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Farmers' preferences and willingness to pay for traits of sorghum varieties: Informing product development and breeding programs in Tanzania

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ABSTRACT

Smallholder farmers' decisions to adopt improved varieties are expected to be critically governed by their preferences and willingness to pay for different traits of these varieties. This study examined farmers' preferences for sorghum (*Sorghum bicolor* (L.) Moench) variety attributes and estimated their willingness to pay (WTP) for these attributes using choice experiment data from >1,300 sorghum farmers in Tanzania. Empirical findings showed that farmers had strong preferences for sorghum varieties that were tolerant to environmental stresses, high yielding, early maturing, fetching higher grain prices, and white in color. Significant heterogeneity was observed in farmers' preferences across various traits. The WTP estimates revealed that farmers were willing to pay the highest premium for tolerance to environmental stresses, amounting, on average, to three times higher than the WTP for other traits. Our results have important implications for demand-driven variety development that could contribute to improving crop productivity and household welfare.

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Choice experiment; preference heterogeneity; random parameter model; Tanzania; variety choice

1. Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) plays a crucial role in the livelihoods of millions of farmers in Tanzania. The crop covers about 0.8 million hectares of land annually, with an average productivity of about 1000 kg/ha (FAOSTAT 2019). Its production is dominated by subsistence farmers, who consume more than 70% of the production. In Tanzania, sorghum production systems are mainly rainfed with minimal pest and disease control and low productive inputs (Msongaleli et al. 2014). Major production regions include Dodoma and Singida in the Central Zone; Tabora in the Western Zone; Shinyanga, Mwanza and Mara in the Lake Zone; and Lindi and Mtwara regions in the Southern Zone. Dodoma, Singida, Shinyanga, Mwanza and Mara together account for more than 60% of the national cultivated area and production of sorghum.

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Sorghum is well-adapted to arid and semi-arid environments, limited rainfall and high temperature of drylands, where other cereal crops, such as maize, cannot grow (Mrema et al. 2017). Its importance has risen in the face of the prevailing threat of climate change and global warming, because it is proven to provide an assured harvest even in bad years (Msongaleli et al. 2014). In addition, sorghum is nutritious and has the advantage of being less prone to mycotoxins than maize (Kulamarva, Sosle, and Raghavan 2009; Seetha et al. 2017), contributing to human health and nutrition outcomes, as well as feed and fodder for livestock. While sorghum utilization is mostly for food purposes, its demand for non-food utilization has grown recently. For instance, the brewery industry in Tanzania is using sorghum to produce clear (lager) beer and nonalcoholic drinks, as well as starch from sorghum for fermentation and bioenergy drink production (Rohrbach and Kiriwaggulu 2007).

Improved varieties of food crops, like sorghum, hold huge potential for increasing smallholder agricultural productivity, and as a result, for improving food and nutrition security and reducing poverty (Maredia, Byerlee, and Pee 2000; Kostandini, Mills, and Mykerezi 2011). Sorghum research and development activities in Tanzania date back to the early 1980s. Since then, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), national agricultural research systems, particularly the Tanzania Agricultural Research Institute (TARI), and universities have collaborated to develop improved sorghum varieties in Tanzania. Tegemeo, Pato, and Macia are among the main sorghum varieties that were released in 1978, 1997, and 1998, respectively. Overall, >15 relevant improved varieties have been developed and released in Tanzania (Gierend, Ojulong, and Wanyera 2014). Many of these varieties are drought-tolerant with short growth cycles favorable for the semi-arid areas.

While the development of these varieties is laudable, efforts and investments targeted at increasing adoption of improved varieties have only been partially successful, and adoption rates of these improved varieties remain disappointingly low (Kimbi et al. 2020). One reason could be that technology development does not properly consider traits of improved varieties that farmers value most. Most of the improved cultivars are developed based on conventional breeding approaches, with a primary focus on agronomic traits, particularly yield and disease resistance. However, while agronomic traits remain essential for varietal adoption, an improved variety's potential, as observed via agronomic traits, may not be a sufficient predictor of demand for the variety (Macours 2019; Shikuku and Melesse 2020). There is now growing awareness of the need to understand pathways linking the development of technologies to their sustained adoption and consider farmer-preferred traits in crop breeding (Noriega et al. 2013; Nhantumbo et al. 2016).

Understanding farmers' preferences for sorghum variety traits can provide useful insights into breeding programs and development initiatives aiming at promoting these technologies at scale. A specific emphasis is how different traits may relate to demand for and adoption of improved technologies. Commonly, participatory variety selection is employed to characterize farmers' needs and preferences in plant breeding to ensure that new varieties fulfil the needs and expectations of end-users (Steinke and van Etten 2017; Magaisa et al. 2021). But participatory approaches do not help to quantify farmers' preferences and willingness to pay (WTP) for traits that are likely to govern their adoption decisions regarding improved varieties and potential trade-offs across varietal traits.

In this study, we used a choice experiment design to evaluate farmers' preferences for traits of sorghum varieties in Tanzania, estimate the WTP for each trait, and identify potential factors that govern heterogeneity in trait preferences. The choice experiment involved six key sorghum attributes: yield, maturity, grain price, color, tolerance to environmental stresses (disease, pest and drought) and cost of seed. These attributes were selected through literature review, sorghum experts' opinion, key informant discussions and piloting with farmers. As clients of breeding, sorghum growers, largely subsistence farmers, are both producers and consumers of the crop. Thus, for new varieties to succeed, they must possess traits that appeal to both growers and end-use consumers.

2. Materials and methods

2.1. *Data and descriptive statistics*

Our analysis relied on data collected from six regions of Tanzania – Dodoma, Singida, Shinyanga, Tabora, Songwe and Mara – in October-December 2019 by ICRISAT, as part of its Accelerated Varietal Improvement and Seed Delivery of Legumes and Cereals in Africa (AVISA) project. The regions covered important sorghum growing dryland agro-ecological areas that accounted for about 70% of total sorghum production in 2017 (ROT 2017). A multistage sampling design was employed to select sample households. First, 10 districts were randomly selected across regions. Next, a simple random sampling was used to select 34 wards and 44 villages for the survey. The final stage involved random selection of households from villages proportional to their population distributions based on sampling frames generated with the help of village extension agents and local administrative officers. A total of 1301 sorghum farmers were interviewed. In addition to the choice experiment data, the survey collected detailed information on household characteristics. Table 1 contains detailed summary statistics for a range of household characteristics.

Table 1. Socio-economic characteristics of the respondents.

Variable	Mean	Std Dev.
Household head is male (%)	61.9	
Age of the household head in years	47.6	13.8
Years of formal education in years	6.1	2.9
Household size	4.4	1.5
Farming is main occupation (%)	94.5	
Average plot size in hectares	1.7	12.9
Total livestock unit (TLU) †	8.6	32.4
Average per capita income ('000 TSh.)	826.3	1,717.5
Household asset index	2.3	52.6
Distance to the nearest all weather road (in walking minutes)	24.0	50.8
Village market is available (%)	38.0	
Access to agricultural extension (%)	36.0	
Farmer group membership (%)	26.5	
Access to credit (%)	6.5	

Source: AVISA project survey (2019) in Tanzania.
Note: † Livestock was measured using tropical livestock units (TLU), which is a common unit used to quantify a wide range of various livestock species to a single figure to get the total amount of livestock owned by a household. We employed a tropical livestock unit applicable for SSA

The majority (62%) of the households were headed by males. The average respondent was about 48 years old, with about six years of completed schooling. The average household had about four family members, about two hectares of cultivable land, and a livestock herd of about nine tropical livestock units (TLU). TLU is a common unit used to quantify a wide range of livestock species to a single figure to get the total amount of livestock owned by a household (Njuki et al. 2011). A TLU applicable for sub-Saharan Africa (SSA) was employed. Farming was the main occupation for about 95% of the households, implying that agriculture was the mainstay for the studied households. The average annual per capita income from all sources was about Tanzania Shillings (TSh.) 826,300 (about US$360). The household asset index was generated using principal component analysis from individual durable household asset items. About 38% of the respondents reported that there was a village market in their communities, and the average household was located about 24 minutes' walking-distance from a main all-weather road. About 36% of the households were visited by an extension officer at least once in the survey year. Moreover, 27% of the farmers belonged to a farmers' group organization. Only 7% households accessed credit from formal lending institutions.

2.2. Choice experiment design and analytical framework

2.2.1. Discrete choice experiment design

Using a discrete choice experiment (DCE) framework, we considered crop varieties as bundles of attributes, which allowed assessment of changes in individual choices, as one or more of the attributes varied. Our use of DCE approach, instead of relying on actual behavior, has several benefits. First, there were no well-functioning seed markets for sorghum varieties in Tanzania. Second, even when markets for varieties did exist, it would be difficult to identify effects of each trait of a variety on farmers' choice decisions based on market data, as there might be correlations between traits. Third, and importantly, choice experiment analyses offer a means through which the nuances of decision-making can be understood by providing insights into implicit trade-offs between different traits (Khanal, Adhikari, and Wilson 2017).

Six relevant sorghum attributes were selected for the choice experiment: yield, maturity, grain price, color, tolerance to environmental stresses (drought, disease and pest) and cost of seed (Table 2). The choice of these attributes was guided by an extensive literature review of factors important for farmer varietal choices. Furthermore, we verified the appropriateness of these attributes and their respective levels using discussions with sorghum breeders at ICRISAT and TARI, and focus group discussions with sorghum farmers. Finally, we conducted a pretest to see whether the attributes were relevant and the levels for each attribute were plausible and understandable for farmers.

Yield, maturity and tolerance attributes are related to agroecological conditions of sorghum. The level of yields was determined by taking the minimum, average and maximum output of sorghum based on data from stations and farmer surveys. Likewise, levels of maturity were defined by taking minimum, average and maximum maturity days after consulting sorghum breeders and literature. Tolerance was defined as the ability to withstand environmental stresses, including drought, diseases and pests, with two levels: tolerant or not tolerant. Color is an important trait considered by

Table 2. Sorghum variety attributes and levels.

Attribute	Measurements	Levels
Color	Color of the grains	White, brown/red
Tolerance	Tolerance to drought/disease/pest	Tolerant, not tolerant
Yield	Ton per hectare (t/ha)	0.5, 1.5, 2.5
Maturity	Number of days to maturity	95, 115, 125
Grain price	Grain market price per kg (TSh./kg)	250, 400, 550
Seed price	Seed market price per kg (TSh./kg)	1000, 2000, 3000, 3500

Source: Constructed by authors.

producers and consumers, since it is mostly used as a proxy for both preference for consumption and value in the market. Color was defined as the color of the sorghum grain, which could be one of the known sorghum colors in Tanzania: white, brown or red. But brown and red were grouped into the same level, as there was confusion about their distinction in different areas and among farmers during the pilot. Lastly, sorghum seed and grain prices were included to capture producer demand for seed and consumer demand for grain, as well as to facilitate estimation of trade-offs for traits. Levels of these attributes were derived from data in local markets for improved seed and grain.

We limit the attributes to six to keep the DCE design relatively simple to minimize fatigue and cognitive burden on the respondents. A full factorial design based on the attributes and their corresponding levels would give 432 ($= 3^3 * 2^2 * 4$) distinct crop variety choices. However, working with all these choices was not practically feasible. Instead, the D–optimal fractional factorial design was used to generate choice sets that allowed the estimation of all main effects. The design offers an efficient combination of orthogonality, level balance, and minimum overlap and reduces the predicted standard errors of parameter estimates (Kuhfeld 2010). This process generated 36 choice sets using random selection without replacement. Further, the 36 choice sets were randomly divided into six blocks using SAS macros to ensure orthogonality between the blocking factor and all of the attributes of all alternatives. Each respondent thus made six choices, with each choice set consisting of two sorghum variety alternatives (variety alternatives 1 and 2) and an opt-out option (alternative 3). Respondents were given a careful description of the experiment, a clear explanation of attributes and their levels, and an outline of how to make a choice. Detailed instructions, definitions of attributes, and a sample choice set are provided in the Appendix (Table A1). In total, 23,418 choice sets were obtained from 1,301 households.

Participation was completely voluntary. Moreover, respondents were informed that they could opt out of the survey at any time with no penalty. Explicit information was also included regarding potentially relevant excluded attributes. Respondents were informed that sorghum variety alternatives presented to them differed only with respect to the six attributes and that all other unstated attributes of sorghum were the same for the two alternatives in a choice set. They were also provided with the so-called "consequential clause" that their responses would be useful for policy-makers, breeders and seed companies in Tanzania to develop and produce new sorghum varieties. The literature has shown that using such an introductory statement helps to frame respondents' mind to translate the hypothetical scenarios into real-life decisions (e.g., Cummings, Taylor, and Laura 1999).

2.2.2. *Analytical framework*

The analytical framework of the choice experiment data is based on the random utility theory (RUT). RUT assumes that a representative individual is rational and, in a given choice situation, selects the alternative that yields the highest level of utility (McFadden 1973). Assuming a linear indirect functional form, the utility (U) of an individual i, for alternative j, in choice situation t, is expressed as a sum of a systematic component V_{ijt}, and a stochastic, unobservable component, ε_{ijt}.

$$U_{ijt} = V_{ijt} + \varepsilon_{ijt}, \quad j = 1, 2, \ldots\ldots, m \tag{1}$$

In line with Lancaster's (1966) theory of demand, the systematic part of the utility function can be decomposed into the sum of separate utilities derived from its constituent parts. That is, $V_{ijt} = \alpha + x'_{ijt}\beta_i$. After replacing this for V_{ijt}, equation (1) becomes:

$$U_{ijt} = \alpha + x'_{ijt}\beta_i + \varepsilon_{ijt} \tag{2}$$

where β_i is a vector of individual-specific coefficients, x_{ijt} is a vector of observed attributes and ε_{ijt} is a random term that is assumed to be an independently and identically distributed extreme value type I. In statistical terms, the extreme value type I distribution, also known as the Gumbel distribution, is used to model the distribution of the maximum or the minimum of a number of samples of various distributions. In our set up, this assumption is useful because the difference of two Gumbel distributed random variables has a logistic distribution and this aligns with our outcome variable, i.e., the choice of an alternative. In this model, called random parameter logit (RPL), the probability that farmer i chooses alternative j from among m alternatives in a choice situation t takes a conditional logit specification (McFadden 1973):

$$L_{ij}(\beta_i) = \frac{exp\left(x'_{ijt}\beta_i\right)}{\sum_{l=1}^{m} exp(x'_{ilt}\beta_i)} \tag{3}$$

The specification in (3) assumes that β_i is known and it is fully explained by using its means only. However, β_i is unknown and it is not feasible to condition on it (McFadden and Train 2000; Train 2009). Assuming that $\beta_i \tilde{N}(\beta, \Sigma_\beta)$, the unconditional probability that a respondent will choose alternative j is estimated by integrating the conditional probabilities across all values of each of β weighted by its density function. That is:

$P_{ijt} = \Pr[y_{it} = j] = \; L_{ij}(\beta_i) f(\beta_i|\theta) d\beta_i$

$$= \int \frac{exp x'_{ijt}\beta_i}{\sum_{l=1}^{m} exp(x'_{ilt}\beta_i)} f(\beta_i|\beta, \Sigma_\beta) d\beta_i \quad (4)$$

In equation (4), $f(\beta_i|\theta) \tilde{N}(\beta, \Sigma_\beta)$. The integral is multidimensional with dimension given by the number of components of β_i that are random with non-zero variance (Cameron and Trivedi 2005). For simplicity, we assume that the off-diagonal elements of Σ_β are zero. The Maximum Likelihood Estimation (MLE) now maximizes:

$$lnL_N(\theta) = \sum_{i=1}^{N} \sum_{j=1}^{m} y_{ijt} lnP_{ijt} \quad (5)$$

Since the expression in (5) cannot be analytically solved, simulated probabilities are inserted into the log-likelihood function, which yields a simulated log likelihood (Cameron and Trivedi 2005; Hensher and Greene 2003; Train 2009) of the form:

$$ln\widehat{L_N}(\beta, \Sigma_\beta) = \sum_{i=1}^{N} \sum_{j=1}^{m} y_{ijt} ln \left[\frac{1}{S} \sum_{s=1}^{S} \frac{exp\left(x'_{ijt}\beta_i^{(s)}\right)}{\sum_{l=1}^{m} exp(x'_{ilt}\beta_i^{(s)})} \right] \quad (6)$$

where y_{ijt}=1 if the respondent chooses alternative j in a choice set t, and zero otherwise; and $\beta_i^{(s)}$, with s = 1, 2, ..., S, are random draws from $f(\beta|\theta)$. Parameter estimates $\beta^s \; and \Sigma_\beta^{(s)}$ represent the mean and standard deviation generated from equation (6) using maximum simulated likelihood (MSL) at r^{th} draw (Cameron and Trivedi 2005; McFadden and Train 2000).

The use of RPL provides several advantages. First, it captures unobserved heterogeneity. Second, it allows possible correlations between the selected alternatives and choice tasks, as it relaxes the strict assumption of independence of irrelevant alternatives (IIA) (Hensher and Greene 2003; McFadden and Train 2000; Train 2009). More importantly, it allows estimation of the respondents' marginal rate of substitution (MRS) for different attributes. With respect to seed prices, the MRS can easily be interpreted as the WTP of the respondents for other sorghum attributes. For any attribute, x^{nm}, the willingness to pay of respondent i could be calculated as:

$$WTP_{ix^{nm}} = \frac{\partial U_i}{\partial X^{nm}} \Big/ \frac{\partial U_i}{\partial W} = -\left(\frac{MU_{x^{nm}}}{MU_w}\right) \quad (7)$$

where $MU_{x^{nm}}$ and MU_w represent the marginal utility of attribute x^{nm} and seed prices, respectively. Commonly, empirical studies assume that the monetary coefficient is fixed and estimate equation (7) directly. However, this approach is problematic since it involves dividing distributions by distributions (Hensher and Greene 2003; Train 2009).

In this study, we follow Train and Weeks (2005) and directly estimate the WTP in a WTP space. This approach involves deriving the WTP estimates directly by reformulating the mixed logit model. It produces more realistic WTP estimates than the conventional method. Rewriting the utility function in equation (2), and differentiating between seed prices (W_{ijt}) and non-seed price attributes (Z_{ijt}), we have:

$$U_{ijt} = \eta_i w_{ijt} + z'_{ijt}\varphi_i + \varepsilon_{ijt} \tag{8}$$

where η_i and φ_i are individual-specific coefficients for seed prices, and other attributes and ε_{ijt} is the random term. Equation (8) can also be expressed as:

$$U_{ijt} = \eta_i[w_{ijt} + z'_{ijt}\gamma_i] + \varepsilon_{ijt} \tag{9}$$

Table 3. Simulated likelihood estimates of the random parameter logit model.

Mean estimates of main variables	Structural preference parameters		SD of the parameter distributions	
	Coefficient	SE	Coefficient	SE
Color white	0.462***	0.060	1.270***	0.085
Tolerant variety	1.853***	0.095	2.114***	0.108
Yield (reference: 0.5)				
Yield 1.5	0.642***	0.062	−0.741***	0.110
Yield 2.5	1.045***	0.068	0.977***	0.109
Grain price (reference: 250)				
Grain price 400	0.564***	0.071	0.935***	0.120
Grain price 550	0.544***	0.063	0.734***	0.093
Maturity (reference:125)				
Maturity 115	0.350***	0.061	0.025	0.173
Maturity 95	0.535***	0.071	1.007***	0.121
Seed price	−0.000***	0.000	0.001	0.085
Constant	29.26	3,987		
Number of respondents	1,301			
Number of observations	23,418			
Log-likelihood	−4,915			
LR $chi^2(9)$	838.5			
McFadden R^2	0.08			
AIC	9,868			
BIC	10,021			
Halton draws	100			

***, **, and * represent statistical significance at 1%, 5%, and 10% level, respectively.SE stands for standard errors; SD stands for standard deviations indicating preference heterogeneity in mean.

where $\gamma_i = \varphi_i/\eta_i$ represents the WTP for the non-seed attributes, which could now be directly estimated by using MSL (Train 2009).

3. Results

3.1. *Preferences for sorghum traits*

Table 3 contains the simulated likelihood estimates of the RPL model for variety choices. All the attributes were specified as random variables with normal distribution, apart from seed price, which was specified to be log-normally distributed to allow for both positive and negative preferences of attributes (Train 2009). Generally, the magnitude of coefficients of the parameter estimates showed how strongly respondents valued the respective attributes relative to alternative reference attributes. Our results indicated that all variety attributes included in the choice experiment significantly determined variety choices with *a priori* expected signs (Table 3). Preference for tolerance trait was the strongest. While farmers normally considered productivity of varieties when making adoption decisions, they also took into account the suitability of such varieties to the local environmental conditions to reduce yield losses and crop failure. As such, tolerance to adverse weather conditions, pests and diseases was one of the most important traits for farmers when choosing seeds.

Farmers strongly valued a sorghum variety that was high yielding and could fetch a high grain price (Table 3). This is consistent with income-maximizing behavior of households. White sorghum varieties were preferred to brown/red varieties. Often, color preferences are largely related to household consumption preferences. Further, while brown sorghum is primarily used for making traditional beer, white sorghum is highly preferred for the production of alcoholic drinks (Xiong et al. 2019). Farmers also revealed strong preferences for early-maturing sorghum varieties. Early-maturing varieties lower the cost of production with respect to input usage, overcome unpredictable weather patterns, and allow multiple cycles of production per season, as well as help poor households to bridge lean seasonal consumption shocks. Finally, the alternative-specific constant of the model captures effects of other attributes not included in specific choice sets on preferences. It was constructed by equating it to 1 if respondents chose either alternative 1 or alternative 2 in the choice sets and to 0 if they chose the status quo (the opt-out alternative 3). This constant is positive but insignificant.

A concern here is that respondents may employ a strategy that ignores one or more of the attributes in their choices that could affect the robustness of the results. To address the issue of attribute nonattendance (ANA), Table A2 in the appendix was generated based on an inferential approach suggested by Hole (2011), and reported the extent to which sorghum farmers might have ignored some of the crop attributes. Consistent with the results presented in Table 3, the probability of ignoring seed prices, tolerance to environmental stress, yield, and grain prices was relatively low. For example, only 24% of farmers would have completely ignored seed prices. In contrast, the likelihood of nonattendance was relatively high for maturity and color, with a probability ranging from 80% to 92%. Based on these findings and in line with previous studies (Hole 2011; Lagarde 2013), we estimated a model that accounted for ANA strategies (Table A3). The results indicated that the estimates of the ANA model with respect to both sign and significance of the coefficients were qualitatively the same as the standard model. However, with respect to model fit, the ANA model did not represent a significant improvement. Compared to the ANA model, the standard model represented a slight improvement with respect to both the log-likelihood values and the two information criteria, i.e., the Akaike information criterion (AIC) and the Bayesian information criterion (BIC).

Column 3 of Table 3 contains standard deviations associated with mean coefficient estimates calculated across 100 Halton draws. Except for maturity (115 days), standard deviation coefficients were statistically significant, indicating considerable heterogeneity in preferences among sorghum farmers; we explore below the source of the observed heterogeneity in trait preferences.

3.2. *Heterogeneity in sorghum trait preferences*

The standard deviations (Table 3) suggested preference heterogeneity for sorghum attributes, indicating that farmers did not attach equal weights to different attributes. We now explore the sources of this heterogeneity using sociodemographic factors. To this end, socioeconomic characteristics were introduced into the models as interactions. This was done by re-estimating equation (5), including the interaction terms between the sources of heterogeneity and selected attributes, accounting for correlations and multicollinearity. Results are presented in Table 4.

Results revealed that farmers with better access to market (i.e., availability of village market) were more likely to have strong preferences for sorghum varieties tolerant to environmental stresses. Moreover, farmers' preferences for higher yield and grain prices also appeared to increase with market access. This is consistent with the literature that market access increases the likelihood and ability of farmers to use information on return and risk in their production decisions. For example, Karuho and Collins (2020) argued that farmers with access to market tended to be more sensitive to grain prices, produced a larger commercial surplus, and across time, tended to be attracted to higher-value markets. Youth interacted positively with tolerance, suggesting that the youth were likely to have a strong preference for tolerant sorghum varieties. This is consistent with Adu et al. (2021) who

Table 4. Preference for sorghum attributes and heterogeneity analysis.

Mean estimates of main variables	Structural parameters		SD of the parameter distributions	
	Coefficient	SE	Coefficient	SE
Color white	0.511***	0.192	−0.240	0.350
Tolerant variety	1.075***	0.266	−1.164***	0.160
Yield (reference: 0.5)				
Yield 1.5	0.442***	0.075	0.593***	0.106
Yield 2.5	0.808***	0.078	−0.630***	0.119
Grain price (reference: 250)				
Grain price 400	0.449***	0.076	0.693***	0.115
Grain price 550	0.435***	0.068	0.430***	0.121
Maturity (reference:125)				
Maturity 115	0.321***	0.059	0.171	0.154
Maturity 95	0.541***	0.069	0.949***	0.099
Seed price	−0.000***	0.000	0.000	0.000
Heterogeneity analysis				
Color White * Age of youths	−0.003	0.004	0.019***	0.003
Tolerant variety * Age of youths	0.014**	0.006	−0.029***	0.003
Tolerant variety *Female‡	−0.149	0.156	−0.461	0.343
Color white * Market access§	0.187	0.138	−1.673***	0.182
Tolerant variety * Market access	0.672***	0.198	−1.971***	0.244
Grain price 400 * Market access	0.340**	0.148	0.649**	0.260
Grain price 500 * Market access	0.263*	0.137	1.053***	0.166
Yield 1.5 * Market access	0.665***	0.143	−0.998***	0.197
Yield 2.5 * Market access	0.687***	0.154	−1.127***	0.195
Yield 1.5 * Poor households¶	0.086	0.143	−0.580***	0.198
Yield 2.5 * Poor households	0.133	0.146	0.579**	0.240
Constant	27.509	760.790		
Number of respondents	1,301			
Number of observations	23,058			
Log-likelihood	−4,861.62			
LR chi2(20)	841.96			
McFadden R2	0.079			

Note: ***, **, and * represent statistical significance at 1%, 5%, and 10% level, respectively. † Household head is considered as educated if he or she has some formal education; ‡ female household head refers to gender of self-reported household head; § market access refers to households who reported to have access to the village market; ¶ poor households refers to households at the bottom 40% of the wealth distribution. Wealth is derived from the household asset index using principal component analysis. SE stands for standard errors; SD stands for standard deviations.

found that younger household heads were more responsive to adoption of new innovations and improved technologies for enhancing crop productivity. However, farmers' preferences for different sorghum attributes did not significantly vary by gender and poverty status of households (Table 4). Yet, considerable unexplained heterogeneity still remained as evident from significant standard deviations, even within the identified sub-samples of respondents. Alternatively, the significance of the standard deviations could also suggest that portion of the sampled farmers preferred attributes of sorghum different from the preferred traits by the majority of the sampled farmers. To get further insights, we estimated the proportion of respondents that had a positive or negative preference for an attribute (Train 2009). The proportion of farmers that had a positive preference for a sorghum attribute, % POS was calculated as: % POS = ∅(β⁄(SD)), where β and SD represent the estimated means and standard deviations of each of the random taste parameters, respectively, and ∅ is the standard normal cumulative distribution function. More than 70% of the respondents favored a tolerant seed variety, higher grain prices, and shorter maturity period (Table A4). Preference was less homogenous for higher yield level. While 85% of sorghum farmers preferred a 2.5 tons/hectare yield level, 19% preferred a less sizable increment (1.5 tons/hectare). These results have important implications for breeding programs related to the potential market size for attribute preferences. Importantly, breeding programs need to weigh the size of the potential market for a specific attribute before scarce resources are committed to improving the attribute. Alternatively, the results implied that breeding programs needed to be aware that not all farmers would welcome improvements in a specific attribute of a variety.

3.3. *Willingness to pay for sorghum traits*

Using mean values of the parameters in Table 3, we estimated farmers' marginal willingness to pay (WTP) for sorghum traits. Technically, the

Table 5. Willingness to pay (WTP) estimates for sorghum attributes, '000 TSh.

Preference attributes	Coefficient	SE	[95% Conf. interval]	
Color white	1.47***	0.25	0.98	1.97
Tolerant variety	6.28***	0.61	5.09	7.48
Yield (reference: 0.5)				
Yield 1.5	1.79***	0.27	1.27	2.31
Yield 2.5	3.15***	0.36	2.44	3.86
Grain price (reference: 250)				
Grain price 400	1.76***	0.29	1.19	2.33
Grain price 550	1.56***	0.26	1.05	2.06
Maturity (reference:125)				
Maturity 115	0.56***	0.21	0.14	0.98
Maturity 95	1.13***	0.24	0.65	1.61
SD of Estimates				
Color white	4.40***	0.46	3.51	5.30
Tolerant variety	6.58***	0.60	5.41	7.75
Yield 1.5	2.36***	0.42	1.54	3.18
Yield 2.5	3.27***	0.41	2.46	4.08
Grain price 400	2.48***	0.46	1.57	3.39
Grain price 550	2.30***	0.38	1.56	3.04
Maturity 115	1.14***	0.54	0.09	2.19
Maturity 95	2.04***	0.45	1.16	2.93
Number of respondents	1,301			
Number of observations	23,418			
Chi-squared (df = 6)	55,075			
Log-likelihood	−5,713			

Note: ***, **, and * represent statistical significance at 1%, 5%, and 10% level, respectively. SE stands for standard errors.

WTP estimates are the derivation of the marginal rate of substitution between significant attributes and significant purchase prices, measuring implicit prices of possible trade-offs across traits conditioned on the choices made by an individual (Hensher and Greene 2003). Table 5 contains the WTP matrix estimated in the WTP space following Train and Weeks (2005).

Farmers were generally willing to pay a premium for all attributes. The WTP estimates showed clear evidence for the importance of grain yield and grain prices. The average WTP for a variety that produced 2.5 tons per hectare was TSh. 3,150, whereas for a variety that yielded 1.5 tons per hectare, it was TSh. 1,790. Similarly, compared to a seed variety that could be sold for TSh. 250 per kilogram, farmers were willing to pay TSh. 1,560 per kilogram for a variety that could be sold for TSh. 550 per kilogram. Meaning, for every additional Shilling that a sorghum grain generates, farmers were willing to pay TSh. 5.2. Perhaps, this is because farmers valued not only immediate yield differences but also differences accruing across a long period that would result from repeated use of the seeds across the subsequent production cycles. In other words, this premium should be interpreted as the present value of all the future earnings farmers expect from their preferred variety. This is evident as 89% of the farmers reported having used their own saved seeds from previous production seasons. However, seed recycling is a known threat to seed quality, with progressive yield decreases (Japhether et al. 2006). Farmers were also willing to pay more for white and early-maturing varieties, ranging from TSh. 560 to 1,470.

The WTP values were even higher for traits associated with tolerance than those of all other traits, indicating the high importance of tolerance sorghum traits to farmers. On average, farmers were willing to pay TSh. 6,280 (about US$2.7) to move from a non-tolerant to a tolerant seed variety. A simple comparison of the mean WTP coefficients (disregarding the heterogeneity) revealed that farmers were willing to pay for tolerant variety two times the amount they were willing to pay for an increase in grain yield of 2 tons/ha (change from 0.5 to 2.5). A tolerant variety was valued about six times the value respondents attached to a change from the longest maturity to the shortest maturity variety. A tolerant variety was also valued four times higher than both the value farmers were willing to pay for changing a sorghum variety from one fetching 250 TSh./kg grain price to one fetching 550 TSh./kg grain price, and from red/brown colored to white one. Tolerance is expected to be the most desired and valued attribute in countries like Tanzania, where crops are susceptible to recurring adverse climatic and agronomic conditions, such as drought, disease and pest. Overall, the WTP estimates for other traits were in the realistic range and consistent with what had been reported in other studies (e.g., Shee, Azzarri, and Haile 2020).

4. Conclusion

The breeding process of improving a specific trait of a variety is likely to alter levels of other traits, affecting potential adoption and impact of the variety. It is thus critical for breeders to know how farmers would value changes in attributes to understand where and when trade-offs are possible. Such information is specifically useful for staple crops, as smallholder farmers' production and consumption preferences are likely to be non-separable. We employed a choice experiment approach to analyze farmers' preferences and WTP for sorghum variety traits in Tanzania.

Our results revealed that all sorghum variety attributes included in the analysis were significant determinants of variety choice. Sorghum growers had strong preferences for sorghum varieties that were tolerant to environmental stresses, were high yielding, fetching higher grain price, early maturing, and white in color. Significant heterogeneity was observed in farmers' preferences for various traits, which was partly explained by household market access. Farmers' willingness to pay for attributes was consistent with their preferences. Tolerance to environmental stresses was valued the highest, followed by increased yield. While sorghum is drought tolerant and research has considerably improved tolerance and yield in sorghum varieties, there is still room for further improvement of these attributes, as demonstrated by high WTP estimates.

Our results have important implications for demand-driven variety development, breeding priority setting, and targeted promotion of improved varieties of sorghum in Tanzania. They can support breeders to identify attributes for which farmers have strong preferences and are willing to pay a premium for selecting priority traits. Importantly, breeders need to be mindful of the importance of non-agronomic traits, like grain market price and color, in sorghum product development and breeding programs in Tanzania. The inclusion of more consumer-preferred traits could help further increase demand for new varieties and speed up varietal replacement. Further, our results suggest that trait-based promotion of varieties could offer an effective strategy to promote adoption of improved varieties on a large scale. While yield and other traits are obviously important, emphasis on the tolerance trait of a variety can be more convincing for farmers to adopt a variety. Finally, our results can be useful for policymakers about potential economic benefits and costs related to varietal development to make informed decisions regarding resource allocation.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendix

Instruction for the choice experiment (Please read the following aloud to the respondent)

We are going to ask you a few questions about whether you would choice to purchase a number of sorghum seed varieties with different seed attributes at a particular price level. The sorghum seeds are arranged in 6 different decision sets. This purchase is hypothetical, that is, you do not actually pay money when you indicate a particular purchase preference. But we would like you to make a choice in each decision scenario as if you were actually facing them in real life seed markets. In each scenario, there are two sorghum seed varieties and you may choose any of them or none of them. When making your choice, assume that all the unstated attributes of sorghum varieties are the same for the two presented varieties.

Consequentiality clause

Because the purchase decision is hypothetical, it might be possible that people would respond in one way but actually act differently. A common observation is that one states a higher willingness to pay than what he/she actually is willing to pay for the amount of the seed in the market. In order to avoid this situation, we ask you to respond to each of the following choice questions just exactly as you would if you were really in a seed market and were going to face the consequences of your decision – which is to pay money if you decide to buy the seed variety within your budget constraint. There are no right or wrong answers, and your honest responses will be very useful for policymakers, breeders and seed companies and businesses in Tanzania to develop and produce new sorghum varieties that can satisfy farmer preferences at reasonable prices.

Description of the attributes of the sorghum seed

Yield: The output of the seed that is measured in tons per hectare and takes three levels.

- 0.5 tons: A variety that has a potential to produce 0.5 t/ha
- 1.5 tons: A variety that has a potential to produce 1.5 t/ha
- 2.5 tons: A variety that has a potential to produce 2.5 t/ha

Maturity. This refers to the number of days a variety takes to mature. It assumes three levels.

- 95 days: 95 days to maturity
- 115 days: 115 days to maturity
- 125 days: 125 days to maturity

Grain price: This refers to the sorghum grain market price per kilogram. It takes three levels

- Grain price 250: Grain market price of 250 Tsh./kg
- Grain price 400: Grain market price of 400 Tsh./kg
- Grain price 550: Grain market price of 550 Tsh./kg

Color: The color of the sorghum seed and assumes two levels

- White color: Sorghum seeds that are white in color
- Brown/ red color: Sorghum seeds that are brown/red in color

Tolerance: Tolerance of sorghum seed to drought, pest and diseases. It takes two levels

- Tolerant: Seed varieties that are tolerant to drought, pest and diseases
- Not tolerant: Seed varieties that are susceptible to drought, pest and diseases

Seed price. The seed market price per kilogram. It takes four levels:

- Seed price 1000: Seed market price of 1000 Tsh./kg
- Seed price 2000: Seed market price of 2000 Tsh./kg
- Seed price 3000: Seed market price of 3000 Tsh./kg
- Seed price 3500: Seed market price of 3500 Tsh./kg

Table A1. A sample choice set presented to respondents.

Attributes	Variety 1	Variety 2	Neither 1 or 2
Yield	2.5	1.5	
Maturity	95	115	
Grain price	250	400	Neither of the two
Color	Brown/Red	White	
Tolerance	Not tolerant	Tolerant	
Seed price	2000	3000	
Which one would you prefer?	☐	☐	☐

Table A2. Estimates of nonattendance probabilities.

Variables	Coefficient	SE	z-value	p-value	95% conf. interval	
Color of the grain is white, yes = 1	0.813	0.027	29.76	0.000	0.760	0.867
Variety is tolerant, yes = 1	0.548	0.020	27.74	0.000	0.509	0.587
Yield in tons per hectare (ref: 0.5)						
Yield is 1.5	0.672	0.073	9.27	0.000	0.530	0.814
Yield is 2.5	0.545	0.056	9.71	0.000	0.435	0.654
Grain price (TSh./kg) (ref: 250)						
Grain prices is 400	0.657	0.090	7.28	0.000	0.480	0.834
Grain prices is 550	0.686	0.081	8.47	0.000	0.527	0.844
Number of days to maturity (ref:125)						
Maturity is 115	0.829	0.170	4.87	0.000	0.495	1.162
Maturity is 95	0.921	0.030	30.63	0.000	0.862	0.979
Seed price (TSh./kg)	0.244	0.071	3.41	0.001	0.104	0.383

Table A3. Estimates and model fit of the two approaches.

Variables	(1)	(2)	(3)	(4)
	Standard model		ANA Model	
	Coefficient	SE	Coefficient	SE
Color of the grain is white, yes = 1	0.462***	0.060	2.572***	0.278
Variety is tolerant, yes = 1	1.853***	0.095	3.605***	0.173
Yield in tons per hectare (ref: 0.5)				
Yield is 1.5	0.642***	0.062	1.324***	0.237
Yield is 2.5	1.045***	0.068	1.812***	0.196
Grain price (TSh./kg) (ref: 250)				
Grain prices is 400	0.564***	0.071	1.325***	0.306
Grain prices is 550	0.544***	0.063	1.266***	0.248
Number of days to maturity (ref:125)				
Maturity is 115	0.350***	0.061	0.679	0.595
Maturity is 95	0.535***	0.071	3.259***	0.923
Seed price (TSh./kg)	−0.000***	0.000	−0.000***	0.000
Constant	29.26	3,987		
Number of respondents	1,301		1,301	
Number of observations	23,418		23,418	
Log-likelihood	−4,915		−5,713	
AIC	9,868		11,462	
BIC	10,021		11,607	

Table A4. Proportion of the respondents with positive/negative preference for an attribute.

Variables	%POS
Color of the grain is white, yes = 1	0.642
Variety is tolerant, yes = 1	0.810
Yield in tons per hectare (ref: 0.5)	
Yield is 1.5	0.193
Yield is 2.5	0.858
Grain price (TSh./kg) (ref: 250)	
Grain prices is 400	0.727
Grain prices is 550	0.771
Number of days to maturity (ref:125)	
Maturity is 115	1.000
Maturity is 95	0.702
Seed price (TSh./kg)	0.192