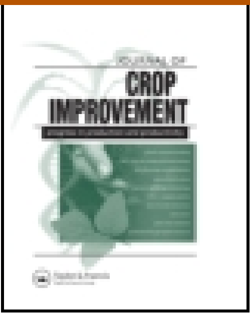

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Learning from farmers to improve sorghum breeding objectives and adoption in Mali

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ABSTRACT

Many efforts have been made to improve sorghum [*Sorghum bicolor* (L.) Moench] varieties, but adoption of improved varieties remains low. Sorghum has diverse panicle architecture and grain qualities that vary within and between races, and utilization and adoption may depend on these traits. Recent efforts in West Africa to improve local guinea race germplasm as a base material have diversified potential options: there are breeding materials with a range of panicle types with increased grain number per panicle and a range of droopiness, as well as laxness and threshability. This study was designed to expand our understanding about sorghum grain and panicle traits that are important for farmers in the Sudan savanna zone of Mali. We combined a sorghum panicle sorting activity with qualitative interviews in Mande and Dioïla to understand farmers' knowledge and preferences about sorghum characteristics. A total of 20 panicle sorting activities and 20 interviews were conducted with men and women sorghum producers. Based on their roles and responsibilities in sorghum production and processing, farmers associated specific panicle types, plant types, and grain traits with aspects of pest control, threshability, storage duration, and yield. Farmers preferred open panicles and droopy architecture for disease and pest control; hard grains for storage and appropriate ratios of flour and grits; high density of grain on the panicle for yield; and specific glume qualities for threshability. Breeding programs need to consider these regional preferences and gender roles to develop appropriate material and increase adoption of productive varieties.

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Introduction

Sorghum is a staple food crop for millions of Malian smallholder farmers and thus plays an important role in achieving food security. Across the semi-arid zone of West Africa, sorghum production and improvement are greatly influenced by environmental variability and regional variations in producer and consumer preferences, and thus the adoption of improved varieties by farmers is as low as 32% (Smale, Kergna, and Diakité 2016). Low adoption levels of improved varieties contribute to low sorghum productivity and food insecurity in West Africa. Participatory plant breeding (PPB) and associated methods of learning from and interacting with farmers have been used to improve the suitability of varieties and thus improve the rate of adoption (Smale, Kergna, and Diakité 2016). In the Sudanian zone of Mali, PPB has been used to develop improved sorghum varieties that are environmentally adapted and meet farmers' needs (Christinck, Weltzien, and Hoffmann 2005; Kante et al. 2017; Vom Brocke et al. 2010; Weltzien et al. 2006). The success and the potential adoption of future varieties depend on understanding farmers' needs when defining breeding objectives.

Local guinea race germplasm, introduced caudatum varieties, and crosses of the two have diverse features that may impact adoption. Sorghum breeders are faced with the challenge of identifying and then incorporating these traits into varieties acceptable to farmers. Four major sorghum races are grown in Mali; Guinea, Durra, Caudatum, and Bicolor (Touré et al. 1998) and each has distinct morphological features. Guinea is the most dominant race grown in the areas of Dioïla and Mande, but some intermediate guinea-caudatum, caudatum, bicolor (sweet stem), and durra types are also grown (Siart 2008). The guinea race has symmetrical grain placement and a panicle that is loosely branched. There is extensive morphological variation for panicle architecture in this race. The caudatum race has asymmetrical grain and panicles that are cylindrical and the length of the primary branch fluctuates within narrow limits from node to node. The durra race is well adapted to drought conditions, sandy soils, and residual moisture regimes. The grain is large and globular and the panicles are compact and often borne on a hooked stalk. The bicolor sorghums tend to be sweet stem sorghums that are not used for grain production (Doggett 1982).

The morphological features of the different races influence grain yield, grain quality (grain hardness), glume opening, threshability, and panicle traits (laxness). Threshing is affected by the degree of glume opening. The more the glumes are closed, the harder it is to thresh. Grain hardness affects resistance to grain mold (Jambunathan., Singh, and Subramanian 1984), grain storage ability, insect resistance (Bueso et al. 2000), milling behavior (Suhendro et al. 2000), flour particle size, cooking properties (Akingbala and Rooney 1987), and parameters such as adhesion, cooked grain texture, alkali gel stiffness (Cagampang and Kirleis 1984), porridge quality (Akingbala and Rooney 1987), and production of high-quality couscous granules (Aboubacar and Hamaker 1999). The objective of this study was to identify and understand farmers' preferences for panicle-related traits, including panicle forms, droopiness, threshability, and visually assessable grain yield and grain quality traits that are critical for farmers to adopt new varieties of sorghum.

Materials and methods

Study area

The study was conducted in the Sudan Savanna zone of Mali (700–1000 mm rainfall) where sorghum is one of the most important cereals produced. A panicle sorting activity, accompanied by focus group discussions and individual interviews, was conducted in two areas: Mande region, which is 80 km southwest of Bamako, and Dioïla region, which is 200 km east of Bamako. Dioïla has more intensified agronomic systems than Mande region. Cotton (*Gossypium herbaceum)* is the dominant cash crop in Dioïla, whereas cotton is marginally produced in Mande. In general, women are involved in all field activities of the family in addition to having their own fields that allow them to support some of their personal needs. Mande and Dioïla regions were selected because of the importance of sorghum in farmers' agronomic systems and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) sorghum program has partnered with farmers' organizations in participatory plant breeding (PPB) activities across multiple years in these two areas.

The study was introduced in each village during parallel sorghum cooking activities through ICRISAT farmer organization partners, Union Local de Producteurs de Cereals (ULPC) in Dioïla, and Coopérative des Producteurs de Semences Maraichère du Mali (COPROSEM) in Mande, which is member of the Association des Organisations de Paysans Professionnels (AOPP). The cooking activities were held on-farm in the selected villages every year by the sorghum program to assess the culinary aspects of varieties tested by farmers (Weltzien et al. 2008). There was overlap in culinary test participants and the panicle sorting study. In addition to the villages with culinary tests, five other villages were selected with the assistance of farmers' organizations.

Study description

Focus group panicle classification

The farmers were asked to classify 80 panicles into three different piles. The first pile included the panicles that farmers preferred and were willing to grow, the second pile included the panicles that were acceptable to farmers but had some disadvantages, and the third pile represented panicles that farmers did not prefer and would reject.

Individual farmer panicle classification

The individual panicle classification was similar to the focus group panicle classification, but the participants were given more latitude in selecting the number of piles. For the individual classification, it was not necessary to have only three piles and the individuals grouped the panicles according to their preferences.

Discussion groups and interviews

After the classifications, discussions were held using a semi-structured questionnaire. The questionnaire asked which parameters they used to classify the panicles into different piles, why they sorted them the way they did, and if there were specific traits that were used to classify the piles. If comments regarding key topics, such as glume, panicle laxness and form, and storability did not arise, we asked about these traits more specifically in follow-up questions. Progressively through participants' answers, other questions arose and were posed.

The focus groups and individual interviews were performed with two enumerators (Authors Isaacs and Sylla) taking handwritten notes, in English and French, and the discussions, conducted in Bambara, were tape-recorded. The tape recording helped the authors to clarify the handwritten notes and address translation issues between Bambara, French, and English language. In the beginning, the demographic data were collected in groups, but some participants were not comfortable, so the data were collected individually after the group discussions.

In each village, the permission of the village chief was sought before commencing activities and consent was obtained. Before the beginning of each session, participants were told how the information would be used and that participation was completely voluntary and they could withdraw at any time. Permission was also specifically requested for tape recording and taking photos of the participants.

Panicle classification

The activities of this study were structured around panicle sorting by farmers. To identify and understand farmers' trait preferences, 80 panicles representing panicle diversity present in the breeding material were selected and used for panicle classification exercises. Before the panicle exercises began, the panicles of the 80 accessions were numbered and classified into five groups according to the panicle shape; Group 1: Guinea panicles, the most open panicle, long and peduncle lax branches and panicles that hang down; Group 2: Intermediate Guinea-caudatum, an open panicle, with lax branches and the panicles that hang down; Group 3: Intermediate Caudatum-guinea, with lax branches and erect panicles; Group 4: Caudatum, with erect panicles and erect branches, or semi-compact panicles; and Group 5: Dura race, with compact panicles (Figure 1).

Figure 1. Sorghum groups 1–5: Different panicle groups according their panicle shape/form with description above in text. Three main types of information were collected from participants: 1) collection of demographic information about participants, 2) panicle sorting activity or panicle classification by participants according to their preferences, and 3) group discussion and individual interviews. The main target of these activities was to understand farmers' knowledge and preferences about sorghum grain and panicle traits.

Data collection and analysis

Basic demographic information and information about cash crops and sorghum production were collected from each individual. Following this, the group or individuals were asked to sort the panicles into piles according to their knowledge and preferences. The data were collected through oral interviews and focus groups of the participants and were analyzed using qualitative methods, including thematic coding based on the research questions, descriptive summaries, and thematic frequencies (Miles, Huberman, and Saldana 2013). Both enumerators' handwritten notes were used to make a final summary of notes, which were then carefully checked with the tape recordings by the first author, who is fluent in all three local languages. The final notes were compiled and coded using emergent themes based on the guiding research questions. Themes are patterns that pull together or unify different pieces of data and ideas and are associated with specific research questions (Miles, Huberman, and Saldana 2013). After the data were thematically coded manually, QDA software was used to retrieve each theme to write descriptive summaries. These descriptive summaries examined the words directly spoken by the farmers that were previously coded into themes. Thus, the descriptive summaries are an analysis of the contents of the data. Finally, these summaries were analyzed collectively and the broader interpretations of the underlying meaning of the summaries were extrapolated in the discussion.

QDA and Excel were used to analyze the frequency of themes from the focus group discussions and individual discussions with farmers. Descriptive statistics were used to analyze demographic data. Panicle type preference was calculated by counting the number of panicles in each pile. The overall farmers' preference for each of the five panicle groups was calculated by counting the number of panicles of that group in each of the three piles using the below formula (Christinck, Weltzien, and Hoffmann 2005):

$$\text{Farmers}' \text{ preference \% panicle group} = (N1 \times 0 + N2 \times 0.5 + N3 \times 1) \times 100/(N1 + N2 + N3)$$

Where

N1 = Third pile or number of that panicle-group in the "rejected" third pile

N2 = Second pile or number of that panicle-group in "medium or acceptable" second pile

N3 = First pile or number of that panicle-group in the "farmer preferred or good" first pile

Results

Socio-economic characteristics

This study covered 175 farmers in 11 villages: 4 villages in Mande and 7 villages in Dioïla. The average age of farmer participants in this study was 41 and ranged from 15 to 68. Sorghum was generally grown as a sole crop, and the average sorghum area produced by women was less than 1 ha, whereas the area produced by men was more than 3.3 ha (Table 1). Men and women were generally represented equally in individual interviews, although there were more women in the focus groups than men (Table 1). Approximately 80% of the participants selected their own seed from their fields for the next season's sowing (Tables 2 and 3). Maize represented the most important cereal crop for the participants, followed by sorghum and pearl millet (Tables 2 and 3). At least 14% of the participants used their harvested sorghum grain only as food; 10% of participants in Dioïla and 1% in Mande grew sorghum only for sale; and 67% of participants in Dioïla and 50% in Mande grew sorghum for both selling and food.

Table 1. Demographics of farmers in focus groups and individual interviews in 2015.

		Locality					
Designations	Gender	Dioïla	Mande	No. of groups or individuals	No. of participants	Age (range)	Area (ha) of sorghum produced (range)
Individual interviews	Male	5	5	10	10	48 (35–67)	4.2 (1–12)
	Female	3	7	10	10	40 (29–48)	0.81 (0.5–1.5)
Focus groups	Male	5	4	9	65	46 (23–68)	3.3 (1–14)
	Female	7	4	11	90	38 (15–60)	0.89 (0.3–2)

Table 2. Sorghum production and its relative importance for participants in percentage (%) in Mande in 2015.

Grain use		Grown in intercrop or sole crop		Types of seed production	Yes	No	Farmer ranking of importance of cereals in village	1	2	3	4
Food	15	Intercrop	33	Select Panicles for seed	80	20	Sorghum	40	52	14	0
Market	1	Sole Crop	23				Maize	60	38	5	0
Food and Market	50	Both	11	Produce seed for sale	22	78	Pearl millet	0	0	51	48
Missing	33		33				Rice	0	8	30	52

Table 3. Sorghum production and its relative importance for participants in percentage (%) in Dioïla in 2015.

Grain use		Grown in Intercrop or Sole crop		Types of seed production	Yes	No	Farmer ranking of importance of cereals in village	1	2	3	4
Food	14	Intercrop	23	Select Panicles for seed	84	16	Sorghum	28	54	0	0
Market	10	Sole Crop	74				Maize	58	45	0	0
Food and Market	67	Both	2	Produce seed for sale	28	72	Pearl millet	0	1	88	36
Missing	10						Rice	0	0	12	64

Panicle sorting results and emergent themes

The results of the focus group panicle sorting showed that all five panicle groups were represented in all three piles, except women did not place Group 5 or compact panicles into the acceptable piles (1 and 2) (Figure 2). Men and women sorted the panicle groups in a similar manner, except Group 5. Forty-two percent (42%) of the panicle samples were rejected by men, whereas 40% of the panicle samples were rejected by women (Table 4). Group 2 (intermediate Guinea-caudatum) was the most preferred group by 61% of men and 54% of women, followed by Group 1 (guinea panicle), Group 4 (semi-compact panicle), Group 3 (intermediate caudatum-guinea), and Group 5 (compact panicles) (Figure 2). Groups 3 and 5 were the least preferred groups by both men and women. Eighty-five percent of Group 5 panicle samples were rejected by men, whereas Group 5 was totally rejected by women (Figure 2). Participants' responses also indicated that Group 3 was less preferred (33%) than Group 4 (Figure 2), whereas the dark and red grain colors were rejected by farmers in Group 1, Group 2, and Group 4. However, during the interviews and focus groups, farmers did identify uses for Group 3 as well as for Group 4, in particular, for animal feed and selling of grain in the market.

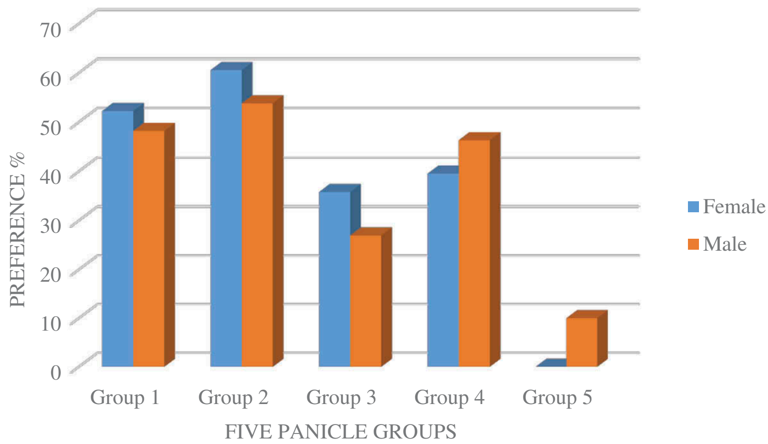

Figure 2. Percentage of panicles of each group that farmers (female and male) placed in different piles according their panicle preferences. Where: Group 1: Guinea (Guineense) panicles, Group 2: Intermediate Guinea-caudatum, which has lax branches and the panicle hangs down, Group 3: Intermediate Caudatum-guinea, with lax branches and erect panicle, Group 4: Erect panicle with erect branches, or semi-compact panicle, Group 5: Dura race and intermediate with compact panicle.

Table 4. Percentage (%) of panicles in different piles.

	Female			Male		
Panicle groups	Pile 1	Pile 2	Pile 3	Pile 1	Pile 2	Pile 3
Number of panicles/piles	224	159	256	172	172	245
% of panicles/pile	35	25	40	29	29	42

Descriptions of emergent themes

To further understand the attributes farmers preferred within panicle groups (Group 1–3), the mixed opinions about Group 4, and what they disliked about Group 5, we asked in-depth questions in individual interviews and focus groups. The emerging themes and the frequency of observation from these interviews are detailed in Table 5. The descriptive summaries reporting what farmers said about each characteristic are described in detail below.

Panicle form

The most important morphological trait that differentiated the panicle groups was the panicle form. From G1 to G5, the panicle form shifts from lax and drooping to compact and erect (Figure 2). Across all interviews (individual and group), farmers indicated that they were accustomed to, and preferred, the lax and hanging panicle types (guinea type). They informed that this kind of panicle hung down because of the weight of the grain and thus they yielded more. In addition, the participants indicated that the hanging panicles were better than the erect kind for threshing because the threshing was done manually. Farmers

Table 5. Frequencies (Freq) of themes and percentage of themes in group discussions.

Themes	Overall mention of themes (n)	Freq (%) of themes	Themes in groups (n)	Freq (%) of groups/themes
Hardness and grain storage	22	6.9	14	70
Hardness and food quality	6	1.9	5	25
Hardness and grain pounding	11	3.5	6	30
Hardness and profit	24	7.5	20	100
Hardness evaluation	12	3.8	9	45
Hardness/others	5	1.6	4	20
Glume opening/threshing	46	14.5	19	95
Grain lost in the field (grain shattering)	23	7.3	10	50
Grain food quality	20	6.3	12	60
Grain yield	74	23.3	20	100
Grain color	22	6.9	14	70
Maturity and adaptation	26	8.2	13	65
Panicle form	22	6.9	20	100
Others	4	1.2	4	20

frequently said the lax kind resisted bird attacks because when the birds tried to land on the thin peduncle or panicle, the stem moved up and down and scared them off. Interestingly, participants also associated the type of panicle form with environmental adaptation. They indicated that the panicles that hung down were more adapted to low input soils than the erect type. On the other hand, some of the farmers found the erect type to yield as well as the lax type, but its grain quality was not good for food, eating, and storage. These farmers said they chose to grow the erect type only for the market because of the high yield and white grain. They appreciated the erect type as a fodder crop because animals liked the leaves and the stems more than those from the plants with drooping panicles. Finally, in contrast to the lax type, farmers indicated that the erect type did not lose much grain in the field during the harvest.

Threshability and glume opening

Threshing ability or glume opening was an important attribute for farmers in Dioïla and Mande, representing 14.5% of the discussion frequency (Table 5). Participants associated threshability with glume opening, and they considered this as an important grain yield component. They preferred sorghum panicles where, at maturity, the entire grain was all or almost all visible through the glumes and the grain was easily threshed. Furthermore, they estimated yield by looking at the panicle from the top to the bottom and determining if the glumes were all well-opened because glumes well-open at the top could be progressively closed toward the bottom of the panicle. They said when the glume was closed, the glume stuck to the grain and threshing became difficult and one could lose a significant part of the grain in the chaff. In addition, one farmer related glume opening and hardness to rainfall:

"When the glumes are not well open, it means grain filling is not complete, and then the grains are not hard because that variety has not completed its cycle because of the lack of rainfall."

Grain loss in the field (grain shattering)

Grain loss in the field is a parameter that farmers considered to be important in Dioïla and Mande, as it was discussed in approximately 50% of the group discussions (Table 5). Farmers are busy at harvest time and they must prioritize harvest activities across all crops. As a result, they might delay the sorghum harvest, and in so doing, they could realize that some varieties lost more grain in the field than others. Participants had two theories about this. The first was that if the glume is open too much, the grain falls; the other theory being that the grain is not "fixed" well in the glume at the point of attachment. For example, a farmer said, "These kinds of varieties lose grain in the field at maturity when the wind blows, and during the harvest loses many grains because we break the stem first before harvest, and therefore grain falls down."

Grain color

Sorghum grain color was reported during this study with 6.9% of discussion frequency (Table 5). Farmers preferred white colored grain and often they associated that color with grain quality, and it was more appreciated for selling for food. Participants did not prefer the red or dark colored grain because they associated red and dark color grain with animal feed. However, several farmers said the dark color grain could be superficial (only on the pericarp), which could be removed during pounding.

Grain hardness

Grain hardness was mentioned in approximately 25% of interviews and it was further discussed in-depth with participants (Table 5). Many aspects of grain hardness were debated and it was clear that for farmers, grain hardness was related to several other important factors, including grain storage, food quality, and profit. Farmers had specific ways in which they evaluated grain hardness.

Hardness and grain storage. Sorghum grain duration in storage, either using traditional or modern storage method, was an important aspect that was frequently discussed by farmers during this study. Participants in the focus groups were unanimous that the duration of grain storage depended on grain hardness; the harder the grain, the longer it lasted in storage. Storage insect attacks were the main problem for farmers (traditional and modern). They remarked that the harder the grain, the more resistant it was to insect attacks and it could be stored longer without any significant insect damage. Farmers also mentioned that insects liked soft grain because it was more floury and sweet.

Hardness and milling process (decortication and grinding). In general, in Mali, women were in charge of the whole culinary process, including decortication, milling, and food processing. In this study, women in Dioïla and Mande appreciated harder grain types (Table 4). The decortication was generally done by pounding with a wooden mortar and pestle, but mechanical mills were also available for this purpose. The women wanted intact, whole grain after decortication, rather than pieces of grain. Thus, they preferred harder grain because they would have whole grain after decortication. Women said, "It is too difficult to pound soft grain because it breaks into pieces before the bran is fully removed, and thus some pieces of grains are lost with the bran." During the decortication process, women used water to clean and wet the pericarp, which facilitated the removal of the bran. To reach saturation, this process takes a short time for soft grains and more time for hard grains. Women said that the amount of the bran after pounding was high for the soft grain compared with the hard grain and that this was undesirable. However, a few said it was painful or difficult to pound the hard grain and it took more time to remove all of the bran.

The ratio of semolina to flour was an important parameter for farmers in Dioïla and Mande. All participants preferred to have both semolina and flour, but a handful of farmers preferred more semolina than flour, particularly in Mande, where one of their main dishes called "Gnegnekini" required semolina. Producers indicated that with hard grain they got enough semolina and flour, whereas with the soft gain type, they would get enough flour but not semolina.

Hardness and profit. The majority of farmers said that hard grain provided many advantages over the soft grain, which included larger cooking volume, better satisfaction of appetite, and longer preservation. Participants said that for cooking, one needed more soft grain than hard grain if one wanted to get the same amount of food; they informed, "the hard grain provides more product at the end of the culinary process for breakfast, lunch, and dinner. With soft grain you can't reach all three meals," meaning the quantity of soft grain product would render less food than a similar quantity of hard grain product. Likewise, a participant said, "If you took 10 kg with hard grain, you must take 12 kg of soft grain to get the same amount of food." Food prepared with hard grain satisfied hunger for a longer period of time than that prepared with the soft grain. Both men and women said that the hard grain was heavier by volume than soft grain; therefore, the hard grain had more value than the soft grain for selling purposes.

Sorghum maturity

The majority of farmers preferred early-maturing varieties because of the unpredictable nature of the rainy season, including an early or late start of the rains, an early or late end to the rainy season, and temporal drought during the season. Farmers preferred early-maturing varieties for multiple reasons, but when discussed in further detail, it was found that "early maturity" and "short duration" referred in general to varieties that were adapted to the local rainfall. For instance, women preferred "early maturity" more because they did not have access to the equipment to till their fields on time because men used them first. As a result, they sowed later and needed an early maturing or quick-maturing variety that would be ready for harvest on time. However, according to farmers, the main difficulty with early maturity was the bird damage on the panicle. On the other hand, the main problem with long-duration varieties was that when the rainfall stopped early, the plants did not mature properly. They wanted varieties that were adapted, or in other words, varieties that ended their cycle with the rainy season and circumvented the temporal drought.

Sorghum variety adoption

In this study, yield was the most important attribute of farmers' preferred varieties; it was mentioned 74 times (Table 5), and farmers also considered other traits, such as grain quality, threshing ability, panicle shape, and environmental adaptation, as important features. Likely, there were trade-offs in these preferences. From the discussions, it emerged that participants needed to test varieties in different fields before adoption. They compared the new varieties with their own variety for at least two seasons in different fields. Farmers wanted to be sure that the new variety would be adapted to their needs, which included soil type, maturity, yield, grain quality, and food quality.

Discussion

Farmers' perception of sorghum grain yield and food security

Sorghum grain yield was the most preferred trait for farmers; therefore, it played an important role in sorghum variety adoption. However, farmers' definition of sorghum "grain yield" must be associated with other traits besides the number of panicles, grain weight from the field, and grain weight after threshing. Close engagement with women in this study revealed multiple grain traits to be important for food security. Women indicated that "grain yield" included how much of it was useful as food through the entire post-harvest process. Thus, yield was defined as "food yield" and comprised threshing (threshing percentage), weight after decortication, efficiency for different food uses, and duration of grain storage without insect attacks for long-term food security. Yapi et al. (1998) reported the reasons for adoption of new sorghum varieties in three regions of Mali to be earliness (85%), productivity (67%), and food quality (34%). Our results confirmed the findings of Yapi et al. (1998) and suggested grain quality and food quality to be properties that were essential for adoption. The inclusion of women in this study provided insights based on their expertise and revealed how the roles and responsibilities of different actors in the household influenced grain and food quality attributes. This concept of food yield emerged from women's conceptualization of grain quality and redefined yield.

Combining farmers' and researchers' knowledge to develop breeding objectives

There are multiple attributes that are important to farmers and the identification and the understanding of these attributes are essential for setting breeding objectives and developing materials that are more likely to meet farmers' preferences. Farmers have unique knowledge about traits, and, in many cases, their explanations about traits are supported by scientific studies on specific traits. Farmers associated harder grain with longer storability and researchers have found varieties with increased grain hardness or increased thickness of the corneous layer of the endosperm to be much less susceptible to the primary grain pests *Sitophilus oryzae, S. zeamais, and Sitotroga cerealalla* (Russell 1966; Wongo and Pedersen 1990). Farmers' knowledge about grain quality and hardness agreed with research, indicating grain hardness was correlated with milling yield, particle size index, test weight, and kernel density (Reichert, Mwasaru, and Mukuru 1988). Research has also found a high positive correlation between grain hardness, grain appreciation, and grain productivity (Vom Brocke et al. 2010). Our study found that farmers had a unique measure of grain hardness that was principally determined by women during the pounding of the grain. Farmers associated glume opening with threshing ability and considered the trait an important grain yield component. Similarly, Adeyanju, Perumal, and Tesso (2015) indicated that genotypes with closed glumes were hard to thresh, and the grain of certain cultivars was tightly attached, causing significant reduction in quality, which in turn reduced market value and processing ability. Likewise, farmers in this study estimated yield by looking at the panicle from the top to the bottom and determining if the glumes were all well-opened, because glumes might be well-open at the top but progressively closed toward the bottom of the panicle, reducing yield. Finally, farmers rejected panicles based on sorghum grain color in this study. Many previous studies reported that sorghum grain color affected the color of the resulting food, especially foods made with alkali, such as tortilla or alkaline tô, as was the case in Mali (Hikeezi 2010; Rooney and Murty 1982).

The proper understanding of what farmers mean when discussing different traits and identifying the nuances of how they value specific traits or several of traits is important for scientists to address to develop appropriate, shared breeding objectives. Previous studies have shown farmer conceptualization and valuation of their farming systems to be holistic, multi-faceted, and often distinct from the scientific community's comprehension. Farmers preferred early sorghum varieties (Christinck, Weltzien, and Hoffmann 2005; Yapi et al. 1998) and many early and extra early varieties have been developed by breeders. However, the adoption of such varieties is still low. This study expands the understanding of sorghum earliness. When discussed in detail with farmers, it became clear that earliness was not just short duration but included varieties adapted to the environment, or varieties that ended their cycle with rainfall and overcame the temporal water stress. Usually, farmers grow local varieties (guinea types) or improved local varieties that are photoperiod-sensitive. These types of varieties provide flexibility with planting dates and are thus well-adapted to the variable rainfall patterns in the region (Dingkuhn et al. 2006; Haussmann et al. 2012). Without this in-depth understanding of farmers' needs, earliness may have been construed only as short-duration, leading to the development of varieties that were not photoperiod-sensitive.

The proper understanding of what farmers mean

Farmers associate the local sorghum race with key traits

In addition to the farmer-identified traits that are consistent with research findings, there is strong evidence from this work that farmers also have unique knowledge regarding traits and variety selection. Farmers associated specific panicle types and plant types with a number of traits because their knowledge about varieties was founded on generations of exposure to locally available germplasm. For example, farmers linked a lax panicle with heavy grain, bird control, hard grain for storage, and high-quality food, whereas erect panicles were associated with soft grain and high fodder quality. This knowledge was generally the basis for their variety selection and likely one of the reasons farmers associated specific plant forms with adaptation in low-input fields. However, breeders view traits as individual characters that can be separated through selection and specific breeding tools. Breeders may develop an erect panicle with hard grain but this is not normal for farmers whose knowledge is based on experiential practice. A challenge for breeders and the social scientists is not only to identify farmers' locally adapted materials for crossing and to understand farmer preferences but also to appreciate how farmers conceptualize combinations of traits and make trade-offs. This is important for understanding what underlies trait preferences so that appropriate varieties can be created, and learning from farmers can provide improved or innovative approaches to adoption.

Men and women's complementary knowledge

Men and women contributed unique and complementary knowledge to variety selection. This knowledge was based on roles in the household and in sorghum production and utilization. However, social structures within the family unit enabled sharing of this information. For instance, both men and women preferred hard grain for somewhat different reasons, and they shared information to determine the actual hardness. While men were in charge of grain and seed storage and desired hard grain to reduce losses from insect damage, women were in charge of processing and desired hard grain because it was easy to process and rendered more food. Collectively, they determined the preferred grain hardness: men evaluated it based on storage duration and how easily the grain could be broken with the fingernail but they also relied heavily on women's experience relative to pounding of the grain. The way the grain breaks and the difficulty of pounding determines the hardness. This illustrates not only the importance of men and women being equally represented in the process to identify important traits, but it also speaks to the need to be familiar with the underlying social structures of families. In Mali, women are involved in the culinary processes, whereas men are in charge of the storage, and these roles link back to the household unit where knowledge is exchanged and used collectively. This type of data collection is essential to inform breeding objectives and suggests that a dedicated social science unit to support breeding programs would be useful.

Conclusions

Identification of how farmers associate specific morphological features and grain or seed traits is key to improving breeding objectives and farmer adoption of new varieties. Results of this study show the value of an in-depth approach to understanding sorghum attributes that are important to farmers, including grain yield, grain hardness, panicle shape, threshing ability, maturity, and adaptation. To do this, breeding programs should include social scientists that inform and support the plant breeders. Uncovering these nuances should not be the sole responsibility of breeders.

Farmers conceptualize varieties and associate traits based on experiential exposure to regional germplasm, whereas breeders are aware of varieties that stretch beyond these norms. Breeding programs must take this into account when developing and introducing new varieties, and it is necessary to identify regional preferences and needs to improve adoption. Through an iterative process of co-learning, testing, and sharing of new materials, farmers and researchers could develop suitable varieties with such a methodology.

Inclusion of men and women in the research process is essential to fully identify the types of varieties that are suitable for a household. Gender roles and social structures influence farmer preferences and accounting for them improves the chances of adoption. A team of researchers that includes social scientists, agronomists, and breeders may better be able to identify these roles and the needs of the regional farmers. This study focused on the farmers' preferences because, in this setting in Mali, farmers were mostly producers and consumers. Other situations may merit additional preference discovery for consumers and strategies to link these with producer needs.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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