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Farmers' synergistic selection criteria and practices for livelihood security through the sustainable uses of on-farm Sorghum landrace diversity, Ethiopia

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The relationships among the multiple criteria that farmers in this study area, the north Shewa and south Wollo regions of Ethiopia, use to select which sorghum landraces to grow were examined in order to assess the extent of synergistic relatedness among them as they fulfilled their roles in meeting the farmers' goals. Surveys were conducted on 300 randomly selected farmers' fields during the 2011/2012 cropping season. In each field, the farmers identified the sorghum landraces encountered at 5m intervals along transect lines, spaced 10 m apart; they were also asked to specify the reasons (selection criteria) for growing each landrace. Pearson correlation, t-Tests and Linear Regression analyses were conducted on the twelve most common selection criteria identified. These statistical analyses demonstrated that the individual selection criteria exhibited various degrees of independent functionality while also exhibiting various and significant magnitudes of relatedness (Biomass and Market – r=0.72, R^2 =0.52, P<0.00001; Grain Yield and Market- r=0.73, R^2 =0.54, P<0.00001; and Biomass and Grain Yield- r=0.79, R^2 =0.63, P<0.00001). These results indicate that the farmers' selection criteria reflect farmers' needs, knowledge and practices; and also that the heterogeneous adaptive responses of both the genetic resources and the agroclimatic conditions provide for livelihood and environmental benefits. These correlations among the selection criteria will have value when designing and redesigning participatory varietal selection and breeding practices for future development of crop varieties with the adaptive capacities to respond to biophysical variations and sociocultural preferences. It is thus crucial to appropriately recognize and to incorporate the continuing roles of these traditional farmers and their selection criteria in crop enhancement programmes and policies for food and livelihood security.

Key words: Adaptive capacity, agroclimatic variations, diversity, Ethiopia, farmers' selection criteria, livelihoods, sorghum bicolor landraces, synergism.

INTRODUCTION

Since agriculture began, farmers have been domesticators, users and managers of diversification and expansion of the cultivated crop genetic resources that they manage and own. "Traditional farmers", as used in this paper, are identified as 'farmers who grow a diversity of crops on highly heterogeneous agroclimatic environments using dynamic time-tested knowledge and practices developed by their predecessors, along with their own ingenuity, to meet their varied livelihoods. Their farm sizes tend to be small and the farmers use animal and human power, inherited approaches and strategies, and ingenuity to meet the challenges presented by natural factors (biotic and abiotic stresses). On-farm, diversity-based practices that have evolved over the ages are essential components. Among the most important are the selection practices, exchange mechanisms and diverse seed systems that have been practiced over many generations. These 'traditional farmers' in their diverse agricultural landscapes, and especially in the world's centers of crop origin and diversity, have generated and maintained a wealth of crops and crop varieties that continue to have local, national, regional and global importance (Meyer et al., 2012).

In contrast, the high-input, mechanized, commercial agriculture currently practiced on large farms in more prosperous settings is geared to produce surpluses for national and global markets through the cultivation of genetically-uniform, high-yielding, hybrid crop varieties. It relies annually on off-farm commercially produced hybrid seeds and manufactured fertilizers and pesticides. The dominant selection criteria for modern commercial agriculture relate to yield and profit. These have been reported to lead to reduced crop diversity with negative consequences for crop nutrient density (Davis et al., 2014). According to Kuhnlein (2014), these commercially grown crops besides lacking nutrient density and cultural meanings, are also directly linked to losses of the local knowledge of ecosystem management for food and nutrition practiced by indigenous and traditional farmers and subsistence oriented people.

Survival in the traditional systems requires that both individual farmers and communities must be self-insured. The only insurance available at both levels is diversity; in both the range of crops grown on individual farms and in the range of landraces of crops and crop varieties grown across communities.

"Survival" does not mean just having 'enough food to eat'; they must also have ''income security'' to meet a whole range of other needs. These are basic and immediate issues of health, survival and more that offer multiple livelihood benefits on a dynamic basis. The traditional farmers have learned by experience that they must imitate nature through the practices of maintaining variability and taking advantage of opportunities to maintain and enhance food and livelihood security. Sunderland (2011) argues that smallholder farmers must maintain and practice biodiversity within the cropping system for livelihood and environmental security while managing agricultural landscapes on multifunctional basis by combining food production, biodiversity conservation and maintenance of ecosystem services. The crop genetic resources of traditional agricultural systems that have been domesticated, diversified, conserved and managed across non-uniform agricultural landscapes and over climatic seasons are, and will remain, the sources of genetic variations and the associated knowledge and practices to maintain/enhance humanity's food supply systems (including high-input, mechanized, commercial agriculture). Note: the term "landraces" is used to designate "variable plant populations adapted to local agroclimatic conditions which are named, selected and maintained by the traditional farmers to meet their social, economic, cultural and ecological needs" (Teshome et al., 2001).

Numerous examples exist on agricultural, medical and pharmacological scientists, seed companies and others having exploited the range of features that the farmers' selection criteria and time-tested knowledge and practices have preserved and long utilized. These include pest resistance (Arnason et al., 1993; Adams, 1977; Dogget, 1958; Teshome et al., 1999b), sorghum classification, phytochemical and pharmacological uses (Farnsworth et al., 1985), medicinal plant studies (Leaman et al., 1995), and to evaluate crop genetic erosion risks (Mekbib, 2009; Tsegaye et al., 2007). Farmers' varietal names of crops and crop varieties also are used as *de facto* sources of information to identify quality nutritional traits in sorghum landrace diversity (Singh et al., 1973; ICRISAT, 1985; National Academy of Sciences, 1996).

Although traditional farmers have made immense critical contributions to human livelihood and environmental security through crop selections and diversifications, their knowledge and practices have not received the attention they deserve (Zeven, 2000). While Cleveland et al. (1994) noted that little scientific data was available on the selection and maintenance of landraces by farmers, Derbie et al. (2002), Abdi and Asfaw (2005) and Mekbib (2008) recognized the dynamic on-farm relationships between farmers' selection criteria and sorghum diversity. Geleta et al. (2002) analyzed the critical role of farmers' selections and practices in the cultivation and uses of oil crops that are integrated with sorghum and teff (*Eragrostis teff*) cereal crops. Elsewhere, Zurita et al. (2016) have established that plant diversity increased with time through the management practices of the Waorani people in Ecuadorian Amazon. Also, Cruz-Garcia and Struik (2015) demonstrated the uses and variations of wild food plants through farmers' management practices over climatic seasons and across various structural aspects of home-gardens in northeast Thailand. Nabhan (2014)

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documented a diversity of heirloom and landraces of various food plant varieties that have increased through the practices of selection as well as seed saving and exchanges; providing healthy locally-produced food options to commoditized foodstuffs of industrial agriculture in the US and Canada.

Farmers' selection criteria are derived from the complementary and competing socioeconomic, cultural, agronomic, ecological, biological, dietary and nutritional needs each farm family desires to satisfy from the diversity of crops and crop varieties the family cultivates. In short, selection criteria reflect the multiple functional values of the crops (Campbell, 2014) farm families cultivate to meet their multiple livelihoods (Sander and Vandebroek, 2016; Teshome et al., 2016b). Farmers employ multiple selection criteria per crop and per field and across the variable agricultural landscape and over climatic seasons based on the recognition that multiple crops and crop varieties are essential to meet their livelihood requirements. A single landrace does not possess all the attributes needed to meet the requirements of individual farmers, and hence all farmers plant more than one landrace and use a range of the selection criteria appropriate to their requirements when deciding which landrace to grow.

We contextualize farmers' selection criteria with growing concern on livelihood insecurity and their adaptive enabling capacity to managing resilient multifunctional landrace diversity for sustainable livelihoods. As the number of farmers' selection criteria increases, the diversity on-farm increases, and the fields in which farmers used more selection criteria were more diverse. The study hypothesize that there must be a degree of synergism acting among the farmers' selection criteria that functions to increase livelihood security. Synergism in this study is used to demonstrate the collaborative effects of multiple selection criteria to meet multiple farmers' livelihoods, which is greater than the sum of their separate effects. This paper examines the differences and magnitudes of relatedness among the selection criteria that farmers use to generate and maintain the sorghum landrace diversity that produces livelihood and environmental benefits.

Study area

The north Shewa and south Wollo study area is located in the central highlands of north-eastern Ethiopia adjacent to the western escarpment of the great east African Rift Valley that bisects the country (Figure 1). Its diverse agroclimatic resources (Table 1) of soils, climate and topography influence the generation, diversification, selection and maintenance of crop genetic resources. The farmers apply their knowledge of agroclimatic variations and adaptive responses of genetic diversity to variable growing conditions and cultural preferences to grow a range of staple and companion crops and crop varieties across the agricultural landscapes and over cropping seasons.

Sorghum [*Sorghum bicolor (L.)* Moench], a staple grain crop in many countries of Asia and Africa, is widely cultivated in the study area for food, income, animal feed, building material, and to improve soil fertility on-farm. Ethiopia is an important centre of origin and diversity for sorghum and a number of other crops (Vavilov, 1926, 1951; Dogget, 1991; Harlan, 1969). Sorghum is the second most important cereal crop in production and acreage in Ethiopia (CSA, 2012). Besides Sorghum, there are numerous complementary, key and companion crops (grain, pulses, oil, fiber, fruits, vegetables, trees and shrubs) that provide resilient livelihood and environmental benefits to the farming communities in the study area (Geleta et al., 2002).

The agricultural system is predominantly a rain-fed seed farming complex (Westphal 1975). Home-saved seeds are the single most important seed source used for seasonal planting and replanting purposes. The seed systems are centred on the diversity of landraces and the time-tested farmers' selection criteria, knowledge and practices. Their landraces constitute heterogeneous populations with adaptations to the heterogeneous economic, socio-cultural, agroclimatic environments and production systems. Resiliency in this study refers to the adaptive capacity of sorghum landraces to rebound back from unfavourable agroclimatic conditions through adaptable farmers' managerial skills for livelihood and environmental security. Mixtures of landraces cultivated through farmers' selection practices offer the farming communities resilience or buffer from climate induced events or other shocks (Nabhan, 2014).

Parts of the study area are moderately vulnerable to high unpredictable droughts and dry-spells that influence the diversity, productivity and productive capacity of the agricultural system, and may result in severe shortfalls in grain and biomass production (Dyer et al., 1992, 1993). The farmers' strategy to reduce such losses is to maintain diverse seed network exchange mechanisms as a sustainable buffer, along with the broad base of on-farm genetic diversity. Sustainability is used in the context of the adaptive capacity of landrace diversity for continuous cultivation through farmers' conscientious selection practices for livelihood and environmental benefits. Multiple functionality of landrace ensures human sustenance and agroclimatic resource base revitalization.

METHODOLOGY

Surveys were conducted on 300 randomly selected farmers' fields in north Shewa and south Wollo during the 2011/2012 cropping season. During the surveys, sorghum landrace samples were collected along transect lines that were 10 m apart. At 5 m intervals along each transect line, the farmers were asked to identify the landrace and to provide the reasons (selection criteria) why she/he had decided to grow each sorghum landrace. Significantly, the farmers' names for the sorghum landraces were consistent across

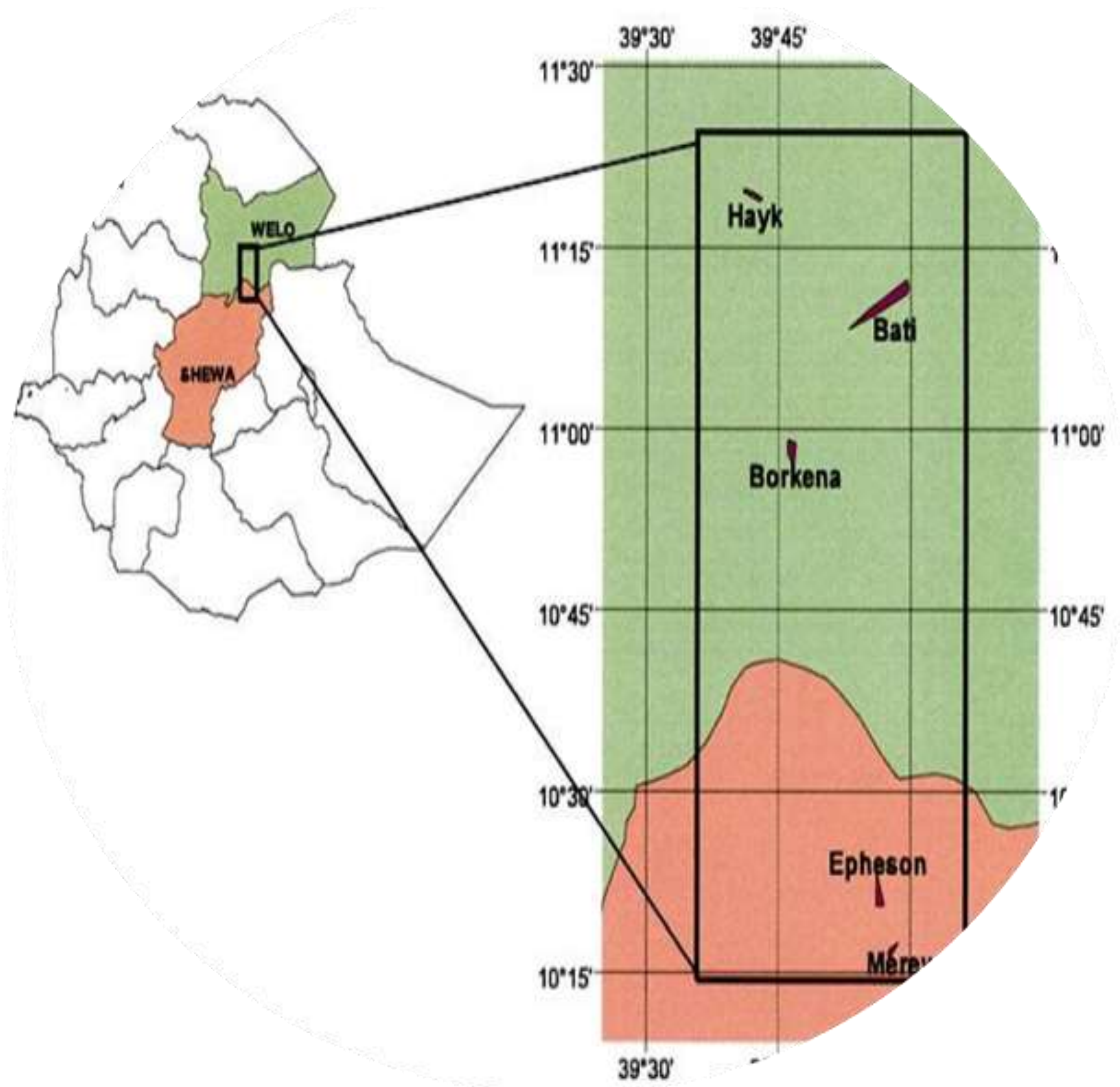

Figure 1. North Shewa and South Wollo Study Area, Ethiopia. (Adapted from Teshome et al. 2007).

the study area and consistent with scientific numerical taxonomy. The individual landrace names have been chosen on the basis of distinctive agromorphological characteristics, use values, and other criteria; which help to provide information on how the landrace is adapted to environmental variations and cultural preferences.

The twelve selection criteria most commonly identified cluster into three major groupings: Agronomic values (Grain yield production, Biomass production, Market values, and Threshability); Home-Uses (Milling quality, Beverage quality, Sweet-stalk, and Fresh green immature-grains); and Resistance to Biotic and Abiotic stresses (*Bird resistant, Insect resistant, Disease resistant, and Drought resistant*). The clustering was done by collaborating female and male farmers with the involvement of researchers while gathering agricultural biodiversity information for the study. These groupings were subjected to correlation, t-Tests, and Linear Regression analyses in order to examine the magnitudes of differences and relatedness among the selection criteria used by the farmers. Microsoft Excel 2013 was used for all the statistical analyses. An alpha value of 0.05 was set for all statistical tests. Readers are reminded that although the data for this study were gathered from 300 randomly selected fields in 5 distinct agricultural communities, the analysis, results and discussion will be presented at the geographical scale of the whole study area. Such approach was employed to facilitate discussion on multiple selection criteria and their relationships as farmers employed them to meet multiple livelihoods through the cultivation of sorghum landraces while responding to agroclimatic variations, policy, political and institutional opportunities and challenges (Manel et al., 2010; Schoville et al., 2012; Teshome et al., 2016b).

RESULTS

The 12 common selection criteria identified and described by participating farmers are presented in Table 2. The descriptions in Table 2 represent the multiple functionality of landrace cultivated through farmers' selection practices

Table 1. Agroclimatic variations in north Shewa and south Wollo study area.

Agroclimatic factors	Descriptions
Landforms	Dominated by ranges of mountains and hills, broken and undulating landscapes with variable sizes of valley bottoms
Slope (%)	Ranges from zero in the flat valley bottoms to in excess of 30% in the steep slopes of mountainous and hilly agricultural landscapes
Altitude (m.a.s.l)	900 to 3000 m/a/s/l
Soil resources (major soil orders)	Highly heterogeneous and variable encompassing the dominant major soil orders of *Alfisols, Inceptisols, Vertisols,* and to some extent *Aridisols* in the drier and *Histosols* in the wetter parts of the study area, support a diversity of cultivated crops and natural vegetation across the altitudinal gradients of the study area
Temperatures (in °C)	monthly minimums = 2- 11°C monthly maximum = 22- 33°C
Rainfall (mm)	Annual minimum = 300 to 500 mm Annual maximum = 750 to 1700 mm Some part of the study area experience bimodal rainfall regime involving short and long rain periods within a year
Natural vegetation	Highly variable and contrasting along the altitudinal gradients of the study area, reflecting the agroclimatic variations from coniferous forest in the highlands to deciduous savannah woodlands and savannah grasslands along the mountain sides and on the valley bottoms to semi-arid and arid scrublands dominating along the rangeland of the Afar escarpment.
Risks to droughts and dry spells	Vary greatly from highly vulnerable in Bati and Merewa to moderately vulnerable communities of Epheson and Borkena and to not vulnerable of the highlands of Hayk agricultural landscape.

for livelihoods. The Pearson correlations among the selection criteria in Table 3 were the outcome of their relationships at the landscape level of the study area. Selection criteria for biomass production and grain yield production are among the highly correlated farmers' selection criteria (r=0.79), benefiting farmers sufficiently in biomass and grain products.

The selection criteria are statistically independent with no cause-effect, and dependent–independent relationship as demonstrated by significant t-Tests for mean differences among the selection criteria and group of selection criteria (Table 4), as employed by collaborating farmers in 2011/2012 cropping season. The frequency distributions for the individual selection criteria (Figure 2) showed the occurrence and relative importance of each selection criterion as employed by farmers for livelihood and environmental benefits. Selection criteria frequency occurrence further demonstrates the influences of each selection criterion in seed selection, planting and harvesting of multiple landrace composition and products. As a result, a range of sorghum landraces were predominantly selected for biomass production, grain yield, milling quality, beverage quality, and market value, in descending order of importance in 2011/2012 cropping season.

In the linear regression and correlation analyses, the t-Tests demonstrated that farmers' selection criteria were different and independent, they functioned with strongly variable degrees of relatedness, as practised in the 2011/2012 cropping season. The linear regression analyses between independent variables of the selection criteria (grain yield production; biomass production, and market values) showed significant relationships (Figures 3, 4 and 5). The significant positive relationship (r=0.73; R^2 = 0.54; *P*<0.000001) between the selection criteria for grain yield production and market values (Figure 3) indicates that as yield increases, the revenue from marketing surplus grains also increases; contributing to household consumption and income security. The positive correlation (r=0.73) and the huge variation explained (R^2 =54%) between yield and market selection criteria establish that, as the demand for their products increases, farmers are incentivized to produce more.

The positive strong relationship between the selection criteria for biomass production and grain yield (Figure 4 - r=0.79; R^2 =0.63; *P*<0.000001) demonstrates the photosynthetic and physiological efficiency of sorghum landraces in generating both biomass, (which, to the farmer, includes all non-reproductive parts of the sorghum crop – roots, leaves, peduncles, nodes and internodes) and grain (including all the reproductive parts of male and female sorghum flowers), without compromising the values of one at the expense of the other. Farmers use both the selection criteria of biomass production and grain production to derive benefits from these landraces in a balanced manner. The relationship between landrace selection criteria for market and biomass production is significantly strong (Figure 5 - r=0.72; R^2 =0.52; *P*<0.00001). From such relationship, farmers cultivate a range of landraces with the capacity to generate

Table 2. Farmers' Selection Criteria for sorghum landraces as practised and described by farmers.

Selection Criteria	Descriptions
Biomass	Includes all plant parts, except the grain, from the root to the flag leaf of a sorghum landrace plant. The cane/stem is used for fuel, construction and fencing. Livestock feed upon leaves and stems. All parts are good sources of organic materials to improve soil fertility. Solid canes of sorghum landraces are sold in the market for income generation.
Grain yield	Seeds and grains harvested from peduncled sorghum heads for home consumption and for sale in the local markets.
Drought resistant	Resistance to climatic and soil constraints causing crop failure
Pest resistance	Resistance to biotic stress causing losses of diversity and production. *Striga* is a notorious plant pest affecting susceptible crops and crop varieties
Disease resistant	Resistance to pathogens causing diseases which decimate diversity and production, example includes *fusarium* a disease caused by fungi.
Insect resistant	Resistance to a variety of insect pests, such as weevils, causing diversity and production losses of many grain crops and crop varieties.
Beverage quality	Sorghum grains rich in secondary metabolites such as phenolic and tannins are fermented and distilled into beverages of variable alcoholic contents for home consumption or for income generation
Sweet-Stalk	Sorghum varieties rich in chewable sugar-rich stem/cane cultivated sparingly either for home consumption or for income generation
Fresh Green Immature-Grains	Quick maturing sorghum landraces cultivated for their nutritious soft-grains for consumption during food scarcity period until harvest.
Milling Quality	Dry-grain landraces free from tannins are selected for human consumption for their high palatability, digestibility and absorbability in human digestion systems.
Marketability	Dry-grain sorghum landraces are selected and cultivated primarily for income generation by selling them in the local market.
Threshability	Sorghum landraces of naked grains with less glume and awn covers are easily threshable. They do not demand too much labor and do not cause itchiness while threshing
Bird Resistant	Landraces with big grains, total glume cover and with long awns are bird resistant. Usually, what is palatable to humans is highly susceptible to bird attacks.

marketable biomass products for income security to improve family purchasing power for household essentials.

The groups of independent selection criteria of agronomic values, home-uses, and resistances to abiotic and biotic stresses, also showed significant relationships between them in the linear regression statistical analyses (Figures 6, 7, and 8). The highly significant strong relationships (r=0.83; R^2=0.69; *P*<0.0.000001) between the selection criteria farmers used for agronomic quality and for home uses (Figure 6) testify to the fact that traditional farmers select, cultivate, conserve and use sorghum products on a sustainable basis, primarily to provide adequate food at home and to save and resave a diversity of seeds to ensure their livelihood security through the cultivation of agricultural biodiversity on-farm. The selection criteria used to select landraces for home-uses and for their resistance to biotic and abiotic stresses (Figure 7) exhibit positive but relatively weak relationships (r=0.61; R^2 =0.37*; P*< 0.001). Such a relatively lower percentage of variations explained (R^2 = 37%) by the relationship (compared to the relationship between home-uses and resistances to biotic and abiotic stresses, Figure 8), between selection criteria for home-uses and for resistances to biotic and abiotic stresses should not be taken as threat in a knowledge-based traditional agricultural systems such as the north Shewa and south Wollo study area. The farmers know the inherent vulnerability of their crops to soil and climatic constraints (abiotic stresses) and to the biotic stresses of insects, pests and diseases; they take appropriate measures to reduce losses. On the other hand, the magnitude of the relatedness between the selection criteria farmers used to select landraces for agronomic quality (threshability, grain yield, biomass production and marketability) and for resistance to biotic and abiotic stresses (Figure 8) is strong with significant positive correlation

Table 3. Pearson Correlations among the selection criteria.

Variable	Grain yield	Biomass	Threshability	Bird resistance	Insect resistance	Disease resistance	Drought resistance	Milling quality	Beverage quality	Fresh green grains	Sweet stalk	Market value
Grain Yield	1											
Biomass	0.79	1										
Threshability	0.39**	0.42	1									
Bird resistance	0.43	0.43	0.38	1								
Insect resistance	0.47**	0.55	0.54	0.71	1							
Disease resistance	0.35**	0.41**	0.58	0.56**	0.74	1						
Drought resistance	0.63	0.67	0.68	0.58	0.69	0.62	1					
Milling quality	0.78	0.68	0.29**	0.33**	0.37**	0.23	0.54	1				
Beverage quality	0.63	0.76	0.37**	0.61	0.60	0.44	0.66	0.61	1			
Fresh green grains	0.60	0.57	0.21**	0.27**	0.24**	0.13	0.41**	0.59	0.52	1		
Sweet stalk	0.56	0.63	0.21	0.34**	0.43	0.23	0.50	0.43	0.55	0.37	1	
Market value	0.74	0.72	0.36**	0.34	0.43**	0.27	0.60	0.70	0.66	0.54	0.44	1

**=Not significant @ P≤0.05.

(r=0.73; R^2 =0.54; P<0.00001). Such relationship demonstrates farmers' selection capacity to cultivate landraces that are threshable, marketable and high grain and biomass yielding that are resistant to biotic and abiotic stresses.

The various farmers' selection criteria that were conscientiously chosen by farmers reflect the multiple functional values of sorghum landraces cultivated in the 2011/2012 cropping season are discussed below for the purpose of emphasizing (demonstrating) their synergistic role in obtaining multiple livelihood and environmental benefits for the practising farming communities.

DISCUSSION

The statistical analyses undertaken, and other information in Tables 2 and 3; and Figures 2, 3, 4, 5, 6, 7 and 8 have demonstrated that the farmers' selection criteria are significantly different from one another. Table 4 indicates that there is no statistical cause-effect or independent-dependent relationships associated with the farmers' selection criteria synergistic relationships to achieve livelihood security through on-farm landrace diversification.

The frequency of statement by the individual farmers that specific selection criteria were applicable to specific sorghum landraces shows the relative importance of each selection criterion and its influences in the selection, planting and harvesting of the range of sorghum landraces in the 2011/2012 cropping season. The first five frequent selection criteria were employed to meet primarily household consumption (grain yield, milling and beverage quality), income security (market value) and animal feed, fuel and construction needs (biomass) of farming communities. Such strategic synergistic selection practices demonstrate the desires of the farming communities to the production of adequate and nutritious food to feed their family, and to secured household income by selling any surplus grain (and other products that they make from the grain) in the local market to meet their household's essential requirements and to purchase assets for future use. The relatively less frequent selection criteria for sweet-stalk and fresh-green-grains were used to cultivate landraces for non-grain products also are used for home consumptions and income generation during the bridging months between flowering and harvesting periods. The selection criteria for drought, insect, disease, and bird resistances are used to grow a range of landraces for their attributes to defy biotic and abiotic stresses, ensuring production and diversity of landraces for livelihood and environmental benefits. Thus, the selection criteria frequency occurrences affirm the egalitarian and inclusive

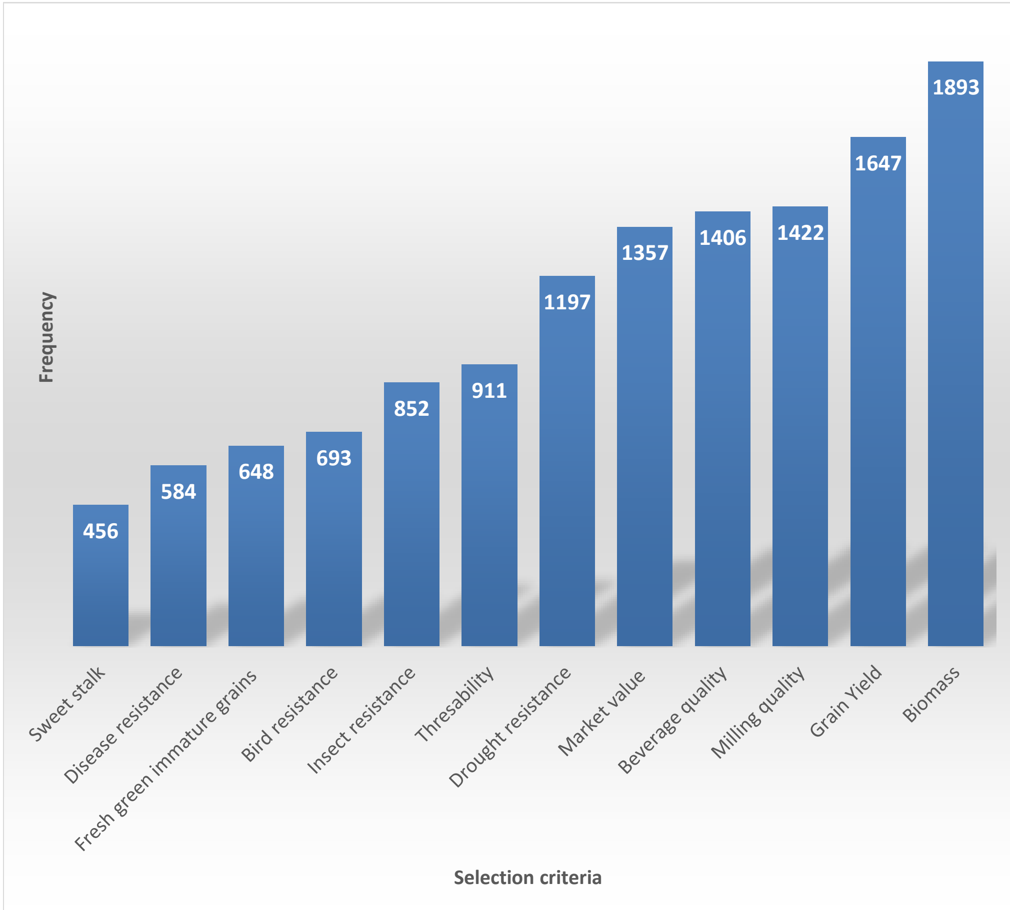

Figure 2. Farmers' selection criteria frequency, 2011/2012 cropping season.

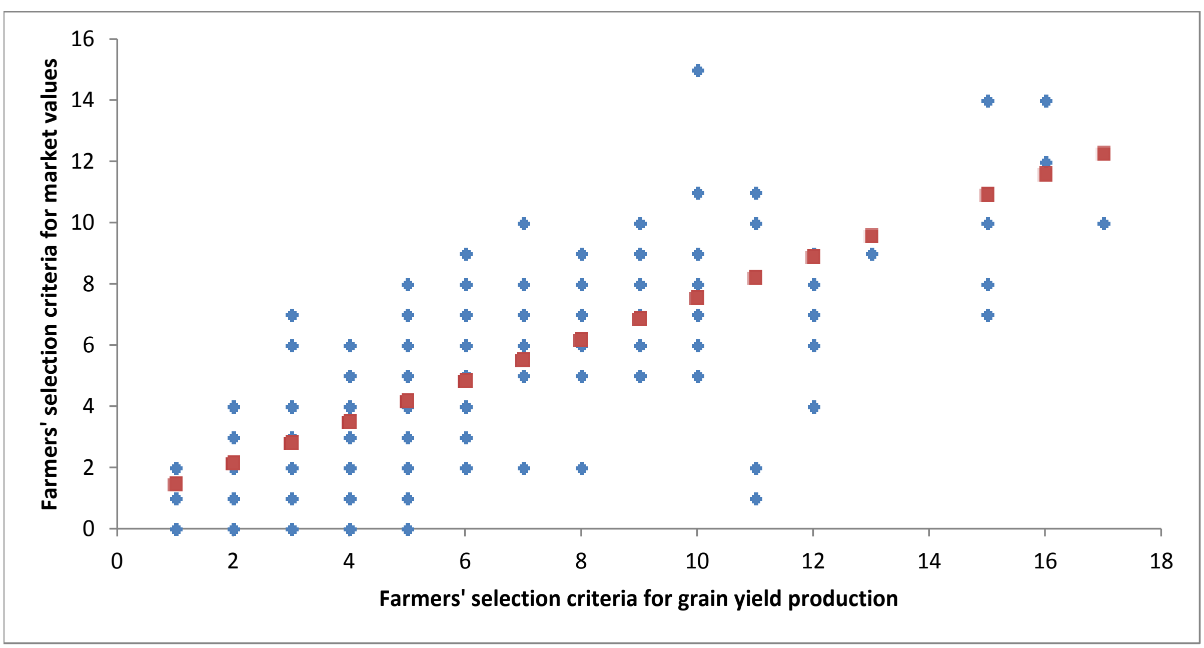

Figure 3. Relationship between farmers' selection criteria for market values and grain yield production based on linear regression analysis (r=0.73; $R^2 = 0.54$; $P < 0.0000001$).

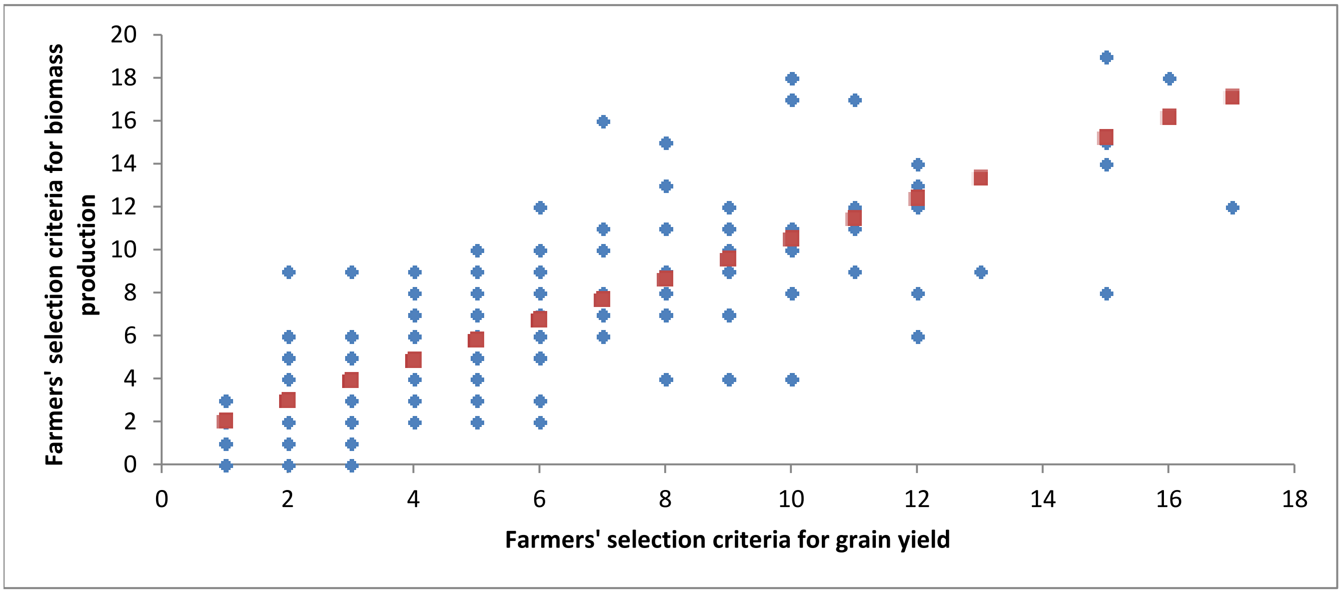

Figure 4. Relationship between farmers' selection criteria for biomass production & grain yield production based on linear regression analysis (r=0.79; R^2 = 0.63; P < 0.0000001).

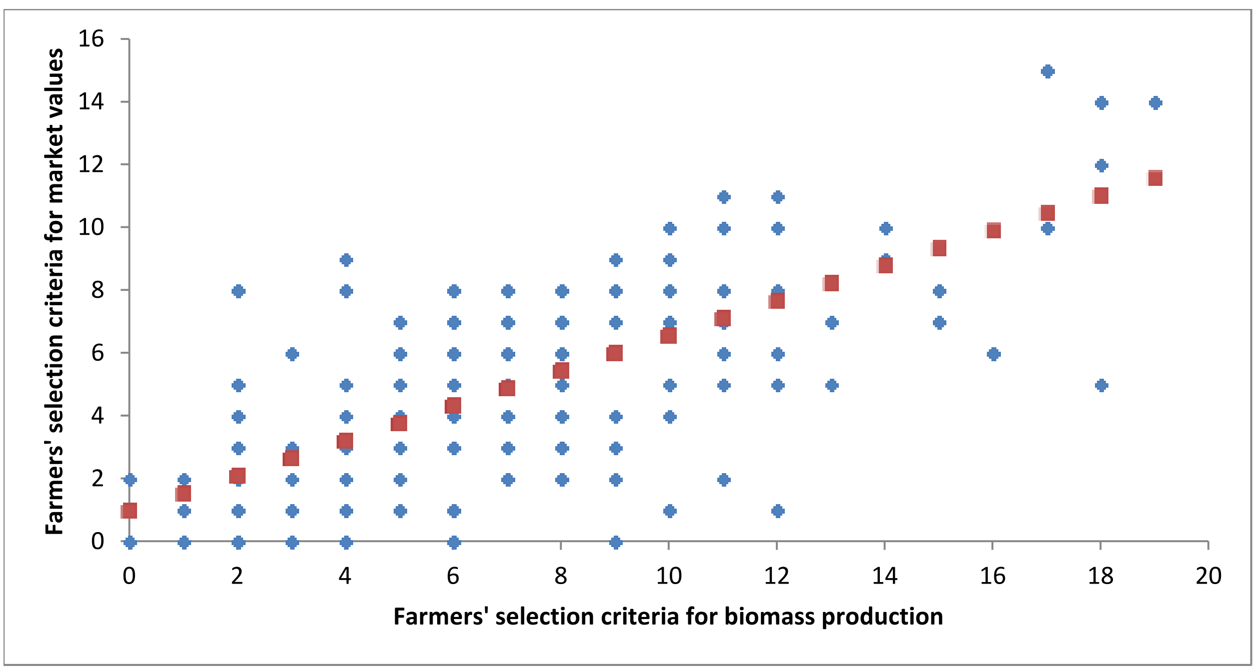

Figure 5. Relationship between Farmers' selection criteria for Biomass Production & Market Values Based on Linear Regression Analysis (r=0.72; R^2 = 0.52; P < 0.0000001).

approaches of farming communities to the generation and maintenance of landraces for livelihood through the seasonal practices of multiple selection criteria on-farm over climatic seasons and across the agricultural landscape of the study area.

Sorghum landraces selected for market values, grain yield and biomass production contributes hugely to food and income security for farming communities. The landraces that produce both grain and biomass represent a bonanza for the farmers as they can meet family food

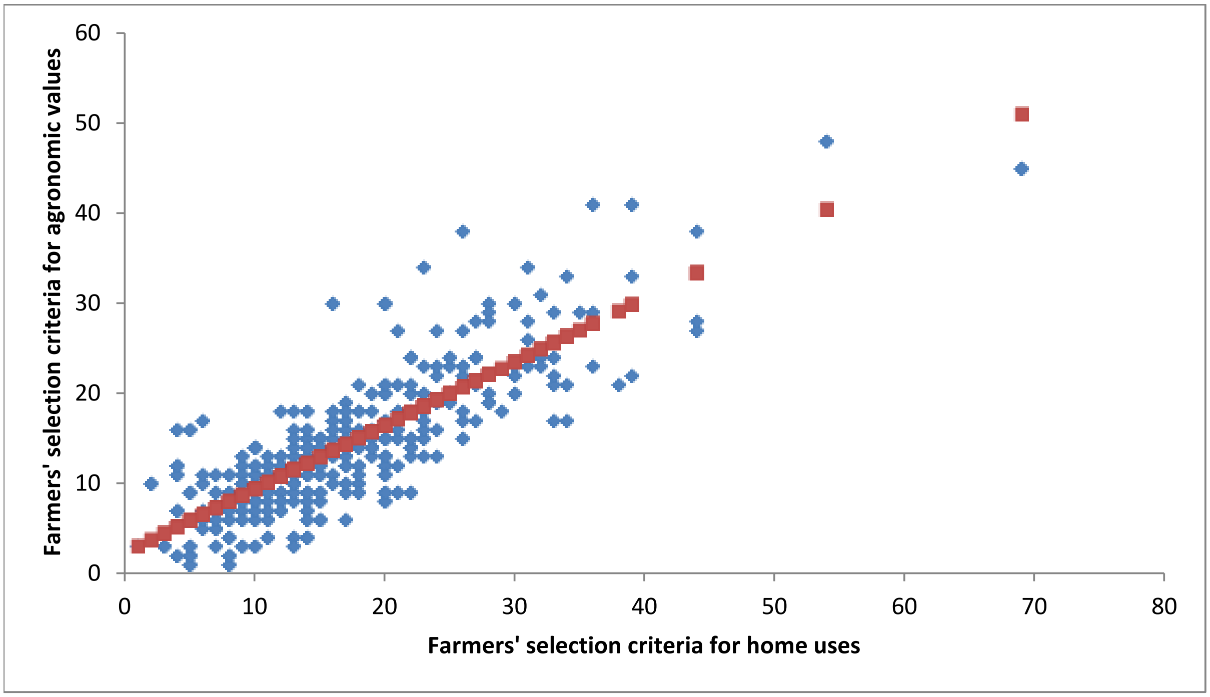

Figure 6. Relationship between farmers' selection criteria for agronomic values & home-uses based on linear regression analysis (r=0.83; R^2 = 0.69; P < 0.0000001).

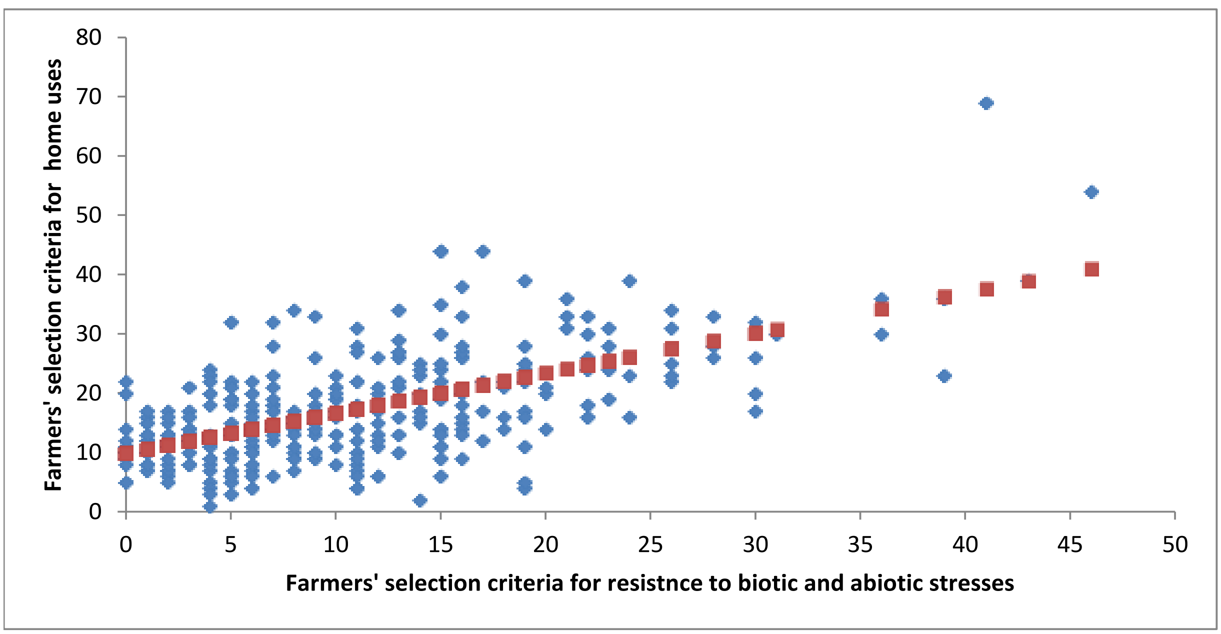

Figure 7. Relationship between farmers' selection criteria for home-uses and resistance to biotic and abiotic stresses based on linear regression analysis (r=0.61; R^2 = 0.37; P < 0.01).

demand and basic income security from the grain yield; while using the abundant, non-grain sorghum products for livestock feed, firewood, fencing, and other construction purposes. The synergistic outcome between yield and biomass selection criteria in sorghum cropping systems is the opposite to that of commercial agriculture crop selection and breeding paradigm for surplus grain yield production by greatly limiting diversity and the potential of non-grain producing vegetative parts of the crop for biomass production.

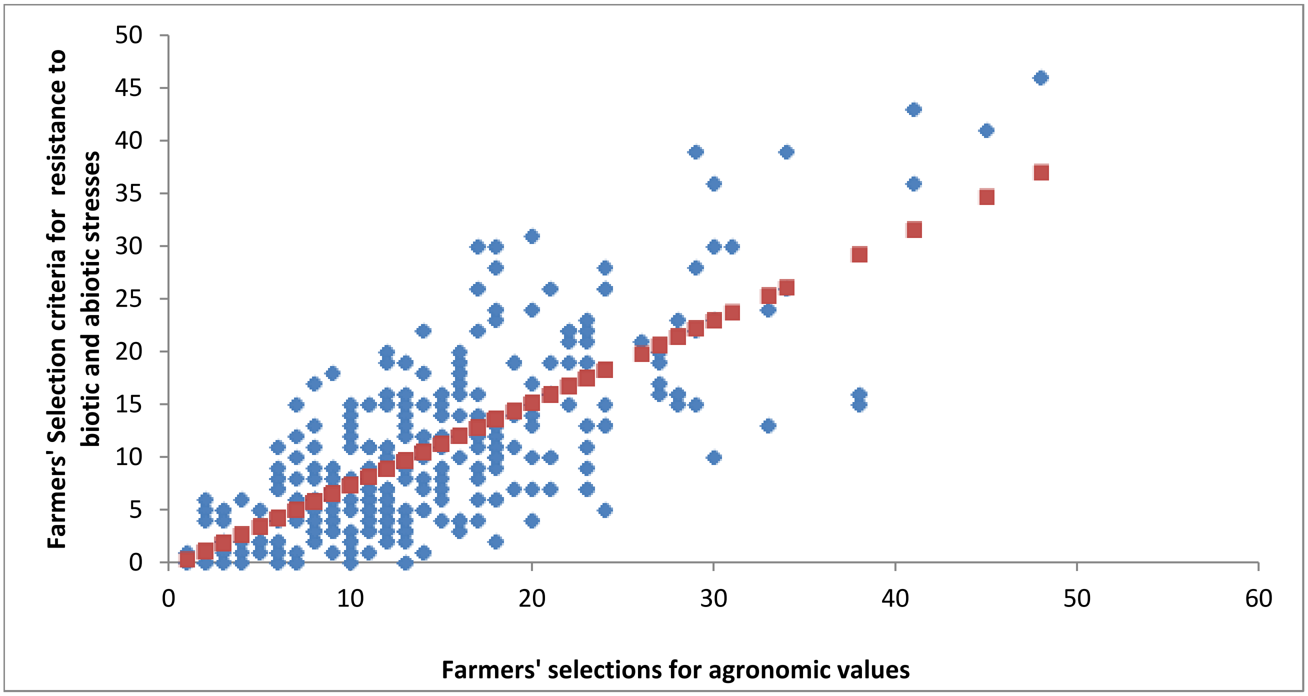

Figure 8. Relationship between farmers' selection criteria for agronomic values and resistance to biotic and abiotic stresses based on linear regression analysis (r=0.73; r^2 = 0.54; p < 0.00001).

Non-grain sorghum landrace production of biomass includes all the plant materials of cane/stems, leaves and roots of sorghum crops cultivated by the farmers. As the demand for sorghum biomass increases farmers produce more non-grain materials to earn more income by selling more biomass in the local market. The farmers generate income by selling solid sorghum canes for firewood, fencing and construction materials.

Fences are erected and shades are constructed using solid sorghum canes/stems. They are also efficient sources of firewood for cooking in the house. Sometimes farmers burn sorghum biomass materials remaining in the field to improve soil fertility by tilling it into the residual ashes. Also, the roots of the sorghum crops are ploughed into the soil to increase the organic matter content of the soil resources. The leaves are mostly fed to livestock that either free graze in the agricultural fields or to stall-fed livestock in pens. The strong positive relationships clearly demonstrate that, as farmers produce more biomass they earn more income; and as the market demand for biomass (non-grain plant parts) produce increases farmers are incentivized to produce more biomass for more income.

Some landraces in the study area are, however, neither cultivated for grain nor for biomass production, but for specialty products of sweet-stalks and fresh-immature-soft-grains. Sweet-stalk sorghum landraces are popular for their chewable, green, sugar-rich stems. The fresh-immature-soft-grain producing landraces are selected for their soft-grains that are free from phenolic compounds affecting the palatability of most sorghum grains. The two specialty sorghum landraces are harvested as bridging crops for human consumption between grain-filling and harvesting months. They are also sold in the local market to augment family income.

The basis for the sustainable production of food and seed in the study area is the extant adaptive capacity of mixture of landraces that farmers own and manage through conscientious selection practices across variable agricultural landscapes and over climatic seasons. Consequently, as farmers increase sorghum landrace selection criteria for the agronomic quality of threshability, and of biomass production, and of grain yield, and of marketability, the selection criteria for the in-home uses of milling quality, sweet-stalks, fresh-green-soft-immature-grains, and beverage quality increase. Through this strong significant relationship, digestible and palatable dry-grain sorghums free from phenolic compounds are selected, cultivated and harvested for home consumption and income generation. Landraces endowed with phenolic compounds are set aside for brewing and distillation either for home consumptions or marketing purposes. The landraces selected for beverage quality, sweet-stalk, and fresh-green-soft-grains are available for home consumption as well as for selling in the local markets.

The strong relationship between selection criteria for agronomic quality and home-use affirms that as individual landraces are actively brought into a diversity of uses in

Table 4. Summary of t-Tests of significance of differences and relationships between groups of Farmers' selection criteria, 2011/2012 cropping season.

Selection criteria	Mean	Variance	Pearson correlation	t-Stat	P-value
Market values and Biomass production	4.39 6.13	7.26 12.19	0.72	-12.60	0.00000
Market values and Grain yield production	4.39 5.33	7.26 8.66	0.73	8.01	0.000000
Biomass production and Grain yield production	6.13 5.33	12.19 8.66	0.79	-6.57	0.000000
Agronomic values and Resistance to abiotic and biotic stresses	14.40 10.76	61.37 69.49	0.73	10.83	0.000000
Agronomic values and Home-Uses	14.40 17.12	61.37 85.03	0.83	-9.28	0.000000
Resistance to biotic and abiotic stresses and Home-Uses	10.76 17.12	69.49 85.03	0.61	-14.35	0.000000

the farm community, their continuing presence in the livelihoods of farming communities is enhanced through the resilient practice of farmers in continuing to use multiple selection criteria in choosing landraces of crops and crop varieties to be grown on their farm. This is enhanced by the sharing of seeds through market mechanisms within the communities. The mixtures of landraces farmers cultivate offer farming communities and their selection practices resiliency or buffer them from climate extremes or human or nature-induced events.

Sorghum landraces selected for home consumption, by and large, are susceptible to biotic and abiotic stresses, including storage pests, and are consumed quickly or sold in the local markets, with precautionary and mitigating strategies and practices being taken to protect quantity, quality and variation for planting the next year. Cleaning, drying and short-and long-term storage practices, that guarantee the grain will remain safe for consumption and viable as seed materials, are well established. Such knowledge-based management strategies increase the diversity and productivity of the landraces cultivated for livelihood security in times when situations conducive to pest proliferation occur, whether caused by climatic variations or human mismanagement.

If farmers increase the selection criteria of landrace for resistance to biotic and abiotic stresses, the agronomic value and quality of the selected landraces for biomass production, grain yield production, threshability, as well as their marketability increases. From these landraces with high agronomic quality, farmers' incomes increase through the sale of quality grains and seeds; the quality of seeds for saving and exchanging increase; and the amount and diversity of seeds and grains stored for future uses increase. Such magnitude of relatedness between selection criteria for agronomic quality and resistances to biotic and abiotic stresses is a good omen for the continued sustainable conservation and uses of sorghum landrace diversity on-farm and for the improvement of farmers' livelihood security in light of the recognizable climate and other variations and extremes.

IMPLICATION AND CONCLUSIONS

The analyses reported demonstrate that farmers' selection criteria in the study area are wide-ranging, with statistical independence of cause-effect and dependent-independent relationships (Table 4). Nevertheless, there are synergistic functions among the farmers' selection criteria that operate in variable degrees of relatedness to achieve multiple livelihood and environmental benefits for the farmers through the generation and management of on-farm sorghum landrace diversity (Table 3; Figures 3, 4, 5, 6, 7 and 8).

Farmers' selection criteria are not only forces of diversification (Meyer et al., 2012; Teshome et al., 1999b) but are also means of deriving multiple benefits for human and environmental security. Selection criteria compositions (Table 2) and their frequency distributions (Figure 2) show the synergistic contributions of each selection criterion to the collective farmers' seed, food and livelihood security through the on-farm cultivation and uses of a range of sorghum landrace diversity in the

2011/12 cropping season. The selection frequency further demonstrates that the resulting diversity of crops and crop varieties on-farm were selected for their adaptive capacity and responses to the agroclimatic variations and sociocultural preferences in that cropping season.

More selection criteria means that more sorghum landrace diversity is cultivated over the diverse growing seasons and across the various agroclimatic agricultural landscapes (Teshome et al., 2016b). The synergistic practices of multiple selection criteria for multiple livelihoods establishes that farmers have an intimate knowledge of their own varied needs, the requirements of the agroclimatic variations and the heterogeneity of the crops they domesticate, select, manage, exchange, and use (Meyer et al., 2012; Samberg et al., 2013) and that the inherent adaptive capacity of the landraces depends on soil and climatic factors (Ayana et al., 2002) as well as societal needs and preferences. Such intimate knowledge that selection of agricultural biodiversity has such positive impacts on their livelihoods encompasses all ages, classes and gender segments of the traditional farming systems.

Having selection criteria, mean decisions must be made. The farmers make their selection criteria decisions by consultation with immediate family members and the community at large. Selections are based on their knowledge of their livelihoods and landrace diversity management and conservation. The decisions are made at various stages of the cropping season. The decisions are especially important at harvest time when each farmer must decide how much of each landrace to harvest for seed, grain and biomass; how much is available for consumption; how much to save for planting and exchange, and how much to sell in the local market. While farmers' selection criteria practices contribute to the livelihood security of the farming family, they also increase the adaptive capacity and responses of the selected landrace and its breeding population to natural pressures of soil and climatic variations. Farmers' selection criteria also reduce the risks of genetic erosion (Mekbib, 2012; Tunstall et al., 2001) by actively involving all the landraces in the seasonal production and use decisions.

The farmers have a wealth of time-tested information on the genetic, physiological, and morphological attributes of the landraces that are particularly responsive to their needs, preferences, selections and farming practices over climatic seasons and across agricultural landscapes. The mixture of traits associated with sorghum breeding systems, grain quality and storability (Ramputh et al., 1999), agromorphological variations (Abdi et al., 2002; Ayana and Bekele, 2000), growing seasons, physiological and ecological adaptations and photoperiod sensitivity offer choices to the farmers to develop multiple, synergistic, selection criteria that will lead to multiple, synergistic livelihoods through the cultivations of the desired diversity of crops and crop varieties according to the season and the agricultural landscape.

Farmers in the study area select late maturing landraces (Mamo et al., 2007) for infertile soils to make use of the limited availability of soil moisture and soil nutrients during long maturing period. The short maturing landraces with the capacity to escape drought and dry spells were selected for immediate harvest and uses. Farmers select over the ages sorghum landraces that are sensitive to photoperiod so that harvest is not hampered by climatic vagaries of untimely prolonged destructive rains and proliferation of pest and diseases.

Sorghum landraces, in variable proportions, are composed of outcrossing and self-pollinating populations. Farmers know the breeding characteristics of their landraces and use them to their advantage in the contexts of retaining desirable landraces and of seeking to develop new landraces.

The farmers generate variations through the selections and cultivations of outcrossing sorghum landraces from cropping season to cropping season across the agricultural landscapes; allowing them to select and capture adaptable, responsive and desirable and novel populations. When they desire to retain distinct stable novel qualities, farmers select self-pollinating sorghum landrace populations. Farmers in north Shewa and south Wollo study area have been observed, cultivating 50 self-pollinating sorghum landraces continuously year-after-year over a twenty year period (1992/1993-2011/2012) for their distinctive and stable morphological characteristics that made selections, harvest, exchange, marketing and processing much easier for the farmers and other end users (Teshome et al., 2016b).

Farmers select sorghum landraces rich in phenolic compounds for fermentations and distillations into beverages of variable alcoholic contents. Fermentation unlocks essential nutrients which are made unavailable to absorptions due to phenolic compounds present in some sorghum landraces (National Academy of Sciences 1996). White and yellow dry- grain producing sorghum landraces are selected for human consumptions as they are free from phenolic compounds affecting the palatability, digestibility and absorptions of essential nutrients by the human digestive system. Yellow grain sorghum landraces *(*such as *Tenglaye)* are rich in vitamin A and other bioactive nutrients. Landraces rich in tannins are selected for their resistance to a host of biotic stresses including storage and field pests (Ramputh et al., 1999). Farmers select their landraces according to use values they attach-dry-grain producing landraces are selected for the superior quality of grains for human consumptions; sweet-stalk landraces for their chewable stem/cane; and fresh- green landraces for their soft and nutritious immature-grains for consumptions between flowering and harvesting months.

Elastic landraces are selected by farmers for their capacity to bounce back from variable intensity and frequency of biotic and abiotic stresses that may affect the diversity and productivity of the cropping system. Farmers use agromorphological plasticity as selection criterion to harness resilient and adaptable landrace populations by cultivating highly plastic landraces over large heterogeneous climatic and soil environments. Generalist landraces are selected by farmers for cultivation across a vast agroecological and sociocultural gradients for multiple uses, while niche-specific specialist landraces are selected and cultivated in restricted agroclimatic and sociocultural environments for specialized uses (Teshome et al., 2007).

Farmers' selection criteria are dynamic and vary by individual farmer's desire and by the desirable crop, and by community, field, landscape, cropping seasons and agroclimatic conditions under which the selected landraces are cultivated for the purposes of attaining the desired selection criteria. Over the 20-year research period (1992/1993-2011/2012) in north Shewa and south Wollo study area, 72% of the farmers increased the number of selection criteria, 11.5% decreased and 16.5% maintained the same number of selection criteria. In the same research period, the number of intraspecific sorghum landraces increased from 60 in 1992/1993 to 68 in 2000/2001 and to 77 in 2011/2012 cropping season.

Farmers' selection criteria and practices have been in dynamic interactions over the ages with the spatio-temporal variations of the agroclimatic resources to respond to farmers' own needs and to societal sociocultural preferences, at large; through the sustainable conservation and uses of agricultural biodiversity farmers domesticate, own, and manage them. This study has established the intimate knowledge and synergistic selection practices of farmers to meet their varied needs through the cultivation of sorghum landrace diversity over climatic seasons and across heterogeneous agroclimatic resources. However, demographic changes, and risks of losses of knowledge and crop diversity through the influences of climate extremes, and inadaptable policies, programs and institutions are threats to cropping systems in the study area and elsewhere in the world (Campbell, 2014; Kuhnlein, 2014; Nabhan, 2014; Shewayrga et al., 2008; Sunderland, 2011; and Teshome et al., 2016b). To mitigate such threats, favourable policies need to be redesigned and developed to ensure ownership and protection of farmers' selection practices for sustainable and resilient livelihood security (Kuhnlein and Erasmus, 2013a), through the cultivation and uses of adaptable diversity of crops and crop varieties (Nabhan, 2014 and Sunderland, 2011).

The study further suggests the establishment and strengthening of programs, policies and institutions to advance/improve food and nutrition security and health at local and community levels (Kuhnlein, 2014) by incorporating farmers' time-tested selection criteria and practices through farmer-led participatory varietal selections and breeding to reflect farmers' varied needs and diverse cropping systems (Mekbib, 2008; Teshome et al., 2016b).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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