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Utilization of Evolutionary and Participatory Plant Breeding Approaches for Rapid Adoption: The Case of Durum Wheat, Central Parts of Ethiopia

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Abstract: Wheat has been almost the first crop domesticated through evolution, natural selection, hybridization, and artificial selection; directly contributed to the adaptation and development of modern varieties. The role of participatory and evolutionary plant breeding in combination can be utilized as a new approach to cope with the complexity of wheat variety adoption and climate change. This method can be also curiously used to improve food security and nutritional value for the rapidly growing human population to reduce the dependence on inorganic agricultural inputs. The experiment was conducted with the objective; to evaluate different mixtures of durum wheat under local climate to improve the variety adoption process and enhance resilience to climate change. Field trials were conducted on 27 heterogeneous durum wheat populations (mixtures) over two locations for one year to test the use of evolutionary plant breeding combined with participatory farmers' selection for local climate adaptation, nutritional value, and grain yield. The result showed that gender preferences associated with important adaptation traits like spike color, head compactness, and plant height are effective for determining high-yielding wheat variety and founded with better adaptation to changing climate. During an evaluation by farmers; mixtures exhibited compact head (MTOPTI_UNS (25), M10_UNS (27), M10_MS (9), and MTIG_FS (12), white-colored head (M10_UNS (27), M10_MS (9), MTOPTI_UNS (9), MTIG_FS (12), M217_UNS (19), and mixtures with tall plants resistant to lodging (MTOPTI-UNS (25), were more preferred and selected by farmers. Broadly, according to the experiment, mixtures (evolutionary populations) have comparative advantages over modern varieties for enhancing resilience to climate change, nutrition, and better adaptation.

Keywords: Climate Change, Evolutionary Plant Breeding, Farmer Preferences, Gender, Participatory Plant Breeding

1. Introduction

Wheat has been one of the first brought to domestication and constituents of the human diet. Evolution or spontaneous hybridization plays an important role in the domestication and improvement of modern varieties of wheat in the world. The most visible role of evolution, natural selection, and human artificial selection are obviously on a dramatic change in plant height reduction, result in yield improvement in modern wheat. Evolution and natural selection between wild and modern varieties are believed to be one of the crucial spontaneous changes for future wheat improvement, more tolerate drought, disease, and require less fertilizer.

In wheat improvement, adaptive and essential genetic resources in wild families and relatives can be utilized carefully as they have enriched beneficial traits. Landraces or farmers varieties, gene bank accessions, and or collections of wheat have an enormous gene pool consisting of rich diversity for important agronomic traits, qualitative traits, biotic and abiotic stress through natural selection and evolution [11].

The pure-line breeding approach remained dominant in recent years which mainly relied on the development of high input production and has been becoming to drastically limit the natural genetic variation in wheat [10]. The radical development in industrial agriculture modifies the physical environment with agrochemicals making similar environments far from each other with consequences of typical monoculture and uniform landscape. To change the breeding strategy deployed by commercial breeding, a highly flexible and dynamic which is fundamentally distinct by decentralizing selection combined with participation selection with farmers is mandatory [4].

For wider adaptation and impact of new variety dissemination for poor-resource farmers, it depends on tangible benefits of farmers on production, consumption, and marketing. Prioritizing breeding objectives by taking into account gender dynamics is one of the most important strategies because men and women are distinct beneficiaries. Taking gender dynamics into account requires, effectively understand the differences in roles, resources, power, and status which affect preferences and adoption, access to inputs, information and the market majorly affect choices about what to produce [12, 13].

In Ethiopia wheat is one of the four major crops produced tremendously of a subsistence nature dominated by countries smallholder farmers cultivated more for consumption and less of it for the market [2]. The highlands of the central parts of Ethiopia are one of the wheat-growing regions where more than 50% of national production comes from [5]. This central part of the country is the one, where commercial breeding is intensively practiced, different agrochemicals applied, pure-line breeding intensively practiced, and subsidized by the government which directly contributed to genetic vulnerability to biotic and abiotic stresses soon. Therefore, the objective of this study was to test different mixtures (populations) of durum wheat under farmer’s conditions for abiotic and biotic stresses, under farmer's preferences by inviting them to select, evaluate and disseminate evolutionary populations.

2. Materials and Methods

2.1. Plant Materials

The experiment was conducted in two locations, Central Ethiopia, at Debre Zeit Agricultural Research Center and Chefe Donsa sites for the 2020 cropping season. Evolutionary populations are obtained by; mixing the seed from the crossing of several inbred lines, and mixtures which are obtained by mixing the seed of several varieties. Twenty-seven evolutionary populations of durum wheat were derived from gene bank accessions, improved varieties, Nested Association Mapping (NAM) inbred lines, and local farmer’s varieties (landraces). The populations were obtained by mixing equal amounts from each variety and each farmer accordingly.

2.2. Farmers Evaluation

The selection of participants under normal conditions was done by district experts. Representative farmers were purposely selected from the two districts based on their; members of the districts, have farmlands, active and with a keen interest in evaluation, selection, and multiplication of populations, have experiences in cultivation of wheat, and age between 20 and 75. Some persuasive involved to get elder farmers predominately in the discussion and suggest selection traits and evaluation of the populations. Five male and five female farmers were notified to select and tag (hanging thread) on single plants as much as they like per each population based on their preferences. Male and female farmers are separately brought to the field and introduced with the objective of the study to select and tag several single plants as much as possible for each population based on their evaluation traits. Plants selected and tagged by farmers were curiously collected and harvested separately. Traits like spike form (compact or loose), spike color (white or brown), and plant height (tall or short) were collected from the selected individual plants separately for males and females. Those selected traits were counted on a plant and gender basis and subjected to analysis because these traits are the most visible and attached to farmers' interest for evaluation and affected by environment, social aspect, and the natural selection process.

2.3. Statistical Analysis

Descriptive statistics analysis was performed using SPSS software based on the count for each gender. Standard deviation, standard error, and box plots were generated to indicate how far the individual farmer's responses were concentrated around the mean or spread out. More precisely standard deviation was used as a measure of the average distance between the values of each farmer's selection data in the set and the population mean. Standard error was estimated to indicate the reliability of each farmer's response to the population means based on the suggested traits by farmers. Box plots were generated to interpret and visualize the distributional characteristics of groups (male and female) farmers' responses in the overall population scores.

Table 1. *Evolutionary populations of durum wheat.*

Entry No.	Entry Name	Entry Abbreviation
1	Mixtures of 217 durum wheat farmers' varieties-Male selected	M217_MS
2	Mixtures of 29 parental lines for NAM population-Male selected	M29NAM_MS
3	Mixtures of Tigray region (10 varieties) from 217 durum wheat farmers' varieties-Male selected	MTIG_MS
4	Mixtures of Amhara region (76 varieties) from 217 durum wheat farmers' varieties-Male selected	MAMH_MS
5	Mixtures of Oromia region (92 varieties) from 217 durum wheat farmers' varieties-Male selected	MORO_MS
6	Mixtures of top 10 Amhara from 217 durum wheat farmers' varieties-Male selected	MTOPAM_MS
7	Mixtures of top 10 Tigray from 217 durum wheat farmers' varieties -Male selected	MTOPTI_MS
8	Mixtures of 12 families of NAM F7 generations (inbred lines)-Male selected	M12_MS
9	Mixtures of 10 improved varieties-Male selected	M10_MS
10	Mixtures of 217 durum wheat farmers' varieties-Female selected	M217_FS
11	Mixtures of 29 parental lines for NAM population-Female selected	M29NAM_FS
12	Mixtures of Tigray region (10 varieties) from 217 durum wheat farmers' varieties-Female selected	MTIG_FS
13	Mixtures of Amhara region (76 varieties) from 217 durum wheat farmers' varieties-Female selected	MAMH_FS

Entry No.	Entry Name	Entry Abbreviation
14	Mixtures of Oromia region (92 varieties) from 217 durum wheat farmers' varieties-Female selected	MORO_FS
15	Mixtures of top ten Amhara from 217 durum wheat farmers' varieties-Female selected	MTOPAM_FS
16	Mixtures of top ten Tigray from 217 durum wheat farmers' varieties -Female selected	MTOPTI_FS
17	Mixtures of 12 families of NAM F7 generations (inbred lines)-Female selected	M12_FS
18	Mixtures of 10 improved varieties-Female selected	M10_FS
19	Mixtures of 217 durum wheat farmers' varieties-Unselected	M217_UNS
20	Mixtures of 29 parental lines for NAM population-Unselected	M29NAM_UNS
21	Mixtures of Tigray region (10 varieties) from 217 durum wheat farmers' varieties-Unselected	MTIG_UNS
22	Mixtures of Amhara region (76 varieties) from 217 durum wheat farmers' varieties-Unselected	MAMH_UNS
23	Mixtures of Oromia region (92 varieties) from 217 durum wheat farmers' varieties-Unselected	MORO_UNS
24	Mixtures of top 10 Amhara from 217 durum wheat farmers' varieties-Unselected	MTOPAM_UNS
25	Mixtures of top 10 Tigray from 217 durum wheat farmers' varieties -Unselected	MTOPTI_UNS
26	Mixtures of 12 families of NAM F7 generations (inbred lines)-Unselected	M12_UNS
27	Mixtures of 10 improved varieties-Unselected	M10_UNS

Table 2. Descriptive statistics from SPSS analysis.

Traits		Location of study	Descriptive statistics	
Spike form	compact	Chefe Donsa	Mean	7.5
			SD	5.4
			SE	0.7
		Debre Zeit	Mean	1.6
			SD	4.0
			SE	0.5
	loose	Chefe Donsa	Mean	0.6
			SD	1.7
			SE	0.2
		Debre Zeit	Mean	1.1
			SD	3.7
			SE	0.5
Spike color	white	Chefe Donsa	Mean	4.8
			SD	3.8
			SE	0.5
		Debre Zeit	Mean	2.6
			SD	5.8
			SE	0.8
	brown	Chefe Donsa	Mean	3.3
			SD	3.9
			SE	0.5
		Debre Zeit	Mean	0.1
			SD	0.4
			SE	0.1
Plant height	tall	Chefe Donsa	Mean	7.6
			SD	5.8
			SE	0.8
		Debre Zeit	Mean	2.1
			SD	4.3
			SE	0.6
	short	Chefe Donsa	Mean	0.5
			SD	0.9
			SE	0.1
		Debre Zeit	Mean	0.6
			SD	2.3
			SE	0.3

Key: SD; standard deviation, SE; standard error.

3. Result and Discussion

Standard deviation, standard error, box plots, and mean was generated using SPSS software for spike form, spike color, and plant height for experimental sites and gender. Generally, low standard deviation and standard error had been shown, except for spike compactness at both Chefe and Debre Zeit sites (Table 2). Low standard deviation implies how far or concentrated the individual farmers' responses mean around the population mean based on the specified selection traits in the data points. A low standard deviation indicates that the data points tend to be very close to the true population mean; a high standard deviation indicates that the data points are spread out over a large range of values or respondent farmers rate the selection as some farmers love and or some hate the populations.

Similarly, a low standard deviation was observed for all traits at both sites, which stipulated the reliability and accuracy of respondent farmers' mean to the actual population mean. Small standard deviation and standard error were more important to understand how far the farmers' respondents' means are from the true population mean and how accurate the individual sample mean is concerning the population mean based on the above-specified selection traits. Box plots based on gender and selection traits had been generated to interpret the distribution and level of group responses. The responses of farmers group into four quartiles and showed the patterns of responses by providing a clear way of visualization and characterization of the group respondents.

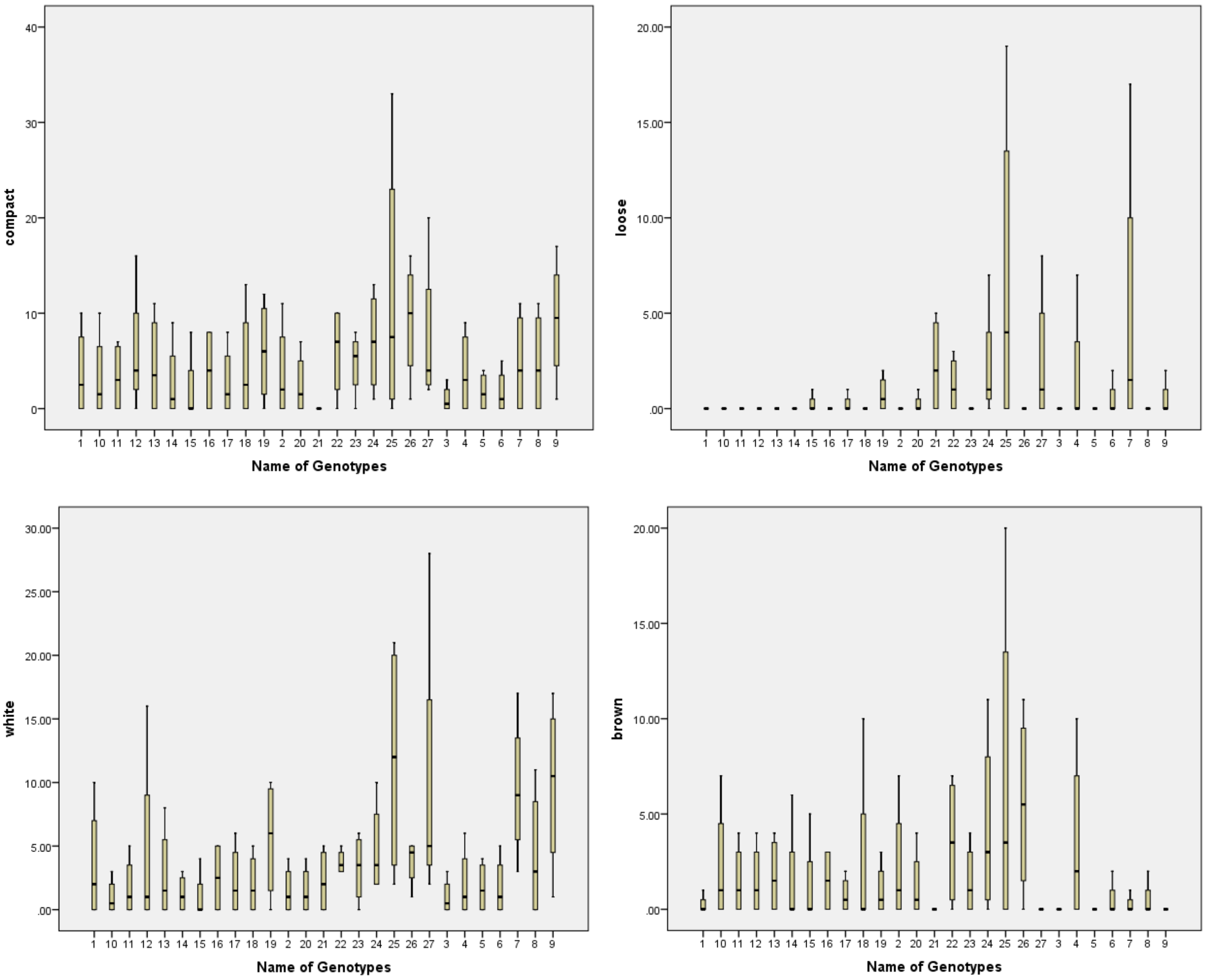
3.1. Farmers Preferences and Evaluation of Populations Based on Farmers' Traits

Gender is believed to be an important factor affecting perception subsequently affect adoption, as men and women have different responsibilities in farming, nutrition, and income. All selected and tagged individual plants were collected from each population separately and counted based on spike form, color, and plant height to evaluate. Based on the farmer's interest in the selection, the more individual plants tagged, the more likely a population would be considered as important for local climate adaptation and grain yield. Accordingly, populations like MTOPTI_UNS (25), M10_UNS (27), M10_MS (9), and MTIG_FS (12) were more preferred by farmers for their head compactness. Populations that have compact heads have been selected than those with loose heads, as head compactness is directly linked to kernel size and weight, stem length, grain number, glume length, and grain yield as cited in [8, 19, 18].

Spike shape (compact or loose) and morphometric characteristics are among the key characteristics of cultivated wheat associated with their productivity as suggested in [6]. The spike length and density as well as the number of spikelet and kernels per spike, the weight of 1000 grains, and several other characteristics are of great relevance for breeders and geneticists. The kernel which is directly linked to spike head shape is also a useful breeding trait since it determines the flour yield along with the grain size and uniformity, thereby, contributing to grain commercial value. Usually, farmers choose and grow varieties trusted in their local areas and vicinity based on a good performance for a specific area, satisfaction, and end-user needs. The acceptance of varieties could vary on end-use goals, socio-economic status, and gender. Which, therefore, result in a conclusion unlikely there is a super variety [1].

In wheat phenotypic characterization, spike color (red or white) is a new practical method for identifying local landraces. Spike color (head) is the most observable trait and directly attracted farmers for selection [9]. Based on spike color populations (mixtures), M10_UNS (27), M10_MS (9), MTOPTI_UNS (9), MTIG_FS (12), M217_UNS (19) were the most preferred by farmers possessed more white color. From mixtures with brown-colored spikes, populations like MTOPTI-UNS (25), MAMH_MS (4), M12_UNS (26), M10_FS (18), and M217_FS (10) were preferred by both female and male farmers dominated by landraces in the mixtures. Wheat spike color is strongly linked to a renewed appreciation of landraces (traditional varieties) that directly affected farmer's preferences as cited in [7]. Although there is no clear evidence that spike color is directly related to yield and yield-related traits, farmers have experienced populations with white color are improved and related to better yield, while the brown (red) colored populations were old and have better adaptation, disease resistance, and good for consumption and taste. Applying color traits for wheat improvement has been limited with exception of red (brown) color is directly related to pre-harvest sprouting; however, pigmentation is thought to be important for adaptation to some stresses [9].

Plant height in wheat is an intrinsic component of plant architecture and inheritance controlled by many closely linked genes with direct effects on lodging stability, harvest index, and grain yield. For plant height as a farmers trait, mixtures (populations) MTOPTI-UNS (25), was the most preferred for tallness while, M10_UNS (27), and MTIG_FS (12), were the most preferred entries with shorter plant height. Even though shorter plants are generally preferred for suitability to mechanical harvesting and associated with a dramatic yield increment as suggested by [17, 16], farmers selected populations with more tall plants than those have shorter which is directly related to using as a roof covering and livestock feed affect preferences.



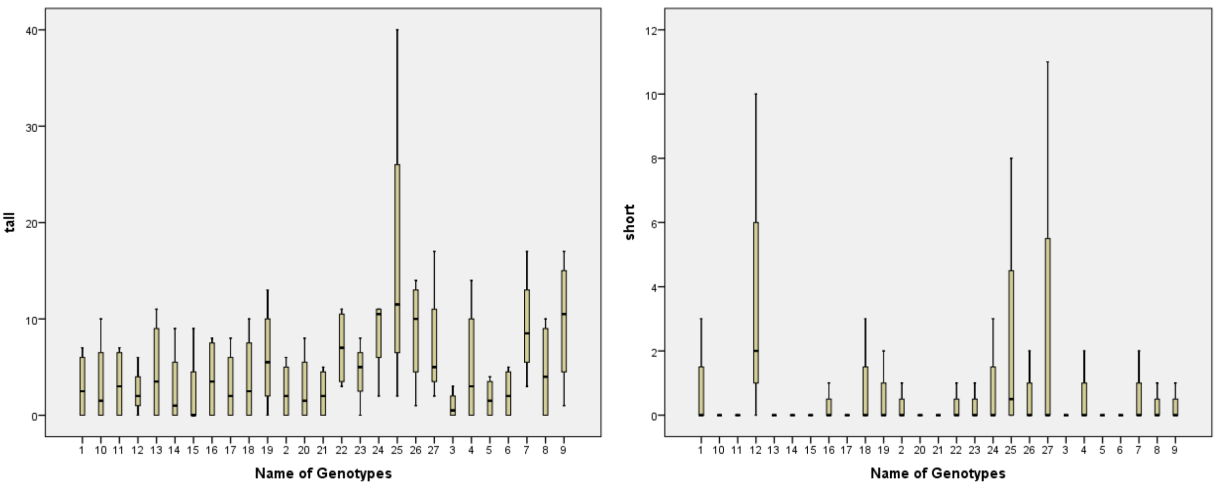


Figure 1. *Box plots of populations for spike form, spike color, and plant height.*

3.2. Association of Gender and Traits in the Selection of Populations

The analysis in the box blot above provides more insight into mixtures (populations) associated with spike form, color, and plant height in line with farmers' selection and preferences. The analysis had also included the association of each trait spike head (compact or loose), spike color (white or brown), and plant height (tall or short) with the sex of farmers and preferences (Figure 3). Spike compactness was associated more with male farmers since male farmers more emphasized yield and yield-related traits. More compact-headed spikes (population) were selected by male farmers as compared to females while, more plants that have loose spikes had been selected by female farmers, which is directly associated with food suitability and local climate adaptation [14]. A considerable amount of compacted spikes have been also selected by female farmers, which indicated female farmers were more curious about selecting and evaluating populations by considering all traits, including climate change, evolution, and nutrition directly or indirectly affect variety adaptation and dissemination.

Spike color of the mixtures was the other trait that affects farmers' gender-based preferences. Accordingly, male farmers selected more mixtures with white color than female farmers, and more brown colored mixtures have been selected by female farmers (Figure 3). The main reason that has been linked to white color to male farmers' interest was directly tightened to yield and improved varieties and brown color to female was the adaptation ability and nutritional quality directly associated to old varieties through their experiences.

Figure 2. *Farmers' selection of populations by gender disaggregate.*

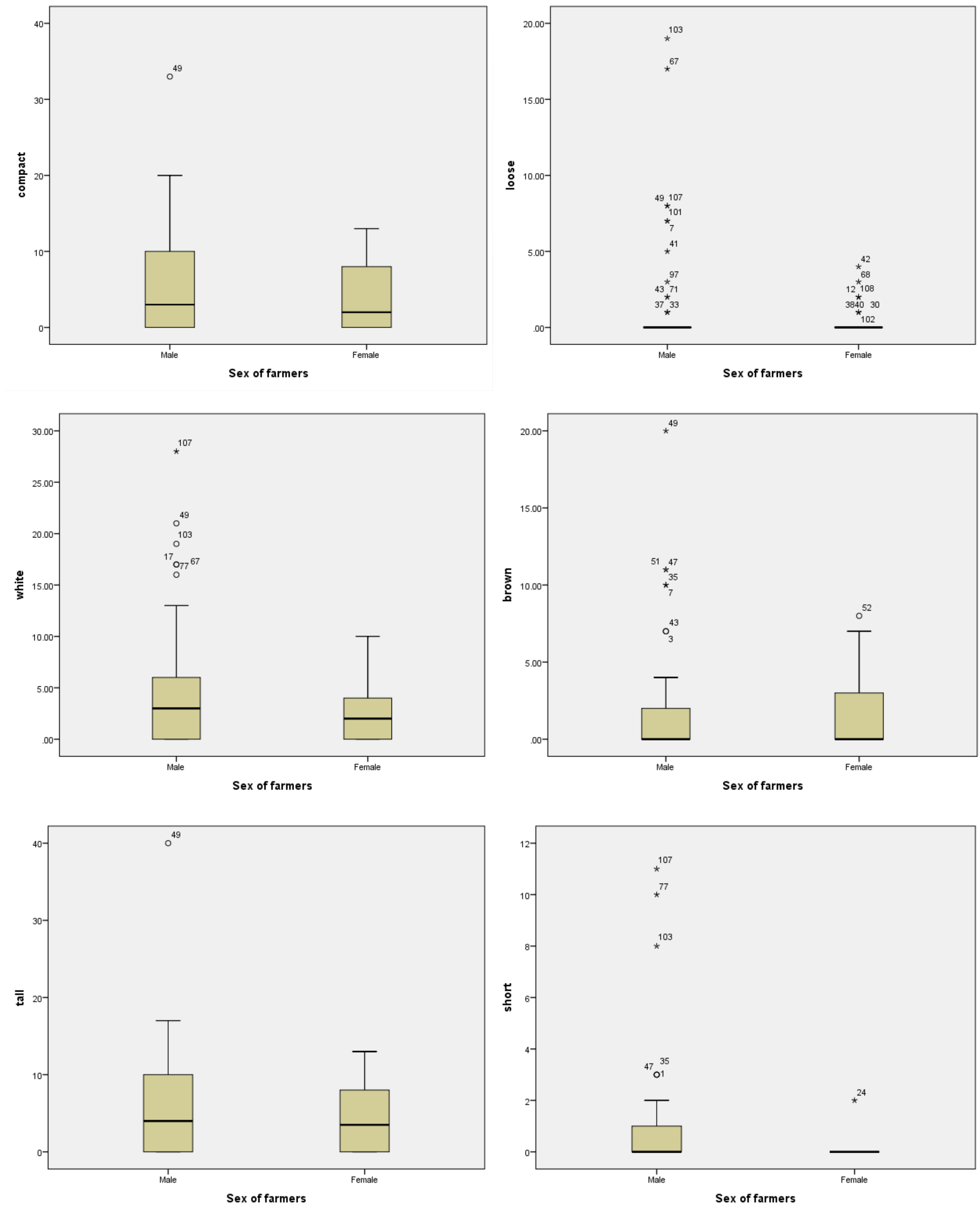


Figure 3. *Box plots of gender and traits association in the selection and evaluation process.*

All populations in the experiment were mixtures of tall and short plants. Both female and male farmers select mixtures with tall plants, however, male farmers selected more short mixtures as compared to females. Even though plant height and grain yield were indirectly related, female farmers gave special attention to selecting taller plants than male farmers did. Male farmers were curious about yield and yield-related traits in the selection and evaluation process by selecting populations with shorter plant height, compact-headed, with more kernel numbers per spike, which directly affects grain yield. While, female farmers, selected seriously populations with tall plants, by considering yield, yield-related traits, disease resistance, number of effective tillers, nutritional quality, adaptation to climate change, and lodging in combination in favor of landraces. Generally, entries MTOPTI_UNS (25) and M10_UNS (27) were the most preferred populations by both female and male farmers for their spike compactness, spike color, and plant height, which implies they exhibited better adaptation and attractive traits by farmers to be promoted to many other farmers for variety adaptation, evaluation, and dissemination in the study areas. Mixtures with landraces have comparative advantages over commercial varieties for some yield-related traits and climate adaptation identified as potential targets to achieve better grain yields in wheat breeding [3, 15].

4. Conclusion and Recommendation

A participatory approach was deployed for variety development and dissemination research in the two districts. Farmers curiously evaluate and select populations based on their traits of interest. Spike form, spike color, and plant height were considered only for analysis of preferences as they are qualitative and easy to manage on the field. Based on those traits, populations that were high yielder, adaptable, and resistant to different stresses in the local area were identified. To study evolution, climate change resilience, and farmers' preferences, a pro-longed experiment is required. The experiment above tried to inter-link farmers' role in evaluating and selecting populations for variety release under a participatory approach. Even though studying evolution, and climate change effect is a very long process in the research, by directly involving farmers, research can be effective and time minimizing. The above study emphasized minimizing the time-consuming conventional breeding method mainly based on research centers to shift to a participatory approach to study in association with climate change and evolution.

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