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Sorghum Production Constraints, Trait Preferences, and Strategies to Combat Drought in Tanzania

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Abstract: Sorghum is an important food crop for people in drought-prone areas of the world. The production in Tanzania has been $\leq$1 t ha^{-1} for a decade. The study was conducted in Iramba, Ikungi, and Kongwa districts to identify factors influencing the sorghum production, adoption rate, and strategies to address drought in Tanzania. The study involved 240 respondents for individual interviews and focus group discussions. Thirty respondents participated in individual interviews while ten farmers participated in the focus group discussion per village. Our study found that birds, poor soil fertility, and drought were the major constraints across the study districts. Drought tolerance, high yield, and early maturity were the most preferred traits by farmers across the study areas. Farmers addressed drought stress in sorghum by practicing early planting early maturing varieties in November and using drought-tolerant varieties. However, most farmers failed to name the diseases and pests affecting sorghum. This study highlights basic information for plant breeders to incorporate traits preferred by farmers in breeding programs when developing new sorghum varieties for sustainable production. The study shows the importance of involving farmers to identify the problems and solutions of sorghum production to increase the adoption rate.

Keywords: adoption rate; drought tolerance; pests and diseases; sorghum production constraints; traits preference

1. Introduction

It is projected that the global population will reach 2 billion people in 2050 due to high birth rates, especially in Sub-Saharan Africa and Asia [1]. The sustainable use of natural resources such as reforestation, contour farming, and tide ridge, organic application in the soil, and use of the improved technologies is important to increase crop production to secure food for people in semi-arid areas [2]. The current food security status in semi-arid areas of Sub-Saharan Africa is low, which entails risks of hunger [3]. Sorghum adapts well in drought-prone areas with fragile soil in the world; therefore, it is regarded as an important crop for food production in long-term use for food security [4]. Tanzania is one of the sorghum producers in East Africa for food and animal feed as well as beer production; its is also a gluten-free energy source that is high in dietary fiber and minerals [5–7]. In Tanzania, however, its mean yield is $\leq$1 t ha^{-1}, which is too low compared to global producers; for instance, Oman produces the highest (28.11 t ha^{-1}), followed by Jordan and Algeria with productivity of 22.21 t ha^{-1} and 13.71 t ha^{-1}, respectively [8,9].

Efforts have been made to increase sorghum production by importing new varieties into Tanzania. Nonetheless, only 5% of the local farmers have adopted these new varieties and the productivity has remained stagnant [10]. Low yield advantage to some of the improved sorghum varieties versus landraces causes a low adoption rate [11]. Nevertheless, sustainable exploitation of potentials in sorghum is low as the crop is drought-tolerant and can, therefore, be cultivated in drought-prone areas to safeguard food security for the people and livestock [12]. The effect of climate change has increased the temperature; floods and poor distributions of rainfall have also increase, which has affected the crop performance. Sorghum is a C_4 plant with high photosynthetic efficiency; however, its physiological growth and production parameters are impaired under extreme drought stress during post-flowering growth [13,14]. At that stage, drought causes poor grain filling, small panicle size, reduction in grain number, and low grain yields, which exacerbate food shortages [15,16].

Apart from drought, poor soil fertility persists in sorghum farms in semi-arid regions of Tanzania. This is caused by high soil erosion, deforestation, burning of vegetation, poor agricultural practices, and unpredicted rainfall [17]. The depletion of nutrients such as nitrogen, phosphorus, and potassium is high, but the application rate of fertilizers in Tanzania is 15.9 kg ha^{-1}, which is far below the average world recommendation of 162 kg ha^{-1} [2]. Diseases and pests are difficult to control; for example, *Striga* (witchweed) on cereal crops may cause 100% sorghum yield loss [18]. The technical information to diagnose and control pests and diseases at an early stage in sorghum is important to minimize its prevalence [19]. The application of the recommended rate of pesticides in crops reduces chemical residuals in the soil, which sustains land for future farming [20]. Efforts have been made to develop new adapted sorghum varieties to address biotic and abiotic effects in sorghum. The Wahi and Hakika varieties are drought-tolerant, mature early, and resist *Striga*; nonetheless, they are difficult to shell, susceptible to storage pests, and Wahi has poor germination [21]. Sorghum farmers lack training in differentiating between the traits of imported and indigenous sorghum varieties. The adoption of improved sorghum varieties has been low for decades compared to local sorghum varieties because of seed access, resistance to storage pests, and affordable prices [22]. Experience shows that high demand of sorghum grains raises price due to decrease of crop production and low quality [23]. The United States of America, as the major sorghum grains exporter globally, controls trends of market prices which affect developing countries [24]. Farmers who live in Tanzania face food shortage almost every year due to erratic rainfall and poor agricultural systems.

Adopting improved sorghum seeds and good agronomic practices is important to enhance yield [7]. Therefore, our study aimed to identify factors influencing the production and adoption rate of improved sorghum varieties as well as strategies to address drought in Tanzania.

2. Materials and Methods

2.1. Study Area

The study was conducted in the representative Dodoma and Singida regions of Tanzania. These are potential areas of sorghum production in the country. The Dodoma region was represented by the Kongwa district (6.200° S 36.417° E/−6.200; 36.417) and the Singida region was represented by the Ikungi (−5°07′60.00″ S 34°45′59.99″ E) and Iramba (−4°25′16.14″ S 34°18′9.65″ E) districts. The temperature ranges between 25 and 32 °C, whereas the rainfall ranges from 350 to 700 mm annually. Rainfall starts in December and occurs until the end of April. The areas are characterized by a dry spell, which lasts for 2–4 weeks during the rainy season (see Figure 1).

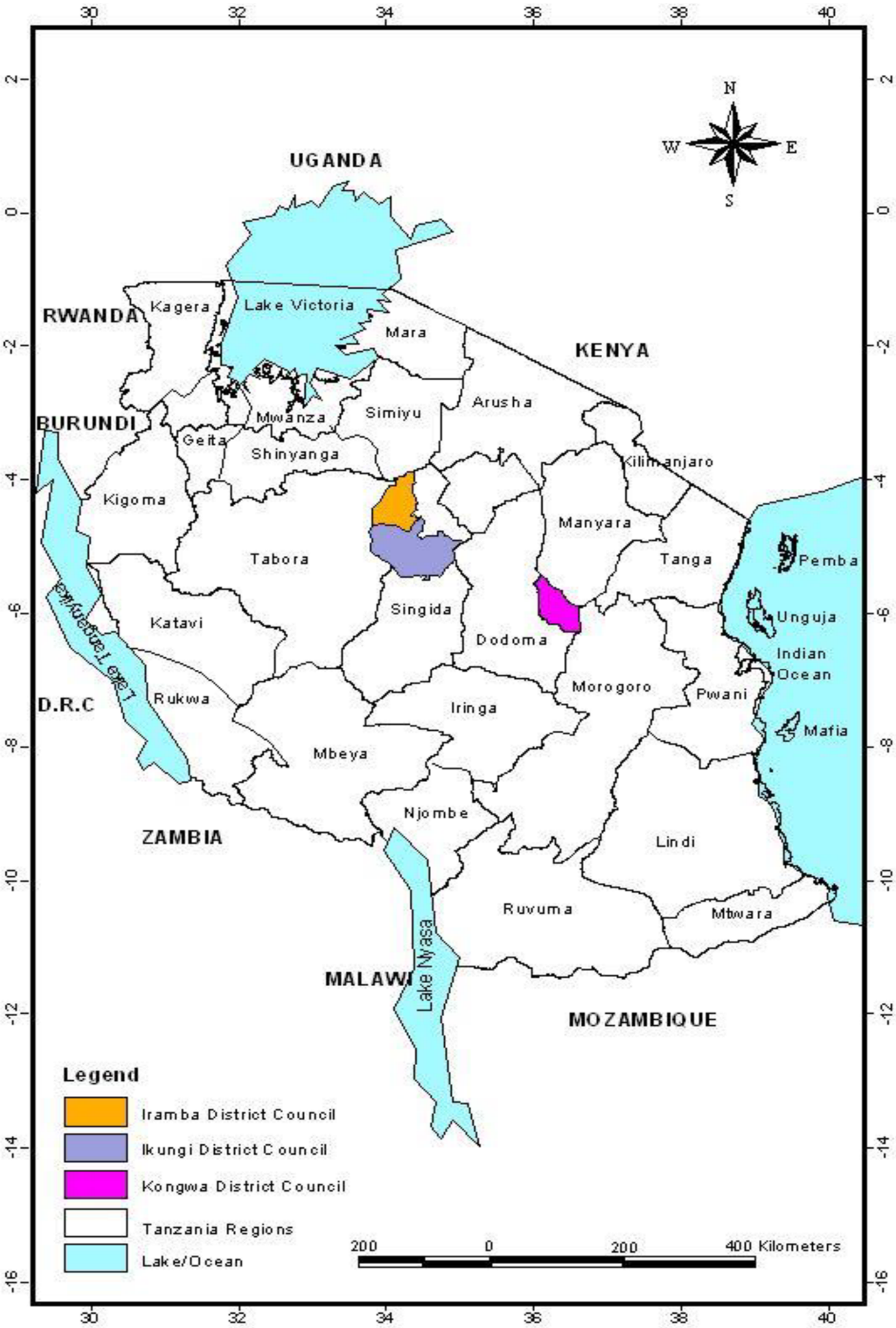

Figure 1. Map shows areas purposively selected for survey in Tanzania.

2.2. Sampling and Respondents

Two regions of Dodoma and Singida, two districts (Iramba and Ikungi) from the Singida region, and one district (Kongwa) from the Dodoma region were purposively selected for this study based on the sorghum production, importance of sorghum to many households as a food security crop, and number of sorghum producers within the districts. Each district was represented by two villages which were purposely selected to represent the district. Forty experienced sorghum farmers were randomly selected per village to participate in this survey making a total of 240 farmers. Ten experienced sorghum farmers per village (total 60 farmers) were randomly selected from the list of 40 farmers to participate in the focus group discussions facilitated by the Village Chairman (VC) and

Agricultural Extension Officer (AEO). The remaining 30 farmers per village, making up a total of 180 farmers, were involved in the individual interview. The sample size used for this study was determined by using the formula as follows (Equation (1)):

$$n = \frac{N}{1 + N(e)^2} \quad (1)$$

where: n is the sample size, N is the population size, and e is the level of precision [25]. The population of sorghum farmers was at least 100 per village in the representative districts. Participatory rural appraisal (PRA) tools including semi-structured interviews and preference ranking were used in this study.

2.3. Research Design and Data Collection

Semi-structured questionnaires and checklists were used to collect data from households, key informants, and focus groups. The information obtained from the focus group discussions and other observations was cross-checked and confirmed with a semi-structured questionnaire. Finally, biographic data were recorded for each respondent.

2.4. Statistical Data Analysis

Data were processed with SPSS version 20 (IBM Corp., Armonk, NY, USA). Descriptive and inferential statistics were used for data analysis. The data analysis on improved sorghum varieties (%) cultivated by farmers per district, constraints of sorghum production and coping strategies used and proposed by farmers to address drought were subject to determination of chi-squares in SPSS software.

The factors influencing the productivity of improved sorghum varieties were estimated by employing the multiple linear regression analysis models as shown below (model Equation (2)):

$$Y = B0 + B1X1 + \cdots + BnXn + E \quad (2)$$

where: Y = dependent variable, X = independent variable, $B0$ = constant value of Y if values of X = 0, n = number of independent variables, and $B1$ to Bn = estimate of effects of X on Y as X increases by one unit; and ε = error term for the unknown variations in dependent variable Y. On the other hand, factors influencing the improved sorghum variety adoption rates were determined by using a binary logistic regression analysis model below (Model Equation (3)) in accordance to [26].

$$Ln(Odds) = ln\left[\frac{p}{1-p}\right] = E(Y) = \alpha + \beta x \quad (3)$$

where Ln is the natural logarithm, p is the predicted probability that farmers adopted the production of improved sorghum varieties, whilst $1 - p$ = the probability that farmers did not adopt, and $p/1 - p$ is the probability of the odds for adoption. However, Y is the dependent (outcome) variable and X is the predictor of the factors affecting improved sorghum variety adoption, α is the constant value of Y when all values of X = 0, while β is the estimated effect of X on Y.

3. Results

3.1. Socio Economic Characteristics of Smallholder Farmers Growing Sorghum

The analysis of socioeconomic characteristics of smallholder farmers growing sorghum in the study area indicated that females (51.7%) had higher participation in sorghum production than males (48.3% and farmers aged between 40 and 50 years old played a major role in farming activities while farmers aged 18–20 participated the least (Table 1). The family size had an impact on levels of sorghum production by farming families. A family with seven to eight members showed the highest sorghum production (27.8%) while families with one to two members showed the least production (6.8%) (Table 1).

Table 1. Socioeconomic characteristics of smallholder farmers growing sorghum in Central Tanzania.

Variable	Frequency	Percent
Gender		
Male	85	48.3
Female	91	51.7
Age category		
18–28 years	22	12.5
29–39 years	38	21.6
40–50 years	53	30.1
51–60 years	37	21.0
Above 60 years	26	14.8
Family size category		
1–2 members	12	6.8
3–4 members	37	21.0
5–6 members	45	25.6
7–8 members	49	27.8
9–10 members	12	6.8
Above 10 members	21	11.9
Farm size category		
1.25–5.0 hectares	42	23.9
5.625–9.375 hectares	26	14.8
10–13.75 hectares	40	22.7
14.375–18.125 hectares	18	10.2
Above 18.125 hectares	50	28.4

3.2. Improved Sorghum Varieties Cultivated by Farmers

The findings revealed that farmers in the Kongwa, Ikungi, and Iramba districts mainly cultivated two improved sorghum varieties, Tegemeo and Serena. Serena was cultivated by 23.2%, 16.4%, and 28.8% in the Kongwa, Iramba, and Ikungi districts, respectively, while 35.7%, 4.9%, and 5.1% cultivated the Tegemeo variety in the Kongwa, Iramba, and Ikungi districts, respectively. Farmers in Kongwa districts cultivated the largest number (8) of improved varieties while the adoption rate was very low in Ikungi district (Table 2). There were significant differences in the adoption rate of improved varieties among districts, particularly Tegemeo, Macia, NACO-Mtama 1, and Pato. The adoption rate of improved sorghum varieties was higher in Kongwa district than the rest of the districts.

Table 2. Improved sorghum varieties (%) cultivated by farmers by district.

Variety Name	Percentage of Improved Varieties Cultivated per District			Chi-Square
	Kongwa	Iramba	Ikungi	
Serena	23.2	16.4	28.8	0.266
Tegemeo	35.7	4.9	5.1	0.000 ***
Macia	32.1	1.6	0.0	0.000 ***
NACO-Mtama 1	17.9	1.6	0.0	0.000 ***
Pato	16.4	0.0	0.0	0.000 ***
Okoa	3.6	0.0	1.7	0.329
Sila	3.6	0.0	0.0	0.114
Wahi	0.0	1.6	1.7	0.623
Lulu	0.0	3.3	0.0	0.149
Pirila	1.8	0.0	0.0	0.340
Hakika	0.0	1.6	0.0	0.388

*** Significant at $p < 0.001$.

3.3. Source of Sorghum Seed Adopted by Farmers

The main source of sorghum seed was own saving (89.8%); 5.7% farmers had access to seed from agro-dealers. Although extension officers are responsible for coordinating farmers on the adoption of improved technologies, only 0.6% of farmers depend on extension officers to obtain seed (Figure 2).

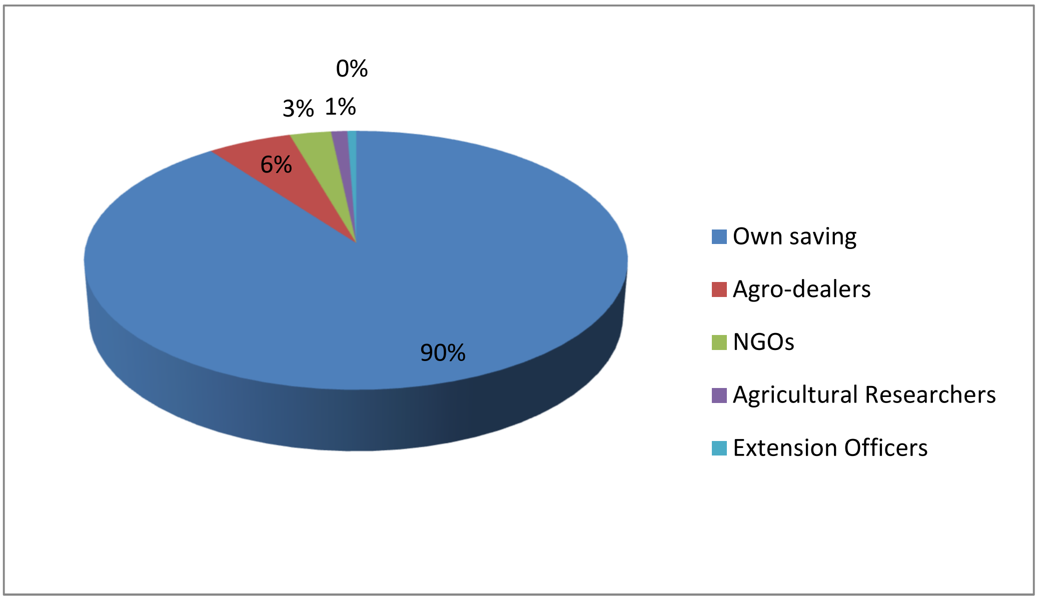

Figure 2. Source of sorghum seed.

3.4. Constraints Facing Sorghum Production

Farmers cited various constraints on sorghum production in their villages. Of these, bird damage and poor soil fertility were reported as major constraints by at least 55% of respondents in each district followed by drought (Table 3). Respondents considered drought the main limiting factor in sorghum production in central Tanzania. Farmers reported that rainfall had been decreasing annually, resulting in drought which affects grain filling of sorghum during post-flowering. It was observed that limited knowledge of fertilizers, a lack of capital to buy them, and few subsidies from the government contributed to soil erosion and low fertility. It was noted that skills and knowledge of soil and fertility management are needed for farmers to maximize the production and conservation of biodiversity. Within these districts, low soil fertility was reported to be among the serious problems in the central zone, yet farmers do not supplement fertilizers to support plant growth, which could enhance the final yield. Farmers in all districts complained that pests and diseases are critical sorghum production constraints. The risk of these was highest in Iramba (47.5%) district. The pests in sorghum included stem borers, aphids, and fall armyworms, whereas the most common disease was the head smut, reported in all three districts. The prevalence of a wide range of diseases and pests was the problem that faced farmers as they lacked prior experience in identifying and naming other sorghum diseases. According to the focus group participants in the Kongwa, Ikungi, and Iramba districts, pests and diseases for sorghum cause great losses. Among the constraints reported, drought was reported to be the most common constraint, followed by a lack of knowledge on the good agronomic practices related to sorghum field management. The low adoption rate for the new technologies reported by the key informants, specifically extension officers, included the perception of crop growers that sorghum is a minor crop, and hence gave it low priority among others. Low prices of sorghum produce output and a lack of reliable markets as well as a limited number of products from the same crop. On part of improved sorghum production adopters, the main constraint was a lack of extension services emanating from limited extension staff contacts.

Table 3. Constraints of sorghum production.

Constraint	Percentage of Constraint per District			Chi-Square
	Kongwa	**Iramba**	**Ikungi**	
Birds	96.4	68.9	94.9	0.000 ***
Problem of market	1.8	4.9	1.7	0.482
Poor soil fertility	58.9	86.9	55.9	0.000 ***
Drought	33.9	63.9	57.6	0.003 **
Pest and diseases	8.9	47.5	18.6	0.000 ***
Poor agronomic management	14.3	19.7	13.6	0.607
Lack of improved varieties	17.9	23	20.5	0.792
Shortage of fertilizers	5.4	8.2	22.0	0.012 *
Few Extension Officers	7.10	0.0	3.4	0.104
Poor mechanization	1.8	3.3	2.03	0.808
Scarce of land	7.1	0.0	13.6	0.013 *

*, **, *** Significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively.

Furthermore, sparsely distributed rainfall was reported as a constraint by participants in all districts; however, the concern was highly reported in Iramba district. The participants reported that the rainfall showed a decreasing trend, which resulted in drought stress during the post-flowering stage. In these areas, a dry spell for 2–4 weeks was common such that post-flowering and grain filling in sorghum are greatly affected. In Iramba district, farmers cited fertilizer shortage to be among the challenges to sorghum production due to a lack of input subsidy as it is for other grain crops such as maize, cashew nut, and cotton, which the government used to subsidize. Another constraint reported by farmers of Nkonkilanga in Iramba district was the limited number of tractors, which reduced their capacity to adopt mechanization; consequently, they used hand hoe and ox ploughs, which do not cultivate well and thus lead to running short of timely land preparation, planting, and harvesting their sorghum crop. Due to rainfall challenges, the majority (96%) of the farmers had the need for seeds of drought-tolerant sorghum varieties, especially those that do better in the period of late January and February months.

3.5. Ranks of Sorghum Variety Trait Preferences by Respondents

Of all the respondents, 82.4% indicated that early maturity was their preferred sorghum variety trait, followed by drought tolerance (75.6%) and high yield. Other desired traits were market accessibility, taste, pest and disease resistance, post-harvest storage life, bird predation resistance, shelling, and plant height; *Striga* resistance ranked last. Participants in the focused discussion groups at Sagara A, Msambu, and Nkonkilangi ranked drought tolerance first. The focused discussion groups at Laikala and Nkuninkana ranked high yield as the second most important sorghum variety selection criterion. The Sagara A and Msambu focused discussion groups rated early maturity as their third most preferred trait, whereas Nkonkilangi, Mseko, and Laikala ranked high yield, drought tolerance, and good germination as their second most preferred traits, respectively. Nonetheless, shelling, drought tolerance, market availability, and resistance to birds, diseases, and pests ranked last for the sorghum growers at Sagara A, Laikala, Nkuninkana, Msambu, Nkonkilangi, and Mseko villages (Table 4).

3.6. Factors Influencing Sorghum Productivity

Factors enhancing sorghum productivity included low production cost, cultivation experience, market demand, sorghum as a food source, and varieties adapted to the specified locations. All of these positively influenced sorghum production (Table 5). Gender (male), age, production area, and sorghum variety (Tegemeo) negatively influenced sorghum production.

Table 4. Ranks of sorghum variety preference by respondents.

Criterion	Rank Sagara A	Rank Laikala	Rank Nkuninkana	Rank Msambu	Rank Nkonkilangi	Rank Mseko
Disease and pest resistance	5th	3rd	3rd	5th	†	5th
High yield	3rd	1st	1st	3rd	2nd	1st
Drought tolerance	1st	5th	2nd	1st	1st	2nd
Striga tolerance	7th	†	†	†	†	†
Grain color	†	†	†	†	4th	†
Early maturing	2nd	4th	†	2nd	†	†
Long post-harvest storage life	6th	†	†	†	†	†
Market availability	†	†	5th	4th	3rd	†
Flavor	†	†	4th	†	†	†
Tolerance to bird predation	†	†	†	7th	5th	3rd
Grain weight	4th	†	†	6th	†	†
Shelling	8th	†	†	†	†	4th
Good germination	†	2nd	†	†	†	†

† Criteria not ranked.

Table 5. Regression analysis of the factors influencing the productivity of the improved sorghum varieties.

Model	Unstandardized Coefficients		Standardized Coefficients	t	p-Values
	B	SE	β		
(Constant)	−404.4	307.9		−1.313	0.237
Gender (1 = male; 0 = otherwise)	−269.2	51.2	−0.46	−5.254	0.002 **
Age	−20.7	2.5	−0.96	−8.212	0.000 ***
Number of men	143.7	15.7	1.05	9.160	0.000 ***
Number of acres	41.34	9.1	0.58	4.571	0.004 **
Acres for sorghum production	−137.7	15.9	−1.37	−8.663	0.000 ***
Sorghum as a food source	178.4	72.3	0.27	2.469	0.049 *
Market demand dummy (1 = high; 0 = low)	244.0	58.4	0.42	4.181	0.006 **
Low production cost (1 = yes; 0 = no)	1710.6	169.8	1.28	10.072	0.000 ***
Length of time growing sorghum (y)	366.0	75.6	0.55	4.838	0.003 **
Sorghum varieties grown (1 = improved; 0 = local)	166.7	40.2	0.49	4.144	0.006 ***
Tegemeo (1 = grown; 0 = not grown)	−636.3	59.4	−1.07	−10.710	0.000 ***
Macia (1 = grown; 0 = not grown)	195.1	63.5	0.31	3.074	0.022 *
Pato (1 = grown; 0 = not grown)	643.3	85.0	0.89	7.567	0.000 ***
a. Dependent variable: yield of improved varieties per acre					
R^2 = 0.977; Adjusted R^2 = 0.929; F = 20.042			p = 0.001		

*, **, *** Significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively.

3.7. Factors Influencing Adoption of Improved Sorghum Varieties

Binary logistic regression results on the factors influencing the adoption of improved sorghum varieties revealed that some factors negatively influenced adoption, whereas others positively influenced the adoption (Table 6). Those promoting the adoption of improved sorghum varieties included early maturity with the probability Exp (9.171) of the adoption indicate that $\frac{\text{Odds}}{1+\text{Odds}}$ early maturity will result in significant crop adopted by 90.2% and above if it was not early maturity, while the value of the odds for area (EXP (B)) = 1.058 indicates that a unit increase in the area under sorghum would significantly increase the adoption rate by 51.4% than otherwise. Similarly, market accessibility odds value EXP (2.851) indicates that access to the sorghum market would significantly increase the adoption rate by 74% than otherwise ($p > 0.05$). The factors negatively influencing the adoption of improved sorghum varieties included a lack of drought-tolerant varieties whose EXP (0.169) indicate that the adoption rate would significantly decrease by 15%, and cultivation experience (EXP (B) = 0.131 would significantly decrease adoption rate by 16%. This implies that with much experience in production of the same crop, the farmer becomes reluctant to adopt new technologies, believing that his own experience matters more than new ones. The values of cox and Snell R2 and Nagelke R2 indicate that about 20.3–32.8% of the variations in the rate of adoption of improved sorghum varieties among the farmers are contributed by the variables specified in the logistic regression model, implying that the factors are very important to consider.

Table 6. Binary logistic regression of the factors influencing the adoption of improved sorghum varieties.

Variables	B	SE	Wald	df	*p*-Values	Exp(B)
Constant	−1.47	0.193	57.651	1	0.000 ***	0.231
Education dummy (1 = primary; 0 = otherwise)	1.61	0.749	4.613	1	0.032 *	5
Age dummy (1 = > 35 y; 0 = otherwise)	1.1	0.534	4.252	1	0.039 *	3.006
Decreasing rainfall trend (1 = yes; 0 = no)	−0.99	0.506	3.83	1	0.05	0.371
Experience dummy (1 = > 3 y; 0 = otherwise)	−2.03	0.732	7.703	1	0.006 **	0.131
Area in acres (farm size)	0.06	0.068	0.683	1	0.409	1.058
Lack of drought tolerant varieties (1 = yes; 0 = no)	−1.78	0.672	7.015	1	0.008 **	0.169
Rainwater harvesting (1 = adopted; 0 = otherwise)	1.93	1.11	3.026	1	0.082	6.899
Early maturity	2.22	0.868	6.525	1	0.011 *	9.171
Food security	−0.74	0.782	0.9	1	0.343	0.476
Market accessibility	1.05	0.484	4.688	1	0.030 *	2.851
Decreasing rainfall trend	−0.4	0.554	0.521	1	0.47	0.671
Model Summary						
−2 log likelihood	Cox and Snell R2		Nagelkerke R2			
129.862	0.2		0.328			

*, **, *** Significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively.

3.8. Strategies Used by Sorghum Farmers to Address Drought

Early sowing was implemented by the highest number of participants (18%) in Iramba district, followed by Ikungi (15.3%) and Kongwa (14.3%). Drought-tolerant varieties were the second strategy to cope with drought in the particular districts (Table 7). Most farmers in Kongwa and Iramba districts cited early maturing varieties as one of the strategies to overcome drought. Other strategies, such as cropping calendar, were used in one district only. The other techniques used by the sorghum farmers to overcome drought are listed in Table 4.

Table 7. Strategies to address drought for sustainable sorghum production.

Technique	Number of Respondents (%) per District			Chi-Square
	Kongwa	Iramba	Ikungi	
Early planting	14.3	18	15.3	0.895
Drought tolerant varieties	8.9	11.5	11.9	0.860
Practice contour farming	12.5	3.3	0.0	0.007 **
Fertilizers application	7.1	0.0	0.0	0.012 *
Timely weeding	1.8	1.6	0.0	0.599
Deep cultivation	7.1	0.0	0.0	0.012 *
Tied ridging	12.5	9.8	5.1	0.373
Early maturing varieties	16.1	14.8	6.8	0.259
Irrigation	1.8	0.0	3.4	0.357
Cropping calendar	0.0	18	0.0	0.000 ***
Intercropping with legumes	0.0	3.3	1.7	0.392
Staggered planting	1.8	0.0	0.0	0.340

*, **, *** Significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively.

There were significant differences in coping strategies to overcome drought stress which were cited by farmers from some of the districts. There were no significant differences for the common responses from participants' districts.

4. Discussion

The present study noted that farmers were aware of the improved sorghum varieties, though the number of farmers who cultivated was not encouraging. Low adoption rates for the improved sorghum varieties among farmers within districts indicates that either technology transfers were not sufficiently carried out or farmers negatively perceived the technology package for the same crop production. Similarly, the cost for adopting the technology could have been higher compared to the use of the conventional crop commodity that farmers used to grow on their farm fields, such that farmers saw it as irrational to produce the crop commodity.

The factors affecting sorghum production globally have not been constant; it differs from region to region and country to country [27]. However, it is reported that climate change, price fluctuation, erratic rainfall, non-food demand, and a lack of breweries are some of the factors affecting sorghum adoption in Sub-Saharan Africa and South Asia [28,29]. This suggests further finding means to transfer improved technologies to the target communities for increased adoption of improved sorghum varieties to maximize productivity.

Strengthening agro-dealers who sell improved sorghum seeds, subsidize seed input cost by the government and extension service delivery may contribute seed and knowledge access to farmers for increasing the adoption rate of improved sorghum seeds. According to the key informants, birds attack farm fields where improved sorghum cultivars are grown due to their taste and other physiological characteristics of the sorghum grains. Similar findings were reported by [30,31] in Southern Africa and West Africa that bird damages and drought stress are the major sorghum production constraints, which affect the food availability to smallholder farmers. Furthermore, limited soil nutrients result in poor physiological plant growth. Dimkpa and Bindraban [32] asserted that fertilizer application supplements soil nutrients, supports physiological plant growth, and boosts the grain yield.

In addition, Deb et al. [33] recommended the application of fertilizers in hybrid sorghum varieties to attain a potential yield of 10 t ha^{-1}. Nonetheless, the current application rate of fertilizers in maize is 15.9 kg ha^{-1} in Tanzania as sorghum is not considered as a potential crop; the government does not provide subsidy as in maize [34]. The distribution of fertilizers to the sorghum production areas in the country is difficult due to poor infrastructure during the rainy season. This raises prices, which smallholder farmers cannot afford [35]. In addition, sorghum should be registered as the potential crop to supplement the gap of maize production, which has decreased due to climate change for long-term food security. Based on our results, we recommend researchers, international organizations, and the government collaborate efforts for training farmers to increase awareness of fertilizers application in sorghum.

Farmers lack knowledge to understand life cycles of pests and diseases which contribute to the failure to control them in a timely fashion. This suggests the use of a participatory approach system and demonstration plots to disseminate technologies for diagnosing the symptoms of pests and diseases in sorghum before it is too late to control. Moreover, this calls upon the strengthening of collaboration between agricultural researchers, extension officers, and farmers to address pests and diseases affecting sorghum production. The findings from these results recommend sorghum breeders develop new and improved climate-resilient sorghum varieties for sustainable food production [36].

Our study suggests that farmers adopt improved sorghum varieties with traits of drought tolerance and promising yields as alternative coping strategies to drought. Some farmers practiced early sowing in the end of October to November before rainfall starts as the strategy to cope with drought; however, this approach affects germination and the emergence of seeds. Farmers who plant sorghum using the recommended cropping calendar from mid-December to the end of January reported to harvest a reasonable yield. Notwithstanding, due to unpredictable weather changes, dry spells may either delay or come earlier in February, causing the withering of plants and prevalence to pests and diseases, which affects productivity. This is in agreement with [9,37], who ranked five sorghum production traits, two market traits, and *Striga* in drought-prone areas under delayed first rainfall before seed germination.

Our study noted that some traits such as post-harvest storage, shelling, and taste ranked the last preference, notwithstanding these traits are important for maintaining the post-harvest grain quality and enhancing the adoption rate of sorghum by-products. The current study suggests that traits of interest are key factors for enhancing the sustainable adoption of improved sorghum varieties to increase sorghum grain production. This is observed in the Asian countries, which account for above a 73% rate of adoption of improved sorghum varieties, with the highest (98%) in China, followed by Iran (87%) [37]. Traits of interest by farmers should be considered before developing new and improved sorghum varieties which are demand driven; a similar suggestion was reported by [38].

In our findings, both men and women participated equally in sorghum farming. Men and women in the study areas believe that working as a team in the families has an impact on the success of farming activities. However, some participants reported that men take over as the head of the family when it comes to selling agricultural products based on their cultures. This demoralizes women and discourages them from participating fully in agriculture activities, especially when they do not receive incentives after selling produce. Climatic conditions affect the adoption of improved varieties from one region to another; for instance, the current study found that Tegemeo, an improved sorghum variety, was negatively influencing productivity in the central zone, different from the lake zone, where the adoption rate was high. This variety is important for maintaining high production and can be used as the basis material for breeding new climate-resilient sorghum varieties in the future [39].

Even though there were a number of factors positively influencing sorghum productivity, market demand was a key for many farmers. Based on our findings, farmers cultivate large farms to increase the volume of sorghum grain production when brewery demand is high. However, they reduce the farm size when the market is not stable to produce food and sell for surplus at the local market where price is usually low. In addition, some brewing industries are specific to white sorghum grains; it is not consistent because there is no legal contract provided to farmers. For sustainable sorghum production, assured crop market and quality products should be contractual arrangements between farmers and buyers, which are legally binding. Alternatively, in order to explore high market demand, farmers should add value to diversify options for markets based on end-users' preferences.

5. Conclusions

The main constraints of sorghum production in Tanzania were poor soil fertility, drought, pests, and diseases. Stem borers, aphids, and *Quelea* birds were the most destructive sorghum pests in the sorghum production areas. The traits preferred by farmers in the studied areas included high yield, early maturity, drought tolerance, and pest and disease resistance. Plant breeders must factor in drought tolerance, pest and disease resistance, demand-driven varieties, long-term post-harvest storage, and other related traits of farmers' preference when they develop improved sorghum varieties for the sustainability of sorghum production. The farmers should integrate organic and industrial fertilizers to sustain soil fertility for long-term use in farming activities to increase productivity. To further address these constraints for enhancing sorghum production on a long-term basis, collaboration among plant breeders, pathologists, entomologists, socioeconomists, soil scientists, extension officers, local government authorities, the ministry of agriculture, and farmers must be enhanced. Strategies to address drought should be well demonstrated to farmers as this is the adaptation to climate change which may sustain high yields of sorghum. There is a need to promote sorghum production to increase the demand of improved sorghum seed that will enable private companies to increase the multiplication of seed with profit. The government of Tanzania should consider sorghum as the priority climate resilience crop by subsidizing inputs of production to smallholder farmers. There is a need to strengthen the sorghum value chain to diversify end products and market options among stakeholders. These will increase the adoption rate of improved sorghum varieties as farmers will buy inputs such as fertilizers to boost sorghum productivity above 1 ton ha^{-1}. The current study provides basic information and strategies for the sustainability of sorghum production and the productivity of the farmers.

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