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Navigating Formal, Informal, and Integrated Seed Systems: Drivers of Choice by Sorghum Grain Producers in Tanzania and Implications for Seed Access

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ABSTRACT

Understanding what drives farmers to choose one seed system over another is important in setting goals for crop improvement programs and designing an effective seed delivery system and marketing strategy. This study used survey data from 1492 households and a multinomial logit model to analyze seed systems choice by smallholder sorghum grain producers in Tanzania. Results showed that 84% of the farmers relied on the informal seed system, 11% on an integrated seed system (involving a combination of informal and formal systems), and only 5% exclusively accessed seed through the formal system. Farmers mainly accessed information on seed, agronomy, and markets from their peers. Proximity and participation in input and output markets, financial literacy, use of crop insurance, and access to financial and extension services were associated with a high likelihood of using formal seed systems. On the other hand, limited access to agronomic, and seed information from peers, as well as long distances to main markets, were associated with the use of informal seed systems. The integrated system was associated with intercropping and willingness to experiment with new ideas and technologies. Making sufficient quantities of quality seed available to farmers at the last mile through various channels, improving farmers' access to financial services, and developing multiple stress-tolerant varieties can enhance the use of improved varieties and formal channels of seed access. We recommend innovative ways of moving sufficient quantities of quality seeds of improved varieties through the informal seed system in the interim while further developing the formal system in the long run.

1 | Introduction

Sorghum ranks as the second most important cereal crop in Africa after maize and third in Tanzania after maize and rice (Kalema, Akpo, et al. 2022; Kimbi et al. 2024; Mbugua et al. 2024; Msongaleli et al. 2017). It is mainly produced under rainfed production systems in semi-arid agroecologies, and most of it is used for food (70%), feed, fodder, and brewing (Kalema, Kimbi, et al. 2022; Akplo et al. 2023; Mbugua et al. 2024). Dual-purpose sorghum ideotypes that provide grain and stover have been shown to increase farm incomes and nutrition, strengthening incentives for farmers to seek quality seed (Akplo et al. 2023). Most of the sorghum research in Tanzania has focused on the adoption and

impact of improved varieties (Kalema, Akpo, et al. 2022; Akpo et al. 2022; Ndossi et al. 2021) and its role in climate change adaptation and mitigation (Westengen and Brysting 2014), with little attention on understanding the drivers of seed system choices by farmers. Recent work also links improved seed access directly to household food security outcomes in SSA, reinforcing the importance of understanding farmer choice of seed systems (Sonde and Traore 2025). This study bridges this gap by examining how farmers access seeds by analyzing the factors that determine farmers' choice of a given sorghum seed system over the alternatives and recommending impact pathways for improved access to quality seed of improved varieties of sorghum using data collected from smallholder producers in Tanzania. Understanding what drives farmers to choose one seed system over another is important in setting goals for crop improvement programs and designing an effective seed delivery system and marketing strategy.

Good quality seed is the foundation for global food and nutritional security, rural development, and resilience to climate change and variability (Louwaars and Manicad 2022; Otieno et al. 2022). Seed systems choice is an important entry point in improving productivity in the agricultural sector, especially among smallholder producers (McGuire and Sperling 2016). Past investments by development partners, such as the World Bank and development and humanitarian organizations, underscore the importance of the seed systems in catalyzing rural development and improving rural livelihoods (McGuire and Sperling 2016; Sperling and Almekinders 2023). Humanitarian support through enhancing farmers' access to quality seeds can scale intervention impacts cost-effectively (Sperling and Almekinders 2023).

The Tanzania Agricultural Research Institute (TARI), in collaboration with the International Research Centres, institutions of higher learning, and private seed companies for example, Advanta Seeds, Seed Co., and Namburi Agricultural Company, have developed improved sorghum varieties, 18 of which had officially been released between 1960 and 2021 (Mbugua et al. 2024). Adoption of these varieties, however, remains low, ranging from 4% to 37%, depending on the sorghum variety and agro-ecological conditions of specific growing regions (Kalema, Akpo, et al. 2022; Kaliba et al. 2018). This low adoption could be associated with the available and accessible seed delivery system. Sorghum seed is delivered to farmers through four seed systems, that is, the formal, semi-formal, informal, and the integrated (combination of) seed systems.

Seed systems can broadly be divided into formal, semi-formal, and informal. A formal seed system is regulated through structured breeding for desired traits, on-farm and off-farm testing, registration, official release, and certified seed production to ensure that responsible institutions maintain seed quality and variety identity. Usually, there is a clear distinction between seed and grain, with the seed properly labeled and treated. This form of seed delivery system is supported by a robust policy and institutional framework (Ojiewo et al. 2020). The system is also characterized by an officially recognized marketing process through seed companies, agro-dealers, and/or agricultural research systems (Louwaars 1994).

In the past, the international development community focused on supporting formal private sector-based, market-oriented seed systems interventions to address low cereal productivity in Sub-Saharan Africa (Hambloch et al. 2021). However, Hambloch et al. (2021) observed that this formal seed systems approach might need to be reoriented to make it more effective in driving wide-scale adoption of improved crop varieties or generating significant benefits to small-scale producers, especially for dryland crops like sorghum. Formal seed systems account for a paltry 10%–20% of the entire seed sector in many African countries (McGuire and Sperling 2016) and specifically just 10% in Tanzania (Kansiime et al. 2021). The bulk of formal seed systems is usually in hybrid maize and vegetable seed, while reports from regulators show that certified seed contributes only 3%–5% for other cereals and legumes (McGuire and Sperling 2016; Sperling and Almekinders 2023). This reality underscores the need to understand farmers' diverse needs better and what makes them choose a given seed system for accessing seeds.

A semi-formal seed system has some quality control mechanisms that are less stringent than a formal system. Under this system, the seed quality control agencies have minimal involvement, with much of the quality control entrusted to community seed production systems such as Quality Declared Seed (QDS), Local Seed Business (LSBs), Community Seed Banks (CSBs) among other localized terminologies (Mbatia 2022; Otieno et al. 2022). This community seed production and delivery system flexibly meets farmers' diverse needs at reasonably affordable seed prices without compromising the higher seed quality standards while minimizing seed access inequalities, particularly in remote areas.

In Tanzania, the semi-formal QDS system was incorporated into the formal seed systems in the National Seeds Act of 2003 and governed under seed rules, regulations and procedures (2007) and the seed regulations (Control of Quality Declared Seeds) of 2020 for control of QDS production (The United Republic of Tanzania 2020; Vernooy et al. 2023). Under this regulatory framework, only open-pollinated varieties (OPV) that are listed in the national variety catalogue can be produced as QDS (Mbatia 2022) and the seeds should only be sold within the district where they are produced (The United Republic of Tanzania 2020). Farmers interested in producing QDS must register as per the laid down regulations that include showing evidence of training on basic knowledge about seed and land size limited to 5 acres. The Tanzania Official Seed Certification Institute (TOSCI) is responsible for registering seed dealers and small-scale seed enterprises and offering training to producers of QDS to ensure that they meet the prescribed quality standards (The United Republic of Tanzania 2023). However, recent studies have shown that most farmers in Tanzania source their sorghum seeds from informal sources (Waithaka et al. 2021).

The informal seed system comprises different pathways through which farmers and traders produce, select, store and distribute seeds directly, either through barter exchange or local grain markets without structured quality control and assurance (Sperling et al. 2022). The seed distribution channels are totally unregulated and include relatives, neighbours, local markets,

traders, among others (Otieno et al. 2022). Local markets are included in the informal system because farmers cannot ascertain the quality of the seed, even though the seed is sometimes packaged to mimic hybrid and/or OPV varieties delivered through formal channels (Mbatia 2022). Seed produced and distributed under the informal system could include traditional and improved varieties, except that there is no involvement of regulatory authorities to provide oversight for quality control and assurance (Mbatia 2022). The informal seed system is guided by indigenous knowledge, local social structures, and standards (Waithaka et al. 2021).

This study advances this discussion by considering farmers who use a combination of formal and informal systems, which we refer to as an integrated seed system. These are farmers whose needs and preferences still need to be fully met by either a combination of formal and informal seed systems. For the purposes of this study, we defined formal seed systems to include seed accessed through government extension staff, national and international agricultural research institutions, agro-dealers, on-farm demonstrations, as well as registered and trained farmer organizations. This category also includes QDS seed. The informal seed system was defined to include unregulated channels of accessing seeds from friends, relatives, purchases from grain traders in local open-air markets, and farmers' own saved seed from previous harvests. The third alternative, integrated system, is heterogeneous and consists of farmers who use a combination of formal and informal systems. They are farmers who might not have had the capital to buy all the seeds that they needed and used some of their own or donations from friends and relatives to top it up. It is plausible that even farmers with enough cash might prefer using both systems for risk hedging, taste, and preferences. The choice of a formal seed system may also depend on the variety type (hybrid or OPV) or the end use, such as contracted farming for commercial or industrial purposes, such as brewery or export industry, while informal channels are mostly for subsistence.

2 | Materials and Methods

2.1 | Sampling and Data Collection

The data used for this study were collected in Tanzania in October–December 2019. A multistage sampling design was used to select a representative sample of 1492 sorghum grain farmers covering seven sorghum growing regions in four zones of Tanzania. The regions included Dodoma, Singida (Central Zone), Mara, Geita, Shinyanga (Lake Zone), Songwe (Southern Highlands), and Tabora (Western Zone) (Table 1). In the first stage, the main growing regions were purposely selected based on the area under sorghum. This was followed by a random selection of 14 districts. A total of 34 wards and 44 villages were selected using a simple random sampling technique from selected districts and assigned households proportional to their population distribution. In each village, a sampling frame of all the households was generated with the help of the extension officers and administrative officials, from which households were randomly selected to participate in the survey (Miriti et al. 2023). The simple random sampling was implemented using the spreadsheet random number generator that helped to generate random numbers corresponding to the unique IDs of households in the sampling frame. Household samples were first allocated to regions in proportion to their sorghum production potential and subsequently to villages in proportion to their population size. In some high-potential villages, however, dispersed settlement patterns led to relatively small numbers of eligible households, which contributed to the uneven distribution of sampled farmers across sites. To account for this imbalance, the analysis was conducted at the household level, and regression models accounted for household-level variation. The study gathered primary-level information about seeds, seed knowledge, seed access, and seed utilization, as well as relevant data on social, economic, market, and demographic variables.

TABLE 1 | Geographic distribution of the study zones, regions, and districts that were surveyed as part of the sampling framework.

Zone	Region	District	Sample
Central zone	Dodoma	Bahi	69
		Chamwino	216
		Mpwapwa	88
	Singida	Mkalama	269
		Singida Rural	263
		Ikungi	100
Lake zone	Mara	Bunda	100
	Geita	Bukombe	6
	Shinyanga	Kahama Rural	2
		Kahama Town	3
		Kishapu	82
		Shinyanga Rural	162
Southern highland	Songwe	Momba	116
Western zone	Tabora	Nzega	16
Total			1492

2.2 | Empirical Model

Random utility framework is used to model individual preferences whose choices are not deterministic (Greene 2012; Verbeek 2017). Under the random utility framework, farmers are assumed to be utility maximizers, such that after considering the costs and benefits associated with each sorghum seed system, farmers will choose the form that maximizes their utility. The choices are also assumed to be discreet, such that at one given time, a farmer can only choose an alternative with the highest utility, and that this utility is stochastic (varies from farmer to farmer). The dependent variable, seed system choices, has no particular order in the alternatives. The farmer has three sorghum seed system alternatives to choose from, that is, formal, informal, and integrated systems. For the i_{th} farmer faced with j-choices, utility can be expressed as

a linear function of observable demographic, social, institutional and economic characteristics (X) such that:

$$U_{ij} = x_{ij}'\beta + \varepsilon_{ij} \quad (1)$$

where $x_{ij}'\beta$ is the systematic component of the utility function, x is a vector of observed characteristics and ε is the stochastic random error term that is assumed to be mutually independent with a log Weibull distribution, that is, $F(\varepsilon_{ij}) = \exp\{-e^{-\varepsilon_{ij}}\}$.

If the ith farmer chooses jth -alternative, then U_{ij} is the maximum utility among the J utilities. According to Greene (2012), the probability that the ith farmer chooses the jth alternative is given as follows:

$$\text{Prob}\left(U_{ij} > U_{ik}\right) \forall k \neq j \quad (2)$$

where j = indicator of alternatives: 1, 2, ... J, and U_{ij} = utility associated with alternative j by ith farmer.

Since farmers' choice of a given seed system over the alternatives does not follow any natural ordering and they are mutually exclusive, a multinomial logit is used to model the probability of a farmer's choice of a particular seed system as a function of socioeconomic, institutional, and demographic characteristics. This approach is preferable as it allows simultaneous presentation of alternatives which helps subjects (farmers) make optimal decisions (Basu and Savani 2017). Empirically, the probability of a farmer choosing either formal or integrated system is compared to the probability of choosing informal alternative, the reference category, and is given as follows:

$$p\{y_i = j\} = \frac{exp\left\{x_{ij}'\beta\right\}}{1 + \sum_2^m exp\left\{x_{ij}'\beta\right\}} \ldots \ldots \quad (3)$$

2.2.1 | Test for the Independence From Irrelevant Alternatives Assumption (IIA)

Under the IIA assumption, if we exclude one of the alternatives from the model, there should not be a systematic change in the coefficients. We use the Hausman specification test as follows:

$$H = \left(\beta_c - \beta_e\right)'\left(V_c - V_e\right)^{-1}\left(\beta_c - \beta_e\right) \quad (4)$$

where β_c is the coefficient vector from the consistent estimator; β_e is the coefficient vector from the efficient estimator, V_c is the covariance matrix of the consistent estimator and V_e is the covariance matrix of the efficient estimator. The IIA test statistic derived from Equation (4), that is, H(chi2(27)) = −0.76 shows no evidence that the IIA assumption has been violated.

2.2.2 | Average Marginal Effects

Since the coefficients and the relative risk ratio from multinomial logit are relative to the base outcome (Jann 2013; Wulff 2015), we estimated average marginal effects to evaluate the average effect of changing the covariates on the probability of observing an outcome. We estimated the average marginal effect of each covariate on the probability of a farmer choosing each seed system choice, as follows:

$$AME_{ij} = \frac{1}{n}\sum_{i=1}^{n}\frac{\partial p_{ij}}{\partial x_{ij}} = \frac{1}{n}\sum_{i=1}^{n}\frac{\partial Pr\left(Y = j|\, x_i\right)}{\partial x_{ij}} = \frac{1}{n}\sum_{i=1}^{n} p_{ij}\left(\beta_{kj} - \underline{\beta_i}\right) \ldots \ldots \ldots \ldots \quad (5)$$

where $\underline{\beta_i}$ is a probability weighted average of the coefficients for different choice combinations, β_{km} is the average effect of changes in independent variables on the changes in the probability of dependent variables.

2.3 | Variable Definition and Description

The variables used in modeling the drivers of seed systems choice are household location, demographic, institutional, and market factors (Table 2). Seed systems typology is the discrete dependent, categorical variable with three choices, that is, formal, informal, and integrated seed systems. The average age of the household heads was 46 years, and the majority were literate with an average of 6 years of formal schooling. About 7% and 26% of all surveyed sorghum farmers accessed credit, insurance, and financial service, respectively (Table 2). Zones were included to control for local specific factors in the estimation model. Farmers' risk profile was measured on a scale of 1–10, with 1 being most risk averse and 10 most risk loving. The average risk score was 4, thereby indicating that most farmers are risk averse.

Farmers in surveyed areas mostly get information on farming practices, seed knowledge, and markets from peer learning, extension, and mobile phones. On average, they cultivated about six acres, and more than half of that area (3.70 acres) was allocated to sorghum production. Intercropping was recorded as a binary variable, with 38% of the farmers answering in the affirmative that they practiced it. Farmers were also asked about the average number of monthly transactions (both buying and selling) they carried out in the nearest market in a typical month. On average, there were six transactions per respondent in a typical month. Most farmers are located far from the main market, with an average distance of about 25.96 km (Table 2).

We asked farmers about the importance of various production constraints they faced in sorghum farming. About 64% and 60% of the farmers surveyed identified drought and bird attack, respectively, as very important constraints in sorghum production. Slightly more than half of the farmers (52%) ranked lack of reliable output markets and poor output prices as very important, while lack of improved varieties and diseases were ranked as very important by 29% and 37% of the farmers surveyed, respectively (Table 2).

3 | Results and Discussion

3.1 | Sources of Information on Markets, Seeds, and Good Agronomic Practices

Most farmers' main source of information is through peer learning (Table 3). The dominant source of market information, in particular, was from fellow farmers, relatives, or friends (60.7%),

TABLE 2 | Household and farm characteristics of sorghum-producing households in Tanzania ($N = 1492$).

Variable category	Variable description	Mean	Std. dev.
Dependent variable (seed systems alternatives)	Formal/Semiformal seed system	0.06	0.24
	Informal seed system	0.83	0.38
	Integrated seed system	0.11	0.31
Location variable	Central zone	0.67	0.44
	Lake zone	0.24	0.37
	Southern highland	0.08	0.27
	Western zone	0.01	0.10
Demographic variables	Respondent is the primary decision maker	0.88	0.32
	Gender of the household head (1 = female)	0.35	0.48
	Age of the household head (years)	46.88	13.49
	Education of the household head (years)	6.21	3.16
	Financial literacy dummy	0.09	0.29
Institutional variables	Produce buyer: brokers (1 = yes, 0 = no)	0.52	0.55
	Produce buyer: Individual (1 = yes, 0 = no)	0.37	0.48
	Have access to credit (1 = yes, 0 = no)	0.07	0.25
	Bank account (1 = yes, 0 = no)	0.26	0.44
	Used insurance products (1 = yes, 0 = no)	0.07	0.25
	Have a village market (1 = yes, 0 = no)	0.42	0.49
	Distance to the main market (km)	25.9	40.53
Primary source of information	Peers on agronomic practices (1 = yes, 0 = no)	0.54	0.50
	Peers on seed knowledge (1 = yes, 0 = no)	0.66	0.49
	Peers on market information (1 = yes,0 = no)	0.61	0.49
	Extension on GAP (1 = yes, 0 = no)	0.27	0.44
	Extension on seed knowledge (1 = yes, 0 = no)	0.22	0.41
	Extension on market (1 = yes, 0 = no)	0.08	0.27
	Use mobile to get agricultural information	0.22	0.42
Agronomic economic and market	Experienced food shortage	0.31	0.46
	Experiment with new technologies	1.09	0.40
	Farmers risk profile	4.24	3.01
	Number of monthly transactions	7.98	9.54
	Use improved sorghum seeds	0.24	0.42
	Total cultivated land (acres)	6.01	6.25
	Area under sorghum (acres)	3.67	52.5
	Intercropping (1 = yes, 0 = no)	0.38	0.48
Production constraints	Bird attack very important	0.60	0.49
	Poor market access and output prices	0.52	0.55
	Drought very important	0.64	0.48
	Diseases very important	0.37	0.48
	Lack of improved varieties	0.29	0.46
	Low yields	0.30	0.46

Note: Means are reported for continuous variables, and percentages for categorical variables.

TABLE 3 | Percentage of households reporting their first or primary source of information on markets, seed, and good agronomic practices in 2019.

Information source	Markets ($n = 1492$)	Seeds ($n = 1492$)	Good agronomic practices ($n = 1492$)
Another farmer, relative, or friend	60.7	59.7	53.8
Government extension	7.0	20.4	24.7
No information	9.8	6.3	12.1
Radio/Newspaper/TV	6.7	2.5	2.4
Brokers/Buyers	8.7	0.1	0.0
NGO/CBO	2.4	3.4	2.7
Seed/Grain stockist	0.6	4.2	0.9
Farmer group	2.0	1.6	1.1
Research Centre (trials/demos/field days)	0.6	1.1	2.1
Own effort	1.1	0.6	0.1
Farmer Coop/Union	0.4	0.2	0.1

Note: Each respondent was asked to name only one (first or primary) source of information for each type of knowledge. Column totals therefore equal 100%. Responses reflect farmers' sources at the time of the 2019 survey, not tied to a specific agricultural season.

followed by brokers (9%), government extension staff (7%), and print and electronic media (6.7%). Reliance on fellow farmers and brokers for market information can expose farmers to exploitation by buyers and misinformation. The primary source of information to farmers on seed knowledge was also from peers (60%), followed by extension staff (20%), seed merchants (4%), NGOs, and community-based organizations (3%). Moreover, the key source of information on good agronomic practices (GAPs) was from peers (54%) and extension staff (25%), with NGOs and community-based organizations (2.7%) and print and electronic media (2.4%) having minor roles (Table 3). Few farmers reported not having received any information on markets (9.8%), seeds (6.3%), and GAPs (12%) from any source.

3.2 | Sources of Sorghum Seed and Seed Systems Choice by Farmers

Majority of the surveyed farmers (80%) reported own-saved seed as the main source of unbought seeds (Figure 1). Seeds from friends and neighbors, agricultural extension officers, and local open-air markets accounted for 5%, 2%, and 1%, respectively, of unbought seed. Few farmers participated in the seed market. Nearly three quarters (73%) of the 329 farmers who purchased seeds bought them from neighbors, 14% from local open-air markets, 8% from agro-dealers, and 10% from other sources like extension officers, local seed businesses (LSB), research institutions, and NGOs (Figure 1).

Farmers used both bought and unbought sorghum seeds. Overall, about 83% of the sorghum grain producers accessed sorghum seed through the informal seed system, 6% through formal, and 11% used the integrated system (Table 4). Specifically, about 88% of the unbought seed was accessed through informal systems, 8.5% through the integrated system, and 3% through the formal system. On the other hand, 69% of the bought seed was sourced from the informal system, 29% from the formal system, and about 1% from the integrated system (Table 4). These findings corroborate past research, which estimated the informal sector to supply between 60% and 90% of the seeds to smallholder farmers in Africa, depending on the crop and variety (McGuire and Sperling 2016; Vernooy et al. 2023).

Over the years, sorghum seed systems have matured in Tanzania, but still experience various challenges that need to be effectively addressed to increase their efficiency and effectiveness (Akpo et al. 2022). To leverage some of the advances made towards improvement of sorghum seed delivery in Tanzania, adapted solutions are needed to solve limited exposure to knowledge, information, low seed availability, narrow distribution channels, and low-income levels which contribute to farmers' dependence on the farmer-managed seed system (Mabaya and Mburu 2016). We find that even through informal channels of seed access, farmers are making important investments in seed purchases and are likely to purchase seeds of improved varieties if they become available.

3.3 | Drivers of Seed Systems Choice

Results from the econometric model showed that seed system preference by sorghum producers differed significantly by zone (Table 5). Producers in the Lake zone were more likely to use the formal system and less likely to use the integrated system when compared to those in the Central zone. However, sorghum producers in the Southern Highland were more likely to use the informal system for seed access than those in the central region.

Female-headed households were 3% more likely to use integrated systems to get their sorghum seed compared to male-headed households. Our results suggest that female-headed households were less likely to use the formal and/or informal system exclusively to access sorghum seeds. Therefore, women farmers have preferences and needs that differ from those of men. For example, sorghum being a very important food crop in

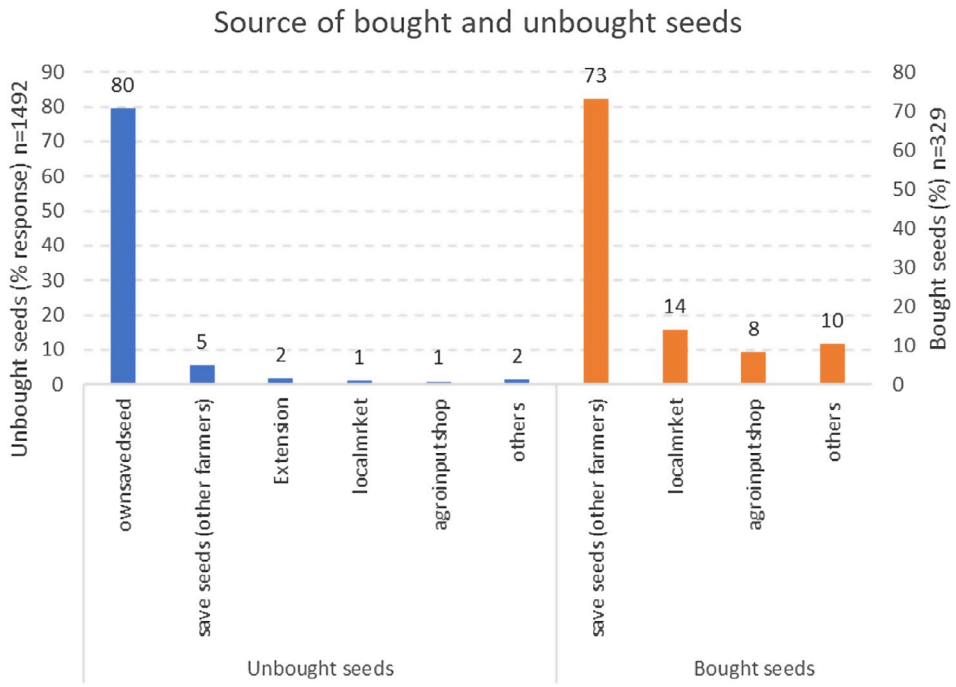

FIGURE 1 | Sources of purchased and non-purchased sorghum seed among sorghum-producing households in Tanzania, 2019 (% of households, $N = 1492$). "Purchased" refers to seed obtained through the formal market (e.g., certified seed companies, agro-dealers, or local markets). "Non-purchased" refers to seed saved on-farm or obtained from friends, relatives, or neighbors. Percentages are calculated at the household level based on survey data collected in 2019.

TABLE 4 | Use of purchased and non-purchased sorghum seed among sorghum-producing households in Tanzania (% of households, $N = 1492$).

Seed system	Unbought seed ($n = 1125$)	Bought seed ($n = 101$)	Bought and unbought ($n = 266$)	Overall ($N = 1492$)
Formal	3.11	29.70	11.28	6.37
Informal	88.36	69.31	65.04	82.91
Integrated	8.53	0.99	23.68	10.72

Note: Households are classified into three mutually exclusive categories: (i) those using only non-purchased seed, (ii) those using only purchased seed, and (iii) those using both purchased and non-purchased seed. Percentages are based on the total sample of 1492 households surveyed.

arid and semi-arid regions, women farmers may seek to balance the household's food security needs with commercial interest. This is consistent with Amri and Kimaro (2010) who found that women in Tanzania and Ethiopia manage seed selection, processing, and storage for food crops while men mainly focused on cash crops. Similarly, in Malawi, Zimba et al. (2023) found that men had preferences for commercial traits while women preferred postharvest traits like taste and storage for sorghum and millet. These responsibilities and market dynamics are likely to shape the specific varieties that are preferred and determine the channels through which seed is sourced.

Access to capital and information can influence farmers' access to seeds (Puskur et al. 2021). Our study shows that being financially literate and participating in insurance increased the likelihood of accessing seeds through the integrated system by 5.5% and 9.6%, respectively. Participation in insurance schemes also decreased the probability of exclusively using the informal channels of seed access by 6.4% (Table 5). This could imply that financially literate farmers better understand production risks and associated risk management strategies. Spreading risks could include planting both the recent varieties sourced from the formal system and varieties they believe are disease resistant and drought-tolerant, sourced from the informal systems. These farmers also appreciate and understand the benefits of investing in improved sorghum varieties while also reducing vulnerability to weather uncertainties. Literature suggests that low financial literacy is associated with vulnerable groups (Lusardi and Messy 2023).

Farmers who got information on agronomic practices from peers were 3.7% less likely to access seeds through formal systems. Getting information on markets from extension reduced the likelihood of accessing seeds through the informal system by 8.7% and increased the probability of choosing the integrated system by 6.3% (Table 5). Proximity to the market is predicted to influence farmers' decisions on seed system choices. An increase in distance to the main market and the nearest passable road increased the probability of using informal seed systems and reduced the likelihood of accessing seeds through the formal system. Having a village market nearby increased the probability of accessing seeds through

TABLE 5 | Determinants of sorghum seed system choice by sorghum grain producers in Tanzania.

	−1	−2	−3	−4	−5	−6
	Formal		Informal		Integrated	
Variables	**dy/dx**	**Std. Err.**	**dy/dx**	**Std. err.**	**dy/dx**	**Std. err.**
Location of residence: base Central zone						
Lake zone	0.039**	0.020	0.012	0.025	−0.051***	0.018
Southern highland	−0.024	0.016	0.076**	0.038	−0.051	0.036
Western zone	−0.011	0.061	0.042	0.089	−0.032	0.071
Demographics						
Female head of the household	−0.005	0.012	−0.024	0.018	0.029*	0.015
Age of the household head (years)	0.000	0.000	−0.000	0.001	−0.000	0.001
Education of the household head (years)	0.002	0.002	−0.000	0.003	−0.001	0.003
Financial literacy	−0.012	0.018	−0.043	0.033	0.055*	0.029
Market participation (yes/no)	0.017	0.013	0.031	0.023	−0.047**	0.020
Input market participation	0.089***	0.012	−0.119***	0.025	0.030	0.023
Primary sources of information						
Peers on agronomic practices	−0.037*	0.019	0.032	0.028	0.005	0.022
Peers on seed knowledge	−0.015	0.019	0.029	0.028	−0.015	0.022
Peers on market information	−0.004	0.014	0.006	0.021	−0.002	0.017
Extension on agronomic practices	−0.002	0.018	−0.020	0.028	0.022	0.023
Extension on seed knowledge	−0.002	0.018	0.050	0.031	−0.048*	0.027
Extension on market information	0.024	0.018	−0.087***	0.033	0.063**	0.028
Use mobile to get agricultural information	−0.009	0.014	0.004	0.025	0.005	0.022
Attended agricultural training even	−0.007	0.019	0.055	0.035	−0.048	0.031
Primary produce buyer-Brokers	−0.025	0.019	0.004	0.030	0.021	0.025
Primary produce buyer- individuals	−0.009	0.019	0.014	0.031	−0.005	0.027
Access to credit (1 = yes)	0.015	0.021	−0.002	0.037	−0.013	0.032
Have a bank account (1 = yes)	0.022	0.014	−0.020	0.023	−0.002	0.020
Used insurance (yes/no)	−0.032	0.022	−0.064*	0.036	0.096***	0.029
Village market in the area	0.011	0.013	−0.033*	0.019	0.022	0.015
Distance to the main market (km)	−0.006**	0.003	0.009*	0.005	−0.003	0.004
Distance to the passable road (min)	−0.007*	0.004	−0.001	0.007	0.008	0.006
Experienced food shortage	0.004	0.013	−0.019	0.019	0.015	0.016
Experimentation with new technologies	0.016	0.011	−0.063***	0.017	0.047***	0.013
Farmers risk profile	−0.001	0.002	−0.007**	0.003	0.007***	0.002
Number of monthly transactions	−0.001	0.001	−0.001	0.001	0.002**	0.001
Use improved sorghum	0.112***	0.013	−0.126***	0.020	0.014	0.017
Total cultivated land (acres)	−0.001	0.001	0.001	0.001	−0.000	0.001
Total area under sorghum (acres)	0.005**	0.002	−0.013***	0.004	0.007**	0.003
Intercropping sorghum with other crops	−0.010	0.011	−0.241***	0.024	0.250***	0.023

(Continues)

TABLE 5 | (Continued)

	−1	−2	−3	−4	−5	−6
	Formal		Informal		Integrated	
Variables	**dy/dx**	**Std. Err.**	**dy/dx**	**Std. err.**	**dy/dx**	**Std. err.**
Production constraints						
Poor market access and low produce prices	0.022*	0.012	−0.019	0.019	−0.003	0.016
Drought	−0.010*	0.006	0.016	0.010	−0.005	0.008
Diseases prevalence	0.028**	0.012	−0.025	0.019	−0.002	0.015
Lack of improved varieties	−0.003	0.013	0.008	0.020	−0.005	0.016
Production constraint: low yields	−0.005	0.013	0.024	0.020	−0.020	0.017
Observations	1492		1492		1492	

Note: Results are based on a binary logit regression of sorghum seed system choice, where the dependent variable equals 1 for the use of formal seed and 0 for informal seed. Significance levels are denoted as ***$p < 0.001$, **$p < 0.01$ and *$p < 0.05$. The analysis is based on 1492 sorghum grain producers surveyed in Tanzania during 2019.

the integrated system by 3.3% (Table 5). This finding suggests that there are seed stockists and seed traders in these village markets and that the low use of formal systems by farmers who live far away from such markets could be more a problem of physical than economic access. For example, we find that an increase in distance from the main market by 1 km reduces the probability of using formal seed systems by almost 1% but increases the probability of using the informal seed system by 1% instead. This is supported by the fact that a 1-min increase in time taken to reach a passable road reduces the possibility of using the formal seed system by almost 1% (Table 5). Sometimes the supply of preferred varieties by farmers is low, further hindering seed access (Ng'ombe et al. 2023). A study in Nigeria showed that improved sorghum varieties raise yields and income when farmers can overcome access barriers (Kamara et al. 2025). In Tanzania, these barriers appear as long market distances and reliance on peer information, which push farmers toward informal systems. Our results show that access to market information through extension reduces informal use and encourages integrated systems, echoing Nigeria's finding that information access boosts adoption.

Farmers willing to take risks and experiment with new technologies and farming ideas were more likely to use integrated system and less likely to rely exclusively on the informal system to access sorghum seeds. For instance, experimentation with new technologies increases the probability of using integrated seed system by about 5% and reduces the probability of using the informal seed system by about 6% (Table 5). The integrated system was also associated with the number of market transactions, reducing the probability of accessing seeds through the informal system. Our findings support earlier evidence that the frequency of transactions can give important insights into seed access mechanisms, especially where small quantities are involved (McGuire and Sperling 2016). Evidence from Ethiopia further shows that adoption of improved seed technology significantly raises crop revenue but also increases exposure to production risk, implying a revenue–risk trade-off for farmers. Farms that combine improved and traditional seeds tend to realize complementary income gains, suggesting that a mix of seed sources can smoothen risks while enhancing returns.

Intercropping sorghum with other crops increased the probability of accessing seeds through the integrated system by about 25% and reduced the likelihood of exclusively using the informal system by about 24%. Intercropping is common in Tanzania and Africa because it provides crop insurance, improves soil fertility through nitrogen fixation, improves productivity, and minimizes pests and diseases (Barasa et al. 2022; Sawe 2022).

Farmers who used seeds of improved sorghum varieties and participated in the output market were more likely to use the formal seed system than the informal one. This category of farmers is most likely market-oriented and contracted by industry players to produce given varieties. They also have better access to certified seeds as off-takers procure seeds of preferred varieties on behalf of their farmers (Kimbi et al. 2024). In addition, the industry players have stringent requirements on grain quality specifications within specific varieties, which these commercially inclined farmers adhere to.

Farmers who identified diseases and lack of improved varieties as the primary production constraints were more likely to choose the formal system over the informal seed system (Table 5). This result suggests that making quality seed of improved sorghum varieties readily available can enhance farmers' participation in the formal seed system and reduce the seed access gap. Orr et al. (2022) observed that the availability of sorghum seeds is sometimes a bigger constraint on the supply of certified seeds than physical or economic access. Farmers who reported drought as a production constraint were less likely to use formal systems and most likely used informal systems to access seeds (Table 5). Drought tolerance is an important trait that farmers consider when choosing seeds of dryland crops like sorghum (Mwamahonje et al. 2021; Ouedraogo et al. 2017), and by extension, the seed system to use to meet that need. Our findings suggest that farmers perceive their varieties to be more tolerant of drought than those from formal seed systems. Since farmers identify severe drought at the post-flowering stage as the most impactful (Derese et al. 2018; Ouedraogo et al. 2017), developing drought-tolerant or escaping early varieties could encourage farmers to participate more in the formal seed system. Further, Zabuloni et al. (2025) recommended advanced breeding approaches for sorghum to target integrative traits such as early maturity, high harvest index, and

water use efficiency, to better align drought tolerance with farmer preferences.

4 | Conclusion and Recommendations

Sorghum is Tanzania's second most important cereal after maize but the most grown crop in the study area. This study examined the factors that determine farmers' choice of different sorghum seed systems in dryland Tanzania. Results show that farmers mostly use their own saved seeds. Those who buy mainly buy from friends and neighbors. The study finds that most of the sorghum producers rely on fellow farmers for information on market, seed knowledge, and agronomy. Our study corroborates findings from other studies that most farmers access seeds from the informal seed system. Households headed by women are more likely to access seed through an integrated (both the formal and informal) system rather than rely on either formal or informal exclusively, suggesting gender differences in preferences and production goals. Sorghum being a very important crop in arid and semi-arid regions, women farmers may seek to balance the household's food security needs with commercial interest.

Providing farmers with financial literacy training and improved access to financial institutions, extension services, and markets can enhance the formal seed system's use. Results show that proximity to markets, availability, and affordability of quality seeds are great determinants of the seed system choice by farmers. Seed merchants, agro-input suppliers, and stockists should be encouraged to establish outlets in local markets to enhance farmers' access to quality seed of improved varieties. Making quality seed of improved sorghum varieties readily available can enhance farmers' participation in the formal seed system and reduce the seed access gap. We find that farmers who are risk takers or intercrop and are willing to experiment with new technologies are more likely to use an integrated seed system. These farmers can be the change agents in their communities, and identifying them to try out and disseminate new technologies can enhance their adoption. Results suggest that farmers would embrace disease-resistant and drought-tolerant sorghum varieties when these traits are validated with farmers in newer varieties. Making them available and creating awareness among producers can increase participation in formal seed systems and enhance their productivity.

Author Contributions

Geoffrey Muricho, Essegbemon Akpo, Mequanint Melesse, and Chris O. Ojiewo designed the study. Emmanuel Mwenda and Devotha Mchau implemented data collection. Zachary Gitonga Papias Binagwa and Ibrahim Shiundu conducted the data analysis and wrote the original draft. Lilian Gichuru, Doris K. Puozaa, and Noel Templer critically reviewed and edited the manuscript. Chris O. Ojiewo provided the study oversight. All authors read and approved the final manuscript.

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Ethics Statement

We hereby confirm that the research is our own work and has not been published elsewhere. The participants were duly informed about the nature and purpose of the study before they participated. Informed consent was obtained from all participants before participation, and all collected data were treated with utmost confidentiality and anonymized and aggregated to protect the privacy of the participants.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The dataset used and analyzed during the current study is available from the corresponding author upon request.

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