Assessment of sorghum production constraints and farmer preferences for sorghum variety in Uganda: implications for nutritional quality breeding

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ABSTRACT

Sorghum [Sorghum bicolor (L.) Moench] is the main food staple grain widely cultivated in sub-Saharan Africa including Uganda. There is a lack of current information on sorghum production constraints and varietal trait preferences in the major sorghum production areas in Uganda. Therefore, the objective of this study was to assess the sorghum production constraints and farmer preferences for sorghum variety in Uganda. A participatory rural appraisal study was undertaken in four selected sorghum production districts in Uganda (Kumi, Bukedea, Oyam and Gulu). Data were collected through surveys using semi-structured questionnaires and focus group discussion involving 128 and 55 participants, respectively. Data were subjected to parametric and non-parametric statistical analyses to draw inferences. A lack of improved sorghum varieties was the major sorghum production constraint reported by 82.8% of participants. Farmer preferred ideal sorghum varieties were short to medium plant height with high grain yield. The quality attributes mostly preferred by farmers were baking quality, nutrition, and seed colour. Farmers in the study areas mainly grew unimproved sorghum varieties with low food values. Overall, the study provides the current evidence on sorghum production constraints and farmer-preferred attributes that will guide sorghum nutritional quality breeding with farmer preferred traits.

Abbreviations: FGD: focus group discussion; ICRISAT: International Crops Research Institute for the Semi-Arid Tropics; NaSARRI: National Agricultural Semi-Arid Resources Research Institute; PCs: principal components; PRA: Participatory Rural Appraisal

Highlights

- Lack of improved crop varieties is the major sorghum production constraints.
- Short to medium plant height with high grain yield were farmer-preferred traits.
- Baking quality and nutrition were the major farmer-preferred quality attributes.
- Majority of farmers commonly grow unimproved sorghum with low food values.
- There is a need for breeding sorghum varieties with high yield and enhanced nutrition.

Introduction

Sorghum [Sorghum bicolor (L.) Moench] is a relatively drought-tolerant crop adapted to grow under harsh production conditions in tropical and subtropical areas of the world. Sorghum is grown primarily for food, feed and bioenergy (Kimber et al. 2013). Globally, sorghum is annually produced on 41.31 million ha of land with a total production of 59.83 million tons with a mean grain yield of 1.45 tons per hectare (USDA 2019). China, India, the United States of America and Mexico are the leading sorghum producers in the world. In sub-Saharan Africa (SSA), Nigeria and Sudan are the
leading sorghum producers. It is the second major crop (after maize) in SSA. In Uganda, Sorghum is the third most important cereal crop after maize and rice.

The area under sorghum production in Uganda is at 398,050 ha accounting for 314,553 tons total annual production. This places Uganda as the fourth leading sorghum producer in East Africa, after South Sudan, Tanzania and Ethiopia (FAOSTAT 2018). Sorghum is mainly produced by smallholder farmers in the semi-arid regions of Eastern, Northern and South Western Uganda as a staple food. Farmers in the country commonly use farm-saved sorghum seed. The crop is mainly grown as pure stand, while some farmers practice intercropping with finger millets, maize, cowpeas and common beans. Sorghum grain is processed to prepare porridge and local bread among rural communities especially women and pre-school age children in Uganda. In urban areas of the country, it may be prepared into a wide variety of other food products such as breads, lactic and alcoholic beverages and weaning meals. Sorghum has become both cash and food crop in sustaining the livelihoods of millions of people in Africa. In spite of its importance, sorghum production is affected by diverse insect pests and fungal diseases, heat, drought, acidic soils, low soil fertility, Striga infestation, Quelea quelea bird and limited policy support (Reddy et al. 2004).

Sorghum is an important staple crop in the African semi-arid tropics including Uganda serving as a daily food requirement (Kumar et al. 2013). Most communities in Africa are often faced with malnutrition which is commonly among women and pre-school age children. In SSA, approximately 500 million people rely on sorghum as their dietary staple to derive the bulk of their energy, protein, minerals and vitamins requirements and, therefore, sorghum has a substantial prospect to be used as a human food and beverage source (gluten-free) in SSA (Taylor et al. 2006). However, the sorghum varieties grown in Uganda and other SSA countries are inherently deficient in micronutrients such as iron (Fe), zinc (Zn), and vitamin A and have a low protein digestibility (Garg et al. 2018). The low grain yield level coupled with deficiencies in these minerals, and bioavailable protein limit the value of sorghum in sustaining food and nutrition security among vulnerable communities in the region. Hence most rural communities are faced with acute malnutrition also referred to as ‘hidden hunger’. Malnutrition has affected approximately half of the world’s vulnerable population, especially babies and infants, pre-school age children, women, and the elderly in most countries of Africa and south-east Asia. For example, in Uganda, 49% and 32% of children under the age of 5 years are approximated to be iron and vitamin A deficient, respectively (https://www.ifpri.org/publication/uganda-country-brief). This has resulted in a global burden of disease and increased risk of morbidity and mortality (Garg et al. 2018). According to the World Bank, Uganda loses $145 million in gross domestic product annually due to vitamin and mineral deficiencies (Shekar et al. 2016). Approximately 815 million people in the world are chronically undernourished by 2016 (FAO, IFAD, UNICEF, WFP and WHO 2017). Therefore, there is global interest in enhancing the nutritional quality of staple cereals including sorghum that form the major constituents of diets among the disadvantaged and marginalised societies to address the hidden hunger (Phuke et al. 2017). For example, each serving of biofortified sorghum of 100 g for children aged 4–6 years old can provide between 13,000 and 18,000 mg zinc and 10,000 mg iron. While 300 g serving for women can provide 39,000–54,000 mg zinc and 30,000 mg iron when consumed daily (Andersson et al. 2017). Consequently, sorghum bio-fortification by increasing mineral micronutrients, especially iron and zinc, protein and other quality traits has gained widespread interest (Kumar et al. 2009; Pfeiffer and McClafferty 2007). More recently, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has developed and released the first three biofortified sorghum cultivars with high grain yield and enhanced grain Zn and Fe concentration in Asia (Parbhani Shakti in India) and Africa (SAMSORG 45 and SAMSORG 46 in Nigeria) in 2018. The released varieties showed high performance and good adaptation and highly adopted by many farmers (Kumar Ashok et al. 2018; Reddy and Reddy 2019). Therefore, sorghum with enhanced quality nutritional traits will have significant dietary value in the rural poor communities in Uganda.

The biofortified crops play a vital role in food and nutrition security since they provide more practical, sustainable, cost-effective and environmentally safe approaches to alleviate malnutrition among the rural communities in the developing countries since these crops are their most important staple food (Bouis and Welch 2010) like Uganda. However, the sorghum improvement research in Uganda has focused on grain yield enhancement and tolerance to associated biotic and abiotic stresses while neglecting nutritional quality breeding. Hence there is a need for breeding biofortified crops to reduce malnutrition. However, it’s important to first understand farmer’s needs, trait preferences and their perceptions on quality and nutrition as well as their farming system through Participatory Rural Appraisal (PRA) where farmers are actively involved in all the stages of technology development and their values, abilities, knowledge, preferences and innovation are highly considered (Chandra...
The participatory approach helps to effectively understand farmers knowledge, experiences, constraints and their needs and varietal trait preferences in crop improvement (Chambers 1992; Mrema et al. 2017) since failure to incorporate farmers needs and preferences has often resulted in consistently low adoption of such technologies. In the past sorghum participatory study in Uganda mainly focused on breeding for grain yield response and Striga resistance.

Understanding the farming system with the agro-ecological and socio-economic conditions under which farmers operate and their production goals is imperative to initiate any crop improvement program. A point in the case, scanty information exists on sorghum production constraints, varietal trait preferences and the role of sorghum in farming systems and people’s diets in the major sorghum production areas of Uganda. Such information is critical to develop a systematic understanding and carry out crop improvement based on the identification of relevant farmer-preferred options such as earliness, drought and Striga tolerance, tolerance to pests and diseases, and high yield potential with good grain quality (Diallo et al. 2018; Sissoko et al. 2016). Consequently, there is a need to document current and relevant information on the prevailing farming practices, constraints and their strategies and varietal trait preferences through PRA across the farming systems. In Uganda, there is no recent participatory research that documented sorghum production constraints, farmer varietal trait preferences and production status among the major sorghum production areas. Previous study conducted by Robert (2011) focused in Striga infestation areas to develop sorghum for Striga hermonthica resistance without integrating quality traits. The study reported Striga as the major sorghum production constraint and various varietal trait preferences were cited by farmers such as red grain colour, erect and head compactness, short plant heights, earliness, Striga resistance and drought tolerance. The objective of this study was to assess the sorghum production constraints and farmer preferences for sorghum variety in Uganda to guide nutritional quality breeding. Information presented by the study is useful for the development of improved sorghum varieties with enhanced quality nutritional traits.

Materials and methods

Study area

The study was conducted in four selected districts in Uganda (Figure 1). The districts include Bukedea and Kumi (from eastern Region) and Gulu and Oyam (northern Region) in 2019. The selected districts have the largest area under sorghum production. The study sites were purposefully selected based on the importance of sorghum production in the country and they differ from each other in terms of farming systems, edaphic and climatic factors, altitude and major vegetation cover (Wortmann and Eledu 1999). Bukedea (1°24’N, 34°5’E) and Kumi (1°30’N, 33°58’E) are found in the Southern and Eastern Lake Kyoga Basin agro-ecology situated at 1143 meters above sea level with mean annual temperatures of 28–31°C (Wortmann and Eledu 1999). This region receives bimodal rainfall with an annual precipitation of 1200 mm and has longer dry season from December to March. The soils are sandy loams of medium to low fertility with moist Combrentum and short grassland vegetation. The prevalent farming system in Kumi and Bukedea districts is finger millet, sorghum and maize production, whole livestock rearing is common in Teso area. Gulu (2°50’N, 32°21’E) and Oyam (2°20’N, 32°23’E) districts represented the Northern moist farmlands under northern farming system (Wortmann and Eledu 1999). Gulu and Oyam districts are situated at 1075 meters above sea level with mean annual precipitation between 1200 and 1500 mm and mean temperature of about 20°C. The common crops cultivated are finger millet, sorghum, maize, simsim and cassava. The northern moist farmlands are characterised by sandy and sandy-clay soils with low organic matter content and nutrient availability.

Sampling procedures

A preliminary survey was conducted in December 2018 in the selected districts to identify and select sub-counties where sorghum is mostly produced through farmer cooperatives and individual farmers. During the preliminary study, a team visited and organised meetings with each of the selected district extension officers. This enabled selection of sub-counties that produce the most sorghum. A multi-stage sampling procedure was used for the study. The first stage included a purposive selection of four sub-counties based on the importance of sorghum production from the selected districts in northern and eastern Uganda. This was followed by the selection of two parishes per sub-county in each district with the largest number of farmers and sorghum production for the study except in Oyam district, where the research was conducted in one parish (Supplemental Table S1). In the last sampling stage, farmers from the selected parishes that consistently cultivated sorghum for the last five years (2014–2018) were randomly selected from the list of all smallholder farmers (represented by the household head) provided
by extension officers to participate in the study. Overall, the PRA was conducted in seven parishes. A total of 183 farmers (128 interviewees and 55 group discussants) participated in the study (Supplemental Table S1). Interview participants during individual household survey were not involved in the Focus Group Discussions (FGDs) and no participant belonged to more than one focus group. Initially, the target size for each FGD was 15 individuals assuming that some invitees would not respond. However, sorghum farmers especially village elders or decision-makers who have grown the crop for the last five years in some villages that had not been invited showed interest and included in the group discussion. The interviewee was designated to participate in the study by mutual agreement among the married couples in each selected household.

**Data collection**

Data were collected using various PRA techniques; face to face interviews for semi-structured interviews, observations made by transect walks of 5 km across selected parishes guided by extension officers, pair-wise ranking, and discussions with focus groups. The FGD was conducted using a checklist of a predetermined study guide for quality data collection. Individual household surveys were conducted before the FGDs in all the study areas, and the research was conducted during the main crop season in 2019. The major crops and sorghum production constraints and varietal preferences were subsequently ranked using the pairwise matrix ranking method. In each district, group discussions were held among a group with a minimum of 14 members comprising of farmers, local leaders (village elders and decision-makers) and key informants (extension officers and experienced sorghum farmers), and the proceedings were recorded. All participants were encouraged to express their views and allowed to freely debate where necessary. In this study, the local extension agents facilitated the discussions using the local dialect of ‘Ateso’ (eastern Region) and ‘Luo’ (northern Region). Each farmer (128 interviewees) was administered a semi-structured questionnaire to supplement the findings of the group discussions. Complementary information was noted through personal observations during the transect walk across the sampled parishes. Observations were recorded regarding the sorghum varieties grown and the different uses of sorghum across the parishes.
Data analysis

Data collected from the FGD and household interviews were cleaned, coded and analysed using the statistical package for social scientists version 20 (SPSS 2011) and Microsoft Excel. To analyse relationships between variables; contingency chi-square tests were used to make statistical inferences at a 0.05 level of significance. The sorghum production constraints and varieties grown were subsequently ranked using pair-wise ranking method. The identified sorghum production constraints and varieties were labelled and tallied in a matrix, both in rows and columns and the scores were obtained from pair-wise ranking based on one-on-one comparisons and is equivalent to the frequency of the sorghum production constraints and the varieties. Finally, the scores were counted, sorghum production constraints, and sorghum varieties were ranked based on relative values. Meanwhile sorghum production constraints pointed by interviewee were also ranked according to the frequencies of the respondents. The agronomic and quality attributes were examined through principal component (PC) analysis based on Eigen values greater or equal to 1 by performing multiple response analysis to generate attributes frequencies of respondents which were later used for principal component analysis (PCA).

Results

Household characteristics

The results of the basic socio-demographic profile of the respondents in each district were summarised in Table 1. Most respondents (61.1%) were in the age group of 25–50, with only 12.5% of respondents below 25 years of age, whereas 23.4% were above 50 years of age. The majority (53.1%) of respondents were male and significantly ($\chi^2 = 16.816; p = .001$) higher than female participant farmers (46.9%) across the study sites. The majority (82.8%) of the households interviewed were male headed. Most respondents (64.8%) were household head; however, there was a close relationship between non-household head respondents and household head. For example, majority of non-household head respondents (80%) were spouses of the household heads followed by sons and daughters of the household head (15.6%). Most respondents (71.9%) were married and living with their spouses, while only 25.0% of respondents were without a spouse (single or never married, divorced/separated, and widow/widower). The majority of the respondents (53.1%) attained primary education. In comparison, 29.7% attained secondary education. However, 7.8% of the respondents interviewed did not attend any formal education, with the highest percentage (12.5%) recorded in Kumi and Oyam districts. The differences in the main occupation of the respondents and household head across the study sites were significant ($\chi^2 = 28.954; p = .049$ and $\chi^2 = 27.409; p = .007$ respectively), and most households (77.3%) interviewed agreed that they entirely earned their living on crop and animal farming, followed by employment on farms (11.7%) and the few respondents with no main occupation were students. The same trend was recorded among the household head where most household head (75.8%) earned their living on crop production and animal rearing followed by salaried employment and casual farm labourer.

Sorghum production and cropping system

Detailed descriptions of sorghum production and the cropping systems in the study areas are presented in Table 2. During FGDs, all the participants reported two cropping seasons across the districts, with the second rainy season being the most preferred cropping season for sorghum production. They prepare another piece of land for the second season planting of sorghum. This was validated during individual household surveys, where more than half (50.8%) of the respondents reported that they produce their sorghum in the second rainy season though with non-significant difference across the two seasons ($\chi^2 = 5.57; p = .135$). Sorghum uses were significantly different among the respondents ($\chi^2 = 26.554; p = .002$). The farmers grow sorghum for sale (41.4%), brewing (24.2%), and for consumption (23.4%). There were significant differences in sorghum variety grown ($\chi^2 = 12.387; p = .006$) and planting methods ($\chi^2 = 9.563; p = .023$) across the districts. The majority (90.6%) of farmers still plant sorghum landraces (75.8%) by broadcasting. Only 6.3% of farmers in Gulu district grow sorghum as the sole crop. In contrast, most of the farmers in Bukedea, Kumi and Oyam preferred growing sorghum as a sole crop. Overall, across the study sites, the majority (62.5%) of the farmers significantly ($\chi^2 = 58.667; p = .000$) grow sorghum as the sole crop compared to intercrop (37.5%).

Major sorghum varieties grown and farmers trait preferences

Farmers were asked to identify the most popular sorghum varieties grown in the last five years of 2014–2018, and different sorghum varieties were reported across the districts. The participants identified local landraces within their farming system with local names; Abir,
Ekolir, Eyera and Ilodir (Eastern Uganda) and Dnoa and Kabir (Northern Uganda) which were classified as local varieties (landraces) for easy identification during this PRA. The farmers also indicated growing some popular improved varieties (released and disseminated varieties) in the study sites, namely, Epuripur, Sekedo, Serena, SESO1, SESO3 and Sila hybrid. The landrace was the most (58.5%) commonly grown sorghum variety by the farmers (Supplemental Figure S1) because the seeds are readily available, free of charge with farmer-preferred traits (Table 4). Most farmers (87.1%) grow one sorghum variety per season across the study area. According to farmers ranking by market value (market demand), the details of sorghum variety most preferred by farmers are presented in Table 3. In terms of market value, farmers in Gulu and Oyam, mostly preferred Epuripur. In contrast, farmers in Kumi preferred landraces, followed by the improved sorghum variety, SESO3.

### Table 1. The basic socio-demographic profile of the respondents and household heads.

| Variable                                | Class                  | Bukedea (n = 32) | Gulu (n = 32) | Kumi (n = 32) | Oyam (n = 32) | Mean | df | Chi-Square | p-value |
|------------------------------------------|------------------------|------------------|---------------|--------------|--------------|------|----|------------|---------|
| Age (year)                               | <25                    | 18.8             | 12.5          | 12.5         | 6.3          | 12.5 | 6  | 4.784      | .572    |
|                                          | 25–50                  | 56.3             | 68.8          | 56.3         | 75           | 64.1 |    |            |         |
|                                          | >50                    | 25               | 18.8          | 31.3         | 18.8         | 23.4 |    |            |         |
| Gender                                   | Male                   | 34.4             | 56.3          | 40.6         | 81.3         | 53.1 | 3  | 16.816     | .001    |
|                                          | Female                 | 65.6             | 43.8          | 59.4         | 18.8         | 46.9 |    |            |         |
| HH head status                           | Male headed            | 78.1             | 78.1          | 84.4         | 90.6         | 82.8 | 3  | 2.415      | .491    |
|                                          | Female headed          | 21.9             | 21.9          | 15.6         | 9.4          | 17.2 |    |            |         |
| Respondent relationship status with HH head | Spouse                | 75.0             | 90.0          | 80.0         | 75.0         | 80.0 | 9  | 6.295      | .710    |
|                                          | Son/daughter           | 25.0             | 10.0          | 20.0         | 7.5          | 15.6 |    |            |         |
|                                          | Son/daughter-in-law    | 0.0              | 0.0           | 0.0          | 0.0          | 0.0  |    |            |         |
|                                          | Other relative         | 0.0              | 0.0           | 0.0          | 6.7          | 2.2  |    |            |         |
| Education level                          | None (iliterate)       | 6.3              | 0             | 12.5         | 12.5         | 7.8  | 12 | 14.307     | .282    |
|                                          | Basic                  | 6.3              | 0             | 0            | 0            | 1.6  |    |            |         |
|                                          | Primary                | 53.1             | 56.3          | 50           | 53.1         | 53.1 |    |            |         |
|                                          | Secondary              | 25               | 40.6          | 25           | 28.1         | 29.7 |    |            |         |
|                                          | College                | 9.4              | 3.1           | 12.5         | 6.3          | 7.8  |    |            |         |
| Marital status                           | Married living with spouse | 68.8             | 78.1          | 71.9         | 84.4         | 75.8 | 12 | 7.669      | .81     |
|                                          | Married but spouse away | 6.3              | 6.3           | 3.1          | 3.1          | 4.7  |    |            |         |
|                                          | Divorced/separated     | 0.0              | 3.1           | 3.1          | 0            | 1.6  |    |            |         |
|                                          | Widow/widower          | 9.4              | 3.1           | 12.5         | 9.4          | 8.6  |    |            |         |
|                                          | Never married          | 15.6             | 9.4           | 9.4          | 3.1          | 9.4  |    |            |         |
| Main occupation                          | No occupation          | 0.0              | 3.1           | 0            | 0            | 0.8  | 18 | 28.954     | .049    |
|                                          | Farming (crop + livestock) | 62.5             | 87.5          | 65.6         | 93.8         | 77.3 |    |            |         |
|                                          | Salaried employment    | 3.1              | 6.3           | 6.3          | 0            | 3.9  |    |            |         |
|                                          | Self-employed off farm | 3.1              | 0             | 0            | 3.1          | 1.6  |    |            |         |
|                                          | Casual labourer on farm | 21.9             | 0             | 25           | 0            | 11.7 |    |            |         |
|                                          | Herds boy/girl         | 3.1              | 0             | 0            | 0            | 0.8  |    |            |         |
|                                          | Other business         | 6.3              | 3.1           | 3.1          | 3.1          | 3.9  |    |            |         |
| Main occupation of HH head              | Farming (crop + livestock) | 59.4             | 90.6          | 62.5         | 90.6         | 75.8 | 12 | 27.409     | .007    |
|                                          | Salaried employment    | 18.8             | 6.3           | 12.5         | 0            | 9.4  |    |            |         |
|                                          | Self-employed off farm | 0.0              | 0.0           | 6.3          | 6.3          | 3.1  |    |            |         |
|                                          | Casual labourer on farm | 18.8             | 0            | 18.8         | 0            | 9.4  |    |            |         |
|                                          | Other business         | 3.1              | 3.1           | 0.0          | 3.1          | 2.3  |    |            |         |

Notes: df = Degree of freedom; HH = Household; n-value for respondent HH head relationship =45 (Bukedea, n = 16; Gulu, n = 10; Kumi, n = 15; and Oyam, n = 4); p-value at .05 level.

### Table 2. The sorghum cropping system of the households.

| Variable                                | Class                  | Bukedea (n = 32) | Gulu (n = 32) | Kumi (n = 32) | Oyam (n = 32) | Mean | df | Chi-Square | p-value |
|------------------------------------------|------------------------|------------------|---------------|--------------|--------------|------|----|------------|---------|
| Variety grown                            | Improved              | 21.9             | 6.3           | 25           | 43.8         | 42.4 | 3  | 12.387     | .006    |
|                                          | Landraces             | 78.1             | 93.8          | 75           | 56.3         | 75.8 |    |            |         |
| Preferred season                          | 1st season (March to June) | 62.5             | 33.3          | 46.9         | 53.6         | 49.2 | 3  | 5.57       | .135    |
|                                          | 2nd season (August to December) | 37.5             | 66.7          | 53.1         | 46.4         | 50.8 |    |            |         |
| Cropping system                           | Sole crop             | 87.5             | 6.3           | 81.3         | 75           | 62.5 | 3  | 58.667     | .000    |
|                                          | Intercrop             | 12.5             | 93.8          | 18.8         | 18.8         | 18.8 |    |            |         |
| Planting method                           | Row                   | 3.1              | 0             | 18.8         | 15.6         | 9.4  | 3  | 9.563      | .023    |
|                                          | Hand broadcast        | 96.9             | 100           | 81.3         | 84.4         | 90.6 |    |            |         |
| Main purpose of sorghum production       | Food                  | 31.3             | 15.6          | 18.8         | 28.1         | 23.4 | 9  | 26.554     | .002    |
|                                          | Cash (sale)           | 40.6             | 43.8          | 46.9         | 34.4         | 41.4 |    |            |         |
|                                          | Livestock feed        | 0.0              | 31.3          | 0            | 12.5         | 10.9 |    |            |         |
|                                          | Brewing               | 28.1             | 9.4           | 34.4         | 25           | 24.2 |    |            |         |

Note: Improved varieties = released and disseminated varieties.
The specific trait preferences such as high yields, early maturity, drought tolerance, market value and brewing qualities were the many reasons for growing the improved sorghum varieties (Table 4). The farmers stated several reasons for their dislike of local varieties, such as late maturity, low yields, low market value, high levels of tannin, and susceptible to Striga. However, high yields, drought tolerance, pest and diseases resistance, readily available seeds, good taste and limited production input requirements were the major reasons for the consistent use of sorghum landraces by farmers.

Almost all the farmers suggested a need to improve sorghum attributes, except few farmers in Gulu (14.3%) and Oyam (5%) who were cautious about crop improvement without compromising the good traits in their landraces. More than 15 desirable sorghum attributes were prioritised by farmers and their order of importance were assessed using the PCA (Table 5). The first three PCs with Eigen values >1 explained 100% of the variation in sorghum attributes to be improved among the respondent farmers. Short to medium plant height had the highest PC1 loading scores of 0.97, followed by high grain yield, Striga resistance, early maturity, good taste and aroma, resistance to drought tolerance, pests and diseases respectively (Table 5). Interestingly, farmers were able to report some of the quality attributes with the highest contribution based on PC2 such as long storage shelf life (0.93), sweet stalk (0.81), low levels of tannins (0.81), high malting ability and brewing quality (0.8), threshability (0.77) and highly nutritious sorghum (0.67) as one of the positive attributes to be introduced during crop improvement. However, the sorghum quality trait preference was further validated, and results indicated that over 89% of the farmers expressed their preferences for quality attributes improvement in the sorghum breeding program. Most farmers urged that the quality attributes in sorghum will be shaped by enhancing baking quality (with loading score of 0.94) followed by highly nutritious sorghum varieties (0.81), attractive brown to light red seed colour (0.78), easy to process (0.65), and good taste and aroma (0.54) based on PC1 contribution (Table 6). Other quality attributes preferred by farmers were high malting and brewing quality, large grain size and low levels of tannin based on PC2 contribution.

### Sorghum production constraints

Farmers reported the constraints to sorghum value-chain during production, processing, consumption and marketing in Uganda (Table 7). A lack of improved crop varieties (released and disseminated varieties) was ranked as the major constraint across the study areas.

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**Table 3.** Pairwise ranking of sorghum varieties grown in the three districts in the last five years (2014–2018) and farmer group according to market value (market demand) in Uganda.

| Sorghum varieties | Gulu | Kumi | Oyam |
|-------------------|------|------|------|
| Epuripur          | Score Rank | Score Rank | Score Rank |
|                   | 2 1 | 2 4 | 3 1 |
| Local (Landraces) | 0 3 | 5 1 | 0 4 |
| Sekedo            | - - | 1 6 | - - |
| Serena            | 1 2 | 3 3 | 1 3 |
| SESO1             | - - | 1 5 | - - |
| SESO3             | - - | 3 2 | - - |
| Sila Hybrid       | - - | 2 2 | - - |

Notes: The scores were obtained from pairwise ranking and is equivalent to the frequency of the sorghum variety in a column and row representing the sorghum variety. Low score = high ranking indicating sorghum varieties is less preferred. In case of a tied score, voting was carried out to rank the respective sorghum varieties. Whereas – denotes sorghum variety not reported.

**Table 4.** Sorghum varieties grown and their associated attributes.

| Varieties       | Gulu                        | Kumi                        | Oyam                        | Non-preferred traits |
|-----------------|-----------------------------|-----------------------------|-----------------------------|----------------------|
| Epuripur        | High yielding, early maturing | High yielding, early maturing | High yielding, early maturing | High bird damage     |
| (Local Landraces)| Tolerant to drought and pest and diseases, resistant to bird damage, readily available seeds, good taste, and limited production input requirements | Tolerant to drought and pest and diseases, resistant to bird damage, readily available seeds, good taste, and limited production input requirements | Tolerant to drought and pest and diseases, resistant to bird damage, readily available seeds, good taste, and limited production input requirements | Low yields |
| Sekedo          |                             |                             |                             | Low yields            |
| Serena          |                             | Cash and food security      |                             | Low yields            |
| SESO1           |                             | High yielding, early maturing |                             | High bird damage and not tasty and poor aroma |
| SESO3           |                             | High food and market value, |                             | Non-tasty and aroma  |
| Sila Hybrid     |                             | High yielding, early maturing |                             | High bird damage     |

Note: – denotes sorghum variety not grown.
Table 5. Principal component analysis of major sorghum agronomic attributes reported in four districts in Uganda.

| Variables                                      | PC1     | PC2     | PC3     |
|------------------------------------------------|---------|---------|---------|
| Eigen values                                   | 7.07    | 5.23    | 3.69    |
| Proportion of variance (%)                     | 44.2    | 32.71   | 23.09   |
| Cumulative variance (%)                        | 44.2    | 76.91   | 100.00  |
| High yielding variety                          | -0.92   | -0.26   | 0.3     |
| Early maturity                                 | 0.88    | 0.2     | 0.44    |
| Resistant to pests and diseases                | 0.63    | -0.36   | 0.69    |
| Drought tolerance                              | 0.76    | -0.07   | 0.65    |
| Long storage shelf life                        | 0.22    | -0.93   | 0.3     |
| Resistant to Striga                            | 0.92    | -0.4    | -0.05   |
| Resistant to birds                             | -0.26   | 0.43    | 0.87    |
| Good taste and aroma                           | -0.79   | 0.23    | 0.57    |
| Threshability                                  | -0.31   | -0.77   | 0.57    |
| High malting ability/brewing quality           | -0.56   | 0.8     | -0.24   |
| Highly nutritious sorghum variety              | -0.58   | 0.67    | -0.45   |
| Attractive seed colour, i.e., white/brown      | 0.5     | -0.31   | -0.81   |
| Short to medium plant height                   | 0.97    | 0.11    | -0.2    |
| Low tannins                                    | 0.57    | 0.81    | 0.15    |
| Stay green trait                               | 0.57    | 0.81    | 0.15    |
| Sweet stalk variety                            | 0.57    | 0.81    | 0.15    |

PC = Principal Component, Bold face values denote high score values indicating the preferred agronomic attributes.

Other important constraints reported by farmers with an average mean of above 50 were drought, lack of agricultural extension services, high costs of production input, bird damage, limited access to markets, unavailability of production inputs, small land holdings and insect pests. However, the importance of these production constraints varied from one district to another (Table 8).

For instance, in Gulu, land shortage was ranked as the most important production constraint, followed by drought, lack of storage facilities and wildfire. In Kumi, the information gap (lack of agricultural extension services) was of prime importance, followed by pests and diseases, bird damage, Striga and soil fertility. In Oyam, drought was reported as the major constraint, followed by a lack of improved crop varieties (released and disseminated varieties), limited market access and pests and diseases.

Table 6. Principal component analysis of sorghum quality attributes reported in the study area.

| Variables                                      | PC1     | PC2     | PC3     |
|------------------------------------------------|---------|---------|---------|
| Eigen values                                   | 3.50    | 3.10    | 2.39    |
| Proportion of variance (%)                     | 38.91   | 34.49   | 26.60   |
| Cumulative variance (%)                        | 38.91   | 73.40   | 100.00  |
| Long storage shelf life                        | 0.50    | 0.10    | -0.86   |
| Easy to process                                | 0.65    | 0.76    | 0.07    |
| Good taste and aroma                           | 0.54    | -0.35   | 0.76    |
| Attractive red to brown seed colour            | -0.78   | 0.53    | -0.34   |
| High malting and brewing quality               | -0.06   | -0.99   | 0.16    |
| Highly nutritious sorghum variety              | -0.81   | 0.14    | 0.57    |
| Baking quality                                 | 0.94    | 0.35    | -0.03   |
| Low levels of tannin                           | 0.40    | 0.53    | 0.75    |
| Large grain size                               | 0.50    | -0.84   | -0.19   |

PC = Principal Component, Bold face values denote high score values indicating the preferred quality attributes.

Table 7. Mean constraints to sorghum in growing, processing, utilisation and marketing in four districts of Uganda.

| Production constraints                        | Mean weight | Sd  | Se  | Rank |
|------------------------------------------------|-------------|-----|-----|------|
| Lack of improved crop varieties               | 82.8        | 121.2| 60.6| 1    |
| High climate variability (drought)            | 71.0        | 73.1 | 36.6| 2    |
| Lack of agricultural extension services       | 69.3        | 83.6 | 41.8| 3    |
| High cost of production inputs                | 64.3        | 77.9 | 38.9| 4    |
| Bird damage                                   | 62.0        | 58.0 | 29.0| 5    |
| Limited access to markets                     | 61.0        | 59.7 | 29.8| 6    |
| Unavailability of production inputs           | 56.5        | 60.4 | 30.2| 7    |
| Diseases                                      | 51.5        | 53.2 | 26.6| 8    |
| Small land holding                            | 51.5        | 51.2 | 25.6| 9    |
| Insect pests                                  | 50.8        | 49.1 | 24.6| 10   |
| Other weeds                                   | 46.0        | 42.9 | 21.4| 11   |
| Low soil fertility                            | 44.0        | 36.1 | 18.1| 12   |
| Lack of labour                                | 38.5        | 30.4 | 15.2| 13   |
| Striga                                        | 38.0        | 46.9 | 23.5| 14   |
| Vermins                                       | 14.3        | 13.7 | 6.9  | 15   |

Note: Sd = Standard deviation; se = Standard error of means.

Table 8. Pairwise ranking of major sorghum production constraints in the three districts and farmer group according to the importance.

| Constraints                                      | Gulu | Kumi | Oyam |
|--------------------------------------------------|------|------|------|
|                                                 | Wameno | Anyin Koefa | Warring |
| Information gap                                 | 6     | 1     | –    |
| Pests and diseases                               | 6     | 2     | 4    |
| Soil infertility                                 | 3     | 5     | 4    |
| Lack of improved crop varieties                 | 3     | 5     | 6    |
| Unavailability of production inputs              | 3     | 7     | –    |
| Limited access to market                         | 6     | 6     | 9    |
| Land shortage                                    | 5     | 5     | 1    |
| Drought                                          | 5     | 4     | 1    |
| Bird damage                                      | 3     | 3     | 1    |
| Wildfire                                         | 2     | 3     | 5    |
| Lack of storage facilities                       | 3     | 3     | –    |

Notes: The scores were obtained from pairwise ranking and is equivalent to the frequency of the production constraints in column and row representing the constraints. Low score = high ranking indicating production constraints not reported.

The role of sorghum in the farming system and people’s diet

Various processing methods of sorghum for consumption by the respondents are summarised in Table 9. Sorghum processing methods (χ² = 36.159; p = 0.000) and food value (χ² = 37.965; p = 0.000) vary significantly across the studied districts. The corticated whole grain is typically pounded locally to make flour, which is then mixed with the cassava flour (52.2%) to make local bread (posho). More than 28% of the farmers use sorghum flour only to make local bread. The sorghum flour is also used for making soft porridge by 18.2% of the respondents, while 0.6% blended sorghum with
other nutritious foods such as soybean and sweet potatoes before used for making either local bread or soft porridge. However, from group discussion, they further stressed that sorghum grains are consumed boiled. The majority (65.3%) of the farmers identified low levels of protein as the major food deficiency in sorghum, followed by high levels of tannin (12.9%), lack of minerals (6.8%), and lack of oils (2.7%). Some farmers (12.2%) failed to report any deficiency in sorghum food value due to a lack of knowledge about food nutrition. However, most farmers suggested breeding as a viable strategy for enhancing the nutrient content of sorghum. Other nutrient enhancement strategies proposed by farmers were sorghum blending with other nutritious food crops like soybean and orange-fleshed sweet potatoes and enhancing food processing techniques. However, about 14% of farmers did not have an idea of how to enhance the nutritional quality of sorghum.

**Discussions**

**The basic socio-demographic profile of the farmers**

The present study examined farmers’ perceptions of sorghum production constraints, varietal trait preferences and the role of sorghum in farming systems and people’s diets to champion sorghum biofortification in Uganda. This study reports the first case effort to understand sorghum production constraints with preferred farmer variety traits mainly targeting nutritional quality traits (Fe, Zn, and protein) of sorghum in the country. Significantly a high proportion of males were recorded than female. The host families were mostly male headed with the most interviewee (64.8%) being household head who were selected based on mutual agreement by the host couple in each selected household (Table 1). These trends are a probable reflection of social differences between men and women owing to the decision-making at the household regarding crops production as observed in this study. In a similar study, Suvi et al. (2020) concluded that males were mostly household heads, control and make decision in most of the key aspects of agricultural production in Africa. Majority of the respondents were in the age group of 25–50 which is considered the most dynamic group for sorghum production in Africa. In a related study, old farmers in Sudan had the lowest sorghum production efficiency compared to young farmers in the age group of 25–35 years (Bushara and Abuagla 2016). A study conducted by Suvi et al. (2020) revealed that the same age group (25–50) of farmers were more involved in rice production in Tanzania. It was found that most respondents were married and living with their spouses with majority attaining some formal level of education (Table 1). The marital status helps to determine the level of participation in decision-making along with the sorghum production and marketing chain. This educated class of farmers in this current study is a power agent for rural socio-economic transformation since they may act as model farmers to other smallholder farmers for new technology adoption. The same educated class in this study acknowledged providing training to fellow farmers in addition to gathering information on agricultural production; constraints, needs and preferences in the community. These results are in agreement with Chepng’etich et al. (2015) findings where they reported that farmers with formal education were more efficient in sorghum production than their counterparts with non-formal education thus enhancing the education level of farmers would improve the technical efficiency of agricultural

| Variables                                      | Bukedea (n = 32) | Gulu (n = 32) | Kumi (n = 32) | Oyam (n = 32) | Mean | df | Chi-Square | p-value |
|------------------------------------------------|-----------------|--------------|--------------|--------------|------|----|------------|---------|
| Food preparation (%)                           |                 |              |              |              |      |    |            |         |
| Bread (sorghum flour only)                     | 34.2            | 7.1          | 44.7         | 28.1         | 28.9 |   |            |         |
| No idea                                        | 34.2            | 7.1          | 44.7         | 28.1         | 28.9 |   |            |         |
| Low levels of protein                          | 51.4            | 66.7         | 69.7         | 73           | 65.3 |   |            |         |
| High level of tannins                          | 22.9            | 23.8         | 0.0          | 2.7          | 12.9 |   |            |         |
| Lack of oils                                   | 5.7             | 0.0          | 0.0          | 5.4          | 2.7  |   |            |         |
| Lack of minerals/vitamins                      | 0.0             | 9.5          | 3            | 13.5         | 6.8  |   |            |         |
| Strategies for improving food value (%)        |                 |              |              |              |      |    |            |         |
| No idea                                        | 20.6            | 0.0          | 27.8         | 13.5         | 14.7 | 9 | 16.814     | .052    |
| Improve sorghum nutrition through breeding     | 41.2            | 58.1         | 44.4         | 45.9         | 48   |   |            |         |
| Mix sorghum with other nutritious food crops   | 20.6            | 30.2         | 22.2         | 21.6         | 24   |   |            |         |
| Enhance food processing techniques             | 17.6            | 11.6         | 5.6          | 18.9         | 13.3 |   |            |         |

Table 9. Sorghum food preparation, food value deficiency and strategies for enhancing the food value.
production. The results indicated that most households are dependent on crop and animal farming. The majority of non-household head respondents had close relationship (such as spouses and sons and daughters of the household heads) with household heads (Table 1) as initially targeted by this study.

**Sorghum production and cropping system**

Uganda has a diverse cropping system with cereals, legumes, oil crops, fruit crops, vegetables and root crops grown either as sole or intercrops. The study indicated that farming was the most important economic activity in the study districts. Sorghum is a widely grown crop across the study area mostly by broadcasting. Farmers mainly grow sorghum for sale (cash), brewing and food to a lesser extend for animal feed (Table 2) which probably indicated that sorghum has gradual change from a food crop to a cash crop with a readily available market for commercial beer lager production in the country as cited by Andiku et al. (2020). Equally important, Sorghum is a staple food crop for the rural poor in Uganda despite being deficient in food value such as low levels of bioavailable protein, minerals (Fe and Zn), and oils in addition to having high levels of tannin (Table 9). Majority of the farmers plant sorghum landraces as the sole crop by broadcasting with few improved sorghum varieties (such as Epur-ipur, SESO1 and SESO3) (Supplementary Figure S1). They prefer planting sorghum in the second rainy season. They urged that there is a low bird damage (migratory movement of birds in first season duration) during the second rainy season in addition to adequate amount of rainfall for sorghum production in the second rainy season. Farmers mostly grow landraces because of several preferred traits (drought tolerant, pest, and disease resistance, resistant to bird damage, readily available seeds, good taste and aroma and limited input requirements for production) (Table 4) which is in the agreement with findings of Mrema et al. (2017), where sorghum landraces were preferred in Tanzania due to adaptability, limited production costs, birds and storage pests resistance, drought and weed tolerance, high market value, good cooking quality and seed availability which agrees with our current study. They further highlighted that landraces have high open market demand and attractive brown to red seed colour which can be used for dual purpose compared to improved varieties. Conversely, farmers cited several non-preferred traits in landraces such as late maturity, low yields, low market value, high levels of tannin and susceptible to *Striga* (Table 4). These traits can be targeted by sorghum breeders to develop improved sorghum with farmer-preferred traits. Moreover, during the transect walk, less bird damage was observed on the brown and light red coloured grain sorghum than the chalky white seeded sorghum though brown seeded sorghum was associated with high levels of tannins. These findings suggested that brown coloured sorghum is more preferred than white seeded sorghum. In a related study, farmers preferred their own saved varieties because of some special preferred attributes (Witcombe 2009) as discovered in the current study. The result further showed that sorghum varieties differed from one region to another (Table 3). This is probably because of the distance of this region from research centres, National Agricultural Semi-Arid Resources Research Institute (NaSARRI) unlike Kumi with close proximity to the NaSARRI, where more improved sorghum varieties were grown by farmers. Therefore, there is an urgent need to widely disseminate the released sorghum varieties in all the major showing growing areas.

**Sorghum varietal preferences**

Farmers who participated in this study preferred sorghum varieties with short to medium plant height, high grain yield, *Striga* resistance, early maturity, good taste and aroma, drought resistance, pests and diseases resistance and quality attributes without under looking the preferred traits in their landraces (Table 5). They further preferred some specific quality attribute; baking quality, nutrition, brown to light red seed colour, easy to process and good taste and aroma (Table 6). The trait preference by farmers is indeed an important aspect because the type of crop variety grown by farmers enhances crop productivity. Different trait preferences (sorghum production constraints) were observed across the study districts (Table 8). For example, the *Striga* resistance preference was only observed in Eastern Uganda (Bukedea and Kumi) probably because the *Striga* persistence in the region unlike in Gulu and Oyam where no *Striga* case has ever been reported. Therefore the various farmer varietal preferences reported in this study could be attributed to the different agro-ecological and socio-economic conditions, production constraints, consumption preferences, specific market requirements, production goals and different varietal traits preferences across the study (Christinck et al. 2017). As stated early, mostly landraces were grown by the farmers in the study area and these diverse landraces are low yielding and late maturing (cannot escape drought) with tall height (difficulty to harvest). Hence these attributes were reported as the most striking traits to be introduced in
the study area with enhanced nutritional quality traits (Tables 5 and 6). This is in agreement with the findings of Robert (2011) who noted that farmers in Uganda had various varietal preferences and they preferred red grain colour, erect and compact heads, short plant heights, early maturing varieties, Striga resistant and drought-tolerant sorghum varieties. Therefore, developing sorghum variety with the reported farmer’s preferred traits and wide adaptability under the prevailing harsh environmental conditions in the country will likely be accepted by the majority of the farmers. Mrema et al. (2017) cited that, variety with yield improvement without most of the preferred farmers’ traits were rejected in most parts of Africa thus participatory developed variety with farmer-preferred traits in crop improvement will be highly owned by farmers.

**Sorghum production constraints**

Across the study sites, farmers identified a lack of improved crop varieties (released and disseminated varieties) as the leading constraint to sorghum production followed by drought, lack of agricultural extension services, high costs of production input, and bird damage (Table 7) which is contrary to PRA conducted by Robert (2011) where he reported Striga as the major sorghum production constraint in Uganda probably because his study concentrated only within Striga infestation areas of the country. According to the respondent farmers, improved sorghum variety is a released and disseminated sorghum variety with farmer-preferred traits including striga resistance and other traits. Farmers used their own saved unimproved crop varieties (landraces) with poor yield and nutritional quality traits as reported in this study. Moreover, the landraces are susceptible to drought, Striga, pests and diseases, and birds, soil infertility as cited by Andiku et al. (2020). More interestingly, both abiotic (drought, soil fertility, lack of agricultural extension services, high costs of production inputs, limited access to markets, unavailability of production inputs, small landholdings) and biotic (bird damage, pests and diseases, Striga) factors were reported by the farmers as the major sorghum production constraints in the study area. These sorghum production constraints have been reported as major sorghum production constraints in many parts of Africa including Uganda (Mrema et al. 2017; Orr et al. 2016). More importantly, drought was reported as the second important sorghum production constraints across the study districts. This is not surprising since farmers are yet to adapt to the ever-changing climatic condition in the country. In Ethiopia (the largest sorghum producer in ESA), drought and Striga were reported as the most important constraints in sorghum production (Gebretsadik et al. 2014). However, it should be noted that the importance of these production constraints varied from one district to another probably because of different agro-ecological and socio-economic conditions, farming systems, and production goals across the districts. For example, bird damage was not mentioned as an important sorghum production constraint in Gulu district. This trend is a probable reflection that white seeded sorghum such as SESO 1 (liked by birds) is not grown on large scale by farmers in Gulu district. This was observed during the study period (Table 3) and the transect walk.

**Sorghum role in the farming system and people’s diet**

Sorghum is mainly used as staple food commonly among the rural people in the developing countries including Uganda. Farmers consume sorghum in different forms in Uganda and good sorghum food preparation methods were reported by farmers in this study (Table 9). Farmers mainly pounded sorghum grain to make flour, which is then mixed with the cassava flour to make local bread. However, these sorghum grains are reported to have low levels of bioavailable proteins, minerals (iron and zinc) and oils and high levels of tannins (Table 9). These results agreed with the study conducted by Reddy et al. (2005) where they observed a low quantity of minerals over a large set of sorghum accessions. Indeed, majority of the farmers in this study proposed conventional breeding as the most viable strategy for enhancing the nutritional quality traits of these sorghum grains. Bio-fortification of sorghum through conventional breeding by enhancing mineral micronutrients especially iron (Fe) and zinc (Zn), protein and other quality traits in grain has been proposed as a sustainable strategy according to Kumar et al. (2009) and Pfeiffer and McClafferty (2007). The same strategy was proposed by Bouis et al. (2011) where they suggested conventional breeding as a sustainable and cost-effective alternative to transgenic- and agronomic-based approaches and therefore it is the most accepted method of biofortification. Importantly, these results provide strong evidence to develop integrated research approaches to breed sorghum varieties with farmer-preferred traits including quality nutritional traits for enhanced adoption. Therefore, there is an urgent need to broaden the study scope by developing and disseminating nutritionally enhanced sorghum with associated technologies to sorghum farmers.
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