mandé and Dioila, Mali.

Variety	Grain Color	Preference Score	Color of Tô	Preference Score
Guana	White (cream)	0.83	Grey or brown (bright)	0.55
Kalaban	Yellow (tan)	0.46	Yellow or olive green	0.93
Tieble	Brown, red flecks	0.63	Grey or brown (bright)	0.68
Weli	White, red/grey flecks	0.10	Black or dark brown	0.03

Local is not included here as it was the local preferred variety and different between villages.

The tô appreciation scores differed significantly ($p < 0.001$) between varieties, with the global appreciation scores being nearly three times larger for Kalaban than for Weli (Table 5). Village differences were present for color, taste and consistency, but no differences were found for global appreciation, nor were there any significant interactions between variety and either region or village for global tô appreciation scores. Kalaban and Weli had the highest and lowest global appreciation scores, respectively, across almost all villages (Figure 4), whereas the scores for Tieble were intermediate across most sites, except in Magnambougou. The remaining varieties had average overall levels of appreciation, with some variation among the villages (Table 5).

The color, taste and consistency were all important predictors for global tô appreciation. Parameter estimates indicated that color and taste were more strongly associated with global appreciation than consistency. These scores, when converted into the proportion of trait scores that corresponded with the global appreciation score, indicated similar findings (Table 6). For example, 100% of the problematic global appreciation score for Weli was associated with color, and 93% of the very good score for Guana was associated with taste. Ordinal regression, with the Local as a baseline, indicated that there were factors other than taste, color and consistency that influenced the global appreciation scores (chi pr. < 0.001).

Table 5. Mean scores for sensory attributes of tô from 225 female and male evaluators in 9 villages in Mali.

Variety	Color	Taste	Consistency	Global	Total
Guana	0.55	0.67	0.63	0.61	2.46
Kalaban	0.93	0.74	0.66	0.75	3.08
Local *	0.58	0.63	0.60	0.56	2.38
Tieble	0.68	0.72	0.65	0.66	2.71
Weli	0.02	0.58	0.67	0.28	1.56
Source	d.f.	Deviance	Mean deviance	Deviance ratio	Chi pr.
Regression	30	3359	111.977	111.98	<0.001
Residual	3297	3721	1.128		
Total	3327	7080	2.128		

* Local indicates the average of the local cultivars that were chosen by each village to compare with the experimental varieties.

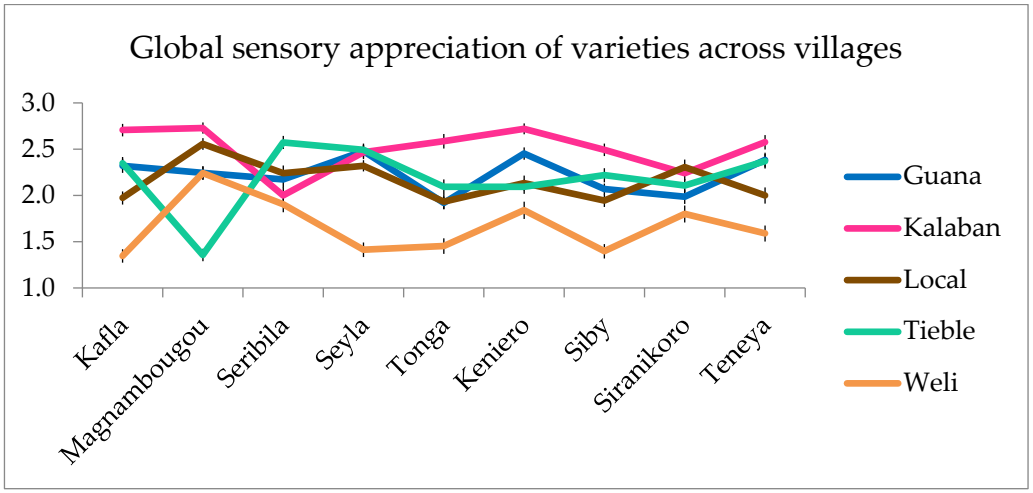


Figure 4. Global sensory appreciation scores of 5 varieties evaluated by men and women across 9 villages in Mandé and Dioila, Mali. Local indicates the average of the local cultivars chosen by each village to compare with the experimental varieties.

3.6. Linking Lab and Field

The laboratory analyses of 100-grain weight and the percentage of discolored grains following manual decortication showed significant correlations with the farmers' preference scores for grain size and grain color (Table 7). There were also significant correlations between laboratory analysis for decortication yield and grain vitreosity and the women's manual decortication yields (Table 7). Discussion with farmers during the culinary testing events revealed that they prefer sorghum varieties with hard grains that do not break or crack easily. The laboratory measurements of grain hardness and the women's observations of the extent of broken grains after manual decortication were significantly correlated.

Table 6. Proportion of participants who gave the same appreciation score for an individual trait and the global assessment, both for a given variety and across varieties.

Variety	Score	Color	Consistency	Taste
Guana	Problematic	0.60	0.59	0.76
	Good	0.70	0.63	0.59
	Very good	0.63	0.84	0.93
Kalaban	Problematic	0.05	0.71	0.88
	Good	0.21	0.55	0.49
	Very Good	0.94	0.74	0.92
Local *	Problematic	0.46	0.68	0.71
	Good	0.69	0.53	0.59
	Very Good	0.66	0.85	0.92
Tieble	Problematic	0.33	0.69	0.73
	Good	0.68	0.59	0.53
	Very Good	0.74	0.84	0.90
Weli	Problematic	1.00	0.36	0.49
	Good	0.04	0.27	0.30
	Very Good	0.09	0.91	0.96
Overall, across varieties	Problematic	0.71	0.50	0.62
	Good	0.54	0.54	0.52
	Very Good	0.72	0.82	0.92

* Local indicates the average of the local cultivars chosen by each village to compare with the experimental varieties.

Table 7. Comparison of laboratory and field test results for grain attributes.

Laboratory	Field	Correlation Coefficient	*p* Value
100-seed weight	Seed size appreciation	0.599	<0.001
% of discolored grain	Grain color appreciation	−0.437	<0.001
Mechanical decortication yield	Manual decortication yield	0.622	<0.001
Vitreosity score	Manual decortication yield	0.486	<0.001
Grain hardness	% of broken grains following manual decortication	−0.495	<0.001

3.7. Effectiveness of Methodology

3.7.1. Differences between the Repetitions

In every village, tô was prepared in triplicate for each variety. The sorghum grain used for triplicate preparation came from different plots, and a different group of women processed the grains for each repetition. However, no significant differences between the three repetitions were observed for grain characteristics and processing observations, except for the texture of the conserved tô on the day after its preparation.

There were no significant differences in the participants' sensory evaluations of tô between the three repetitions, indicating consistent evaluation by the participants and uniform preparation of tô. The 2006 culinary testing was conducted with each participant evaluating all repetitions, in contrast to previous years, in which a different group of participants evaluated each repetition. As the results of previous years' culinary testing showed inconsistency between repetitions for color, taste and global appreciation, the modified methodology appeared to be an improvement.

The interviewers noted that responses given by 13 participants were doubtful or inconsistent over the three repetitions in the 2006 culinary tests. Exclusion of these participants' responses from the analysis did not change the results of the culinary test, and, therefore, the presented analysis includes all participants' responses.

3.7.2. Difference between Men and Women, Villages and Zones

There were significant village × variety interactions for all organoleptic properties ($p < 0.01$). This indicates that the villages, to some extent, evaluated the varieties differently and that the methodology used was capable of detecting these differences. However, when ranked, variety results were quite consistent across villages. Similarly, while women expressed a generally lower appreciation of the varieties than men, the rankings of the varieties for these trait preferences were similar.

The zones did not have an effect on the organoleptic means over varieties, but a significant zone × variety interaction ($p < 0.01$) indicated that the varieties were evaluated differently in the zones. However, there was a tendency for the same varieties to be preferred between the zones, as was observed across villages within zones. Among the grain characteristics and processing properties, significant differences between zones were only exhibited for grain humidity and insect attacks.

4. Discussion

The participatory methodology used for culinary testing of sorghum varieties was very thorough, involving evaluations of many traits at various stages of processing and use. These evaluations enabled effective differentiation between varieties for these traits by the intended users of newly developed varieties. They also facilitated discussions on the meaning of these results in the context of their villages and households. One discussion of great relevance was spurred by asking which of the numerous quality traits evaluated did the participants consider to be most important in their lives. The answer was that something not explicitly evaluated was actually most important; their greatest concern was "food yield", the total amount of food or the number of meals that can be prepared from the harvest of a particular variety.

The results and experiences gained through these culinary tests thus provide opportunities for examining how such evaluations can be effective for the development of varieties that contribute to food security for smallholder sorghum farmers in West Africa. We discuss these aspects herein.

4.1. Assessing Varietal Differences for Grain Characteristics

The substantial differences among varieties observed for their decortication yields are highly relevant for the amount of food that can be produced per measure of grain. While the variety with the best decortication yield lost only 18.3%, the worst variety lost 32.1%, almost one third of its total grain weight, when the women removed the bran before grinding flour (Figure 2). Thus, the variety with the highest decortication yield would provide more food than the variety with high decortication losses, even if that variety had a 10% higher grain yield. Evaluation of decortication yields is, thus, necessary for identifying sorghum varieties that contribute to the food security of smallholder farmers.

The varieties that women scored lowest for grain appreciation, Weli and Kalaban (Table 3), were the two varieties with the lowest decortication yields (Figure 2). These women's scores apparently synthesize various grain quality factors. Grain discoloration, as exhibited by Weli, is disliked since the increased decortication required to remove the discolored layer to obtain an acceptable product results in more work and greater losses. Softer and smaller grains, as exhibited by Kalaban, as well as broken grains, are not appreciated [7], as greater losses occur during decortication and the subsequent washing. Prior research also revealed that the presence of grains with closed glumes is not appreciated by women and men farmers [9], as these grains must be removed before processing. The women's assessments of grain quality thus synthesized factors that influence the amount of work carried out and the losses incurred during grain processing. Female processors' scoring for grain appreciation is, therefore, pertinent for assessing varietal differences for both food yield, i.e., how much food is produced, and the time and labor required for processing. This is further evidence that the choice of varieties made by households in a

food security context is based on the combined roles, tasks and responsibilities of women and men within their households [18,19].

Realizing the importance of diverse grain traits for a new variety's eventual acceptance and use, the sorghum breeding program started hiring experienced women to score the appreciation of approximately 1000 early-generation grain progenies per season. The process of culling out progenies with inferior grain quality before investing additional efforts into testing will help to improve the overall effectiveness of the breeding process. The ability of several experienced women to effectively and consistently differentiate among numerous grain samples was confirmed by the significant discrimination among varieties in the culinary test (Table 3).

The processing of sorghum grain is a women's job in the Malian context [14]. Female evaluators in the culinary tests indicated that the ease of decortication, i.e., the amount of time and effort required to obtain acceptably "clean" grits for grinding flour, was a major concern. Based on this feedback, the researchers began noting the amount of time required for decortication. However, the numerous complicating factors, such as the skill levels and whether two or only a single person pounded, make it easier to focus solely on the women's subjective assessments of the ease of decortication. These appreciation scores may synthesize several factors, such as the extent of grain discoloration, how easily the seed coat separates from the grain and the shape and hardness of the grain, that women indicate affect the difficulty of decortication.

The significant differences between varieties that women observed for ease of decortication, grinding flour and preparation of tô (Table 3) indicate the need to consider varietal differences in grain quality and how they affect women's workloads. Such efforts would represent an example of breeding for varietal traits to respond to women's specific roles and responsibilities based on an understanding of gender preferences [20], and consciously practicing an approach of doing no harm [21].

4.2. Assessing Varietal Differences for Organoleptic Qualities

The consistency of tô is recognized to be an important quality attribute [22]. The tô should be stiff, but not dense, and a person should be able manipulate it with the forefingers and thumb without it adhering to the fingers. Although certain sorghum varieties produce a consistently poor tô texture [23], only small varietal differences were observed for consistency in the culinary tests (Table 5). The similarity of the test varieties to the local varieties for tô consistency is encouraging. Evaluations of sorghum experimental varieties in subsequent years showed that unacceptable levels of tô consistency occur and lead to clear rejection. Thus, assessment of tô consistency is necessary.

Observations of the tô consistency on the day after its preparation exhibited major differences between varieties (Table 3), starkly contrasting with observations made on the first day. Participants indicated that the ability to keep tô for the next day's breakfast was very important, and, thus, the Weli variety was unacceptable for this purpose (Table 3). This experience underlined the importance of conducting a second-day evaluation for tô consistency and not relying solely on the results from day one.

The overall global appreciation of tô is complex, as the appreciations for tô color, taste and consistency showed associations with the overall appreciation scores (Table 6). Nonetheless, the overall appreciations for the new experimental test varieties differed greatly, from quite unacceptable to similar or even superior to the local varieties (Table 5). The sensory evaluations thus helped us to learn about tô acceptability and revealed differences between the experimental varieties that neither the participating farmers nor the researchers were previously aware of. These differences were so significant that they may well have influenced farmers' adoption decisions.

We now know, more than a decade after these tests were conducted, that Kalaban was the only one of the three experimental varieties under test that was released and entered into seed production. The farmers appreciated its very early maturity, which enabled them to harvest grain during the period in which the market price was high. However, this

variety was soon replaced by other early-maturing varieties with superior decortication yields. The variety Tieble, in contrast, was already released and is in continuous seed production at the present time. This variety, derived from a landrace, had highly acceptable overall tô appreciation and was best for decortication yields.

4.3. Methodological Options for Effective Culinary Testing

The culinary acceptability of sorghum varieties was found to be influenced by many independent traits. This is challenging for breeders and farmers deciding which progenies to advance or varieties to cultivate. The test results demonstrate this challenge, with the Kalaban variety being ranked highest for overall tô appreciation (Table 5) but unacceptable for grain traits, being the second from last for grain appreciation and lowest for decortication yield and ease of decortication (Table 3).

One approach to dealing with the problem of the many quality traits, each of them of major importance, is to identify thresholds for acceptability that breeding materials need to meet to be retained. These thresholds may be effectively set in a participatory manner. Processors and farmers, both women and men, clearly communicated their knowledge of acceptability levels for specific traits and to what extent they were willing to make trade-offs between traits using the interview tools described herein. The participatory discussion of the test results showed that the performance of the farmers' local varieties provided appropriate reference points for setting these parameters.

The methods for culinary testing as described herein are not feasible for evaluating large numbers of early-generation progenies. Only the first step of the procedure, the visual grain evaluation, is applicable for these large numbers of samples. Such scoring by experienced female processors at the experiment station proved to be effective for rejecting problematic progenies before multi-location field testing. Scoring of grain samples for hardness or overall appreciation may serve as a proxy for tô texture [24] or decortication yields (Table 3).

The repeatability of the culinary tests between villages (Figure 3) and between women and men suggests that one option for increasing the number of varieties being evaluated in any one year is to let each village choose which varieties to test. A larger number of varieties can thus be tested by conducting culinary tests in several villages.

One important advantage of conducting culinary tests in several villages is that the participatory discussion of results and possible conclusions facilitates decision-making by a large number of individuals and different local organizations regarding seed production and the use of different varieties for processing. Participatory culinary testing of sorghum varieties has been conducted continuously in Mali since 2003 by IER, ICRISAT and collaborating farmer organizations. These tests are a social event for the village, in which farmers participating in variety testing gather with their neighbors for food and discussion of different varieties and seed aspects. Women take responsibility for leading and find voices in their areas of expertise. The discussions with both women and men impacted the breeding programs at least as much as the quality data collected, as exemplified by the revelation of "food yield" as a key criterion for farmers' choice of varieties.

5. Conclusions

The culinary testing, conducted by interested female processors in their villages and households, contributed to more effective sorghum variety development through relevant and repeatable discrimination among varieties for various aspects of grain quality. Researchers became aware of the farmers' concept of "food yield" through discussions about this process with participating farmers. The testing enabled us to learn about the quality traits and trait relationships that are most pertinent for improving new varieties' contributions to food security. These tests were also especially empowering for the women who conducted the variety evaluations; for these tests, they took leading roles and influenced variety and seed innovation decisions based on opportunities for improving food yield.

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Appendix A

Detailed information on grain and culinary test measurements collected and recorded in 2007.

Characteristics		Scores
Analysis in village by women and men		
1. Grain characteristics	Grain color Presence of insects Glumes Broken grains Grain size Smut Overall appreciation	1 = Poor 2 = Good 3 = Very good
	Humidity	Percent
2. Decortication	Ease of decortication Grain color after decortication	1 = Poor 2 = Good 3 = Very good
	Water used during decortication	Milliliter
	Weight of decorticated grains Weight of bran	Gram
	Duration of decortication	Minutes
3. Grinding	Ease of grinding Impression of color of flour Coarseness of flour Hardness of breaking Global evaluation of grinding	1 = Poor 2 = Good 3 = Very good
	Weight of flour Weight of broken pieces	Gram
	Duration of grinding	Minutes

Characteristics		Scores
4. Preparation of tô	Meal savings Impression of color of tô Texture of tô Global evaluation of tô	1 = Poor 2 = Good 3 = Very good
	Potassium used Water used	Milliliter
	Weight of unused flour Weight of tô	Gram
	Color of tô	
5. Sensory evaluation	Taste Color Texture (consistency) Global evaluation	1 = Poor 2 = Good 3 = Very good
6. Conservation of tô	Taste Color Texture (conservation) Global appreciation	1 = Poor 2 = Good 3 = Very good
Field analysis by technician		
1. Color of tô	1 = Yellow, olive green (very good) 2 = Bright grey or bright brown 3 = Bit dark grey or brown 4 = Blackish or dark brown (bad color) 5 = Black or very dark brown (very bad color)	
2. Texture of tô (measured the next morning)	1 = Very consistent 2 = Consistent 3 = Soft 4 = Sodden 5 = Very sodden	
Laboratory analyses		
1000-kernel weight % of grains attacked by anthracnose % of grains attacked by moisture % of dis-colored whole grains % of dis-colored decorticated grains Pericarp thickness Presence of testa Vitreousness of grain Decortication yield (TADD) Ease of decortication (TADD) % of broken grains (TADD) % of broken grains (manually decorticated)		

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