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Farmers participatory evaluation of bread wheat varieties through seed producer cooperatives: evidence from Ethiopia

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Abstract
The limited engagement of farmers and their community agents in the process of variety development and evaluation is one of the main factors for lower rates of variety adoption, which resulted in lower crop productivity. Participatory bread wheat variety evaluation was jointly conducted by breeders, members of seed producer cooperative (SPC) and local experts with the objectives to identify farmers' selection criteria, to assess farmers' preferred varieties and to increase the SPC's variety portfolios. Twelve released bread wheat varieties were evaluated during 2019 cropping season at Sekela district of Amhara region, Ethiopia. Pair-wise ranking was used to identify farmers' selection criteria and direct matrix ranking to prioritize those selected criteria. Varieties were planted in two sets with and without lime application. Grain yield, followed by earliness, disease tolerance, and tillering capacity, was identified the first preferred criterion by farmers. The mean values showed that higher yield was recorded with the lime application compared to no lime application. *Lemu* (6.4 t/ha), *Alidoro* (6.3 t/ha), *Dambal* (6.3 t/ha), *Obora* (6.1 t/ha) and *Liben* (6.1 t/ha) had greater yield with lime application. The t-test results indicated that significant difference between with and without liming for the number of tillers per plant, spike length per plant, plant height, 1000 seed weight, and hectoliter weight, but non-significant difference for grain yield. The selected varieties should be included in the production plan of the cooperatives for large scale production to increase the variety portfolios and to address the demand of the farming community.

Keywords Bread wheat · Ethiopia · Food systems · Participation · Plant breeding · Seed producer cooperatives

1 Introduction

In countries like Ethiopia, whose economy is mainly dependent on agriculture [1], improving the agriculture sector is vital. The agriculture sector contributes about 32.7% of the GDP, of which the share in the crop production sub-sector is about 65%, with a 4.7% annual growth rate [2]. Improving the crop yield can be achieved with the crop intensification approach, which aims to maximize the crop productivity of farmland with new agricultural inputs

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[3]. The use of modern agricultural inputs (improved crop varieties, fertilizers, agrochemicals, and irrigation) leads to higher productivity and economic development [4–6].

Developing improved crop varieties is a time-consuming and resource-intensive process. Plant breeders are responsible for the development of varieties with better yield advantages, ecological adaptability, tolerance to biotic and abiotic stresses, and desirable qualities [7]. In Ethiopia, the public plant breeding institutes are dominant for crop variety development, release, and registration. According to Ethiopian Agricultural Authority (EAA) [8], a total of 1540 crop varieties have been released and registered in Ethiopia until 2022. Of which, nearly one-third are cereal crops. Bread wheat accounts 6.6% (102) of the total released and registered crop varieties in Ethiopia. However, fewer varieties are under production [9, 10].

Farmers mostly demanded seeds of older improved crop varieties due to slow varietal adoption mainly with the limited varietal promotion activities [11]. Some bread wheat varieties, such as *Kubsa* (HAR 1685), which was released in the 1990s, is still under production [12]. Weaker promotion limited early-generation seed supply and weaker seed marketing and distribution are the main factors for low varietal adoption by farmers [13]. Moreover, looser integration across the seed value chain also contributes to a limited variety adoption by farmers.

Efforts have been made by different actors to promote improved crop varieties in Ethiopia using diversified approaches. The most common approach is the promotion of the varieties through the existing extension system. In such a case, agricultural offices at the district level take the main responsibility of varietal promotion. They demonstrate varieties based on the research recommendations, and farmers are invited to assess the performance of the varieties at the critical growth stages. Those varieties selected by farmers will be further included in the extension program for large-scale production. In such scenario, the involvement of farmers regarding variety evaluation is limited only during field days. Research institutes also promote crop varieties in collaboration with district-level agricultural offices and other development partners, with different degrees of farmers' participation in the process [14]. Besides variety promotion, breeders use their efforts to gather farmers' opinions for future research consideration and respond to their needs [15]. Other stakeholders, such as development partners and NGOs, contribute to the promotion of improved crop varieties in farming communities.

The participatory variety evaluation (PVE) helps to understand farmers' preferred variety selection criteria and varieties suitable for farmers' conditions. The PVE can accelerate the dissemination of crop varieties to the farming community in a relatively shorter time [16]. PVE is sometimes used interchangeably with participatory variety selection (PVS), as both have the same goal of selecting farmers' preferred varieties for wider dissemination and adoption. However, there are methodological differences between PVE and PVS in the process of selecting formers' preferred varieties. The PVS aims to advance some selected varieties to the next breeding stage; PVE aims to provide farmers with a basket of varieties to choose the best ones for immediate production [17]. PVS includes large materials, however, the PVE works with a few. Moreover, PVS mainly consists of breeders with limited involvement of farmers, while in the PVE, farmers have more roles [17].

Several PVS activities have been conducted in Ethiopia to select varieties or genotypes based on farmers' selection criteria. Most of the variety selection activities were conducted by selecting farmers from the locality nominated by local experts and development agents [14, 18–20]. In such cases, breeders manage the field trials, and the involvement of farmers is limited, mainly focusing on the evaluation of varieties at critical crop stages. Farmers are mostly invited to participate and evaluate the varieties during organized field days. Other researchers conducted variety selection with a group of farmers who shared an interest in variety selection and technology promotion. Researchers use farmer research and extension groups (FREGs) for variety selection [15, 21]. FREGs are often organized by research institutes to speed up the development, verification, promotion, and dissemination of agricultural technologies. The participation of farmers in variety evaluation under FREGs is higher than that of those farmers randomly selected by local experts for specific purposes. The involvement of business-oriented producing organizations, including seed producer cooperatives (SPCs), in variety selection and promotion is a better strategy for efficient promotion of the selected varieties [22]. SPCs, established by groups of farmers, contribute to technology diffusion [23].

Seed producer cooperatives in Ethiopia are specialized seed business enterprises established with the objective of producing and marketing good-quality seed of diversified crops and varieties [22]. For SPCs, seed is a commercial product to generate income and improve members livelihoods [22]. SPCs have good experience with research institutes in variety adaptation, and multiplication. Improving the crop variety portfolios of the SPCs is mainly dependent on variety adaptation and demonstration practices, which are implemented in close cooperation with research institutes, local public offices, and development partners [22, 24]. Working with research institutes to increase crop and variety inflow is one of the key activities of SPCs [25], although variations among them [26]. Gumet Wonz, based in the Sekela district of the Amhara region, is the SPC operationalizing in the district. This SPC has experience working with nearby research centers, local public offices, and development partners to make its seed business sustainable [27]. Participatory research with well-organized group farmers, mainly in the form of business-oriented enterprises like SPCs, could greatly enhance identifying varieties according to the choice of the farmers and speed up the promotion of the selected varieties. Therefore, this study was conducted with the objectives of identifying farmers' selection criteria, assessing farmers' preferred varieties, and increasing the SPC's variety portfolios.

2 Materials and methods

2.1 Study context

The study was conducted in Sekela district, Ethiopia. The district is located between 10° 55′ 0″ latitude and 37° 31′ 60″ longitude, with an elevation of 3062 m above sea level, an average annual rainfall range of 1600 mm to 1800 mm, and an average temperature of 18 °C (Fig. 1). The district is suitable for the production of several highland field and horticultural crops, including wheat, barley, tef, faba bean, field pea, potato, carrots, and cabbage predominantly under rainfed conditions. The district is endowed by fertile farmland and water resources suitable for crop production and livestock husbandry [27]. However, the district is affected with soil acidity which challenges the crop productivity [19].

Soil acidity became a serious problem in the highlands of Ethiopia [28]. Soil acidity affects about 40% of the total arable land in Ethiopia [29]. Soil acidity is a major constraint for agricultural productivity in Ethiopia, which in turn prevents profitability and contributes to food insecurity [30]. The use of inorganic fertilizers (e.g., urea and DAP) for several years, among others, is mentioned as a key factor in aggravating soil acidification [31]. To address the effect of soil acidity, lime application is commonly recommended and widely practiced in Ethiopia [32]. The response to lime application on acid soils was highly significant, confirming the importance of correcting acidity [33]. The use of integrated soil fertility interventions is a successful approach to reclaiming soil acidity. These include maintaining and incorporating crop residues, integrated use of organic and inorganic fertilizers, liming, and crop variety choice [30]. A study in the Amhara, Oromia, SNNP, Sidama, and Tigray states of Ethiopia confirmed that integrated soil fertility management can play an essential role in improving productivity and addressing food insecurity [33].

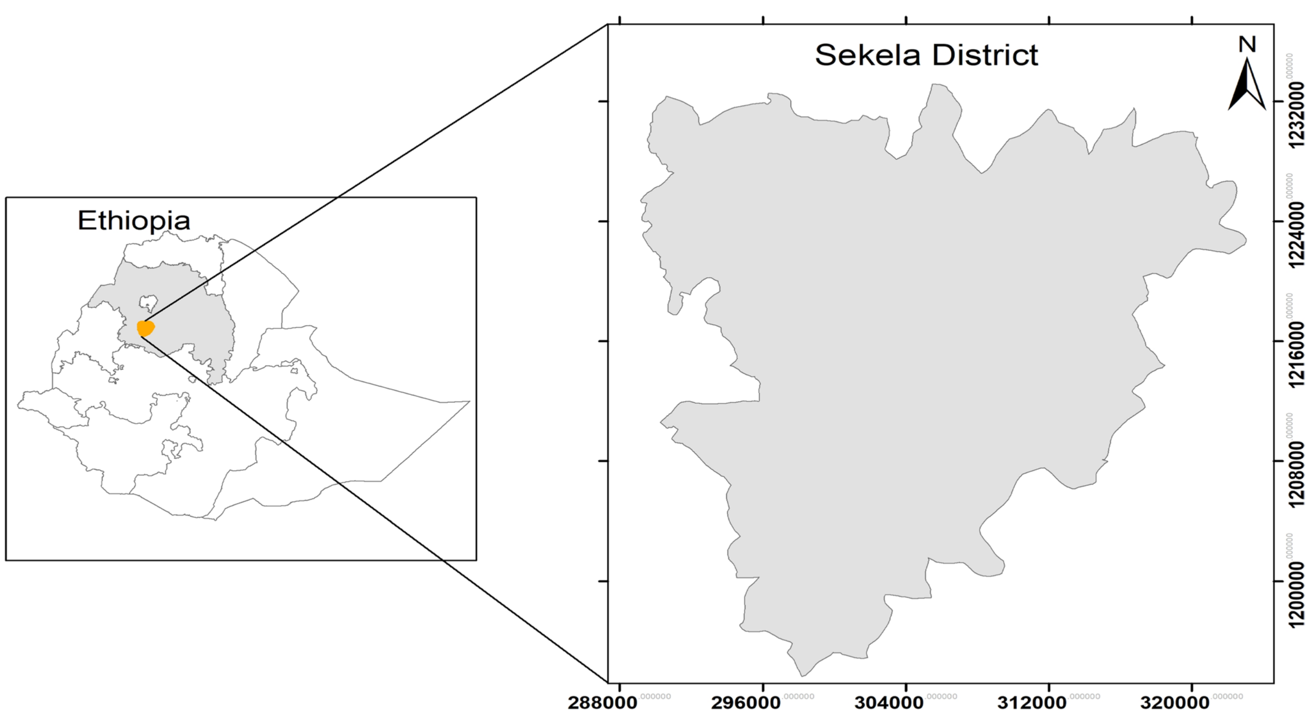

Fig. 1 Map of the study area

Wheat is one of the staple food crops in the district [34]. The production of wheat in the area (2.2 t/ha) is lower than the national average of 3.1 t/ha [34]. A shortage of good-quality seed is one of the determinants of lower productivity [35]. Gumet Wonz SPC was established in the area in 2013 with the objective of producing and marketing good-quality seed to the local market and beyond, eventually contributing to seed supply improvement [22]. The SPC is mainly active in the production and supply of wheat and barley. It sells its seeds directly to farmers, institutional buyers, and in contractual arrangements with public seed enterprises and seed unions. This cooperative is led by an executive committee along with other supporting committees such as the controlling committee and the seed quality control committee. It has good experience working with researchers in variety demonstration and dissemination.

2.2 Joint variety evaluation working modality

The implementation of the PVE modality was developed together by the Gumet Wonz SPC, Sekela district office of agriculture (DOA), Adet agricultural research center (ARC) and German Corporation for International Cooperation (GIZ) project. The modality specifies the role and responsibility of each of the four actors. The SPC was at the center of the working modality because SPCs are responsible for increasing their crop and variety portfolios to satisfy the interest of their customers. Moreover, as per the directive for organizing seed production and marketing cooperatives in the Amhara region [25], SPCs need to work with research institutes to identify potential crops and varieties for their business to increase the crop and variety inflow [22].

Traditionally, agricultural research institutes in Ethiopia have conducted PVE on rented farmer's fields. Depending on the agreements with farmers, research institutes conduct PVE with either of the two approaches. The first approach is where research institutes are responsible for all costs. They rent the land from the owner and cover all costs related to farming practices including ploughing, weeding, threshing, and transportation, while taking back the produce. Whereas the second approach, research institutes rent the land, and the land owner manages all the farming activities by himself or herself. However, in return, the landowner takes the final product once the required data is collected by researchers. In the present study, however, the SPC was responsible for all costs except technical and technology-transfer-related activities. The specific role and responsibility of actors is presented in Table 1.

2.3 Variety selection

The National Crop Variety Register was reviewed to access the list of registered wheat varieties in Ethiopia [8]. From the list, bread wheat breeders initially proposed those varieties that could be suitable for similar agroecology in the study district. The breeders also have reviewed their previous experiments to identify potential varieties. A total of twenty varieties were initially selected National Crop Variety Register. Discussions were held among breeders, agricultural experts,

Table 1 Roles and responsibilities of actors in the implementation PVE at Sekela district, Ethiopia

Actor	Role and responsibility
Gumet Wonz SPC	Secure land free on charge for trial Properly implement all the production practices as per the research recommendations and local practices Select farmers for training Follow all day-to-day activities Organize field days
Sekela DOA	Regularly follow the trial management Provide regular technical support to SPC Properly record all data together with researchers and SPC Support SPC to facilitate field days Facilitate regular variety evaluation events with SPC
Adet ARC	Provide technical support for SPC and experts of district office of agriculture Property record research data together with district agriculture office Provide properly weighted seed of the selected varieties and fertilizers for trial Ensure the quality of the data collected Data analysis and reporting
GIZ project	Provide and facilitate training to farmers and district experts Facilitate the overall PVE practices

and farmers about the proposed varieties. Breeders explained the typical features of the proposed varieties, including yield potential, agroecological suitability, disease tolerance, seed color, seed size, and grain quality such as wheat flour. Then, consensus reached among participants to evaluate twelve bread wheat varieties. These were *Wane*, *Obora*, *Lemu*, *Tay*, *Danda'a*, *Kakaba*, *Alidoro*, *Dembal*, *Ogolcho*, *Liben*, *Buluq* and *Hulluka*. The SPC has produced *Danda'a* since 2016. Table 2 is presented the descriptions of the varieties.

2.4 Development of farmers' variety evaluation criteria

A pair-wise ranking tool was used to know and compare farmers' variety evaluation criteria [36]. A total of 24 farmers, including 7 females, participated in the identification and ranking of bread wheat variety evaluation criteria. Farmers were first asked to mention their own evaluation criteria. They initially listed ten important criteria and then refined them to six: earliness, spike length, tillering capacity, disease tolerance, biomass yield, and grain yield. Farmers were asked again to compare these criteria and explain their reasons for choosing a specific criterion when comparing them. The criteria were ranked pair-wise in a table, with the criteria both horizontally in the rows and vertically in the columns [36]. Every time, following a critical discussion among farmers, they chose one criterion over the other. The total number of criteria that appeared on the table was counted and ranked accordingly.

2.5 Farmers' variety evaluation procedures

Direct matrix ranking was used to compare the bread wheat varieties based on the six criteria determined [36]. The identified criteria were listed in the first column of a matrix, and varieties were put in the first row. Farmers were individually requested to rank the varieties for each of the criteria listed using five scales (1 = very good, 2 = good, 3 = average, 4 = poor, 5 = very poor). Criteria were ranked by distributing a fixed number of stones for better convenience to farmers. Five stones represented the very poor performance, and one stone presented the very good performance. The number of stones for each criterion for the respective variety was counted and multiplied by the relative weight, which was determined using a pair-wise ranking procedure. The weighted ranking of varieties was calculated as the product of the values of the criteria. The score for each variety was used to compare the varieties with each other.

2.6 Experimental design and agronomic data collection

Twelve varieties were planted in two sets. The first set was with the application of lime with a lime rate of 3.5 t/ha, and the second set was without lime application. The two sets were designed to allow farmers to see the effect of lime on the performance of the varieties. The varieties were planted in rows with a plot size of 4 m^2. All agronomic practices were practiced as per the recommended wheat production package. Frequent field visits were organized for farmers to evaluate the varieties at different growth stages of the crop. During the farmer field visits, the secretary of the SPC was assigned to take notes about the merits and drawbacks of the varieties. All the recommended agronomic data were collected by researchers and district-level experts, together with farmers. At the plot level, data were collected from ten plants, and the average values were recorded. Data were collected on the number of tillers per plant, spike length (cm), plant height (cm), thousand seed weight (gm), hectoliter weight (gm), harvest index, and grain yield (kg/ha).

2.7 Data analysis

Data collected through the participation of farmers were analyzed using a pair-wise ranking and direct matrix ranking procedures. The farmers' variety evaluation criteria were identified using pair-wise ranking. Direct matrix ranking was used to rank the varieties by farmers based on the pre-determined evaluation criteria. A mean comparison was used to see the difference among varieties for specific traits. A t-test was employed to compare the phenotypical traits, grain yield, and yield components data between liming and non-liming sets. SPSS v23.0 was used to analyze the collected data.

Table 2 Descriptions of selected bread wheat varieties

Variety	Year of release	Maintaining research center	Typical characteristics
Wane	2016	Kulumsa ARC	Mid to highland altitude areas, erect type, white color, moderately resistant to stem rust and stripe
Obora	2015	Sinana ARC	Highlands of Bale and similar agroecology, erect type, white seed color, resistant to stem rust
Lemu	2016	Kulumsa ARC	Highland altitude areas, erect type, white color, moderately resistant to stem and stripe rust
Tay	2005	Adet ARC	Mid to highland altitude areas, erect type, very white seed color, tolerant to rusts and Septoria
Danda'a	2010	Kulumsa ARC	Mid to highland areas, erect type, white color, moderately resistant to stem rust
Kakaba	2010	Kulumsa ARC	Low to mid high-altitude areas, erect type, white color, moderately resistant to stem rust
Alidoro	2007	Holeta ARC	Highlands of northwest, southwest and west Shoa and similar areas with sporadic rust infestation, semi-erect type, red color, resistant to Septoria
Dambal	2015	Sinana ARC	Highlands of Bale and similar agroecology, erect, slightly red to amber, resistant to stem rust
Ogolcho	2012	Kulumsa ARC	Lowland-mid altitude areas, erect type, white grain color, resistant to major rusts
Liben	2015	Bako ARC	Shambo, Arjo, Gedo and similar agroecology, erect type, white color, tolerant to major wheat diseases (Septoria, yellow, leaf and stem rust)
Bulluq	2015	Bako ARC	Shambo, Arjo, Gedo and similar agroecology, erect type, cream seed color, tolerant to major wheat diseases (Septoria, yellow, leaf and stem rust)
Hulluka	2012	Kulumsa ARC	High attitude areas of Ethiopia, erect type, white color, resistant to major rusts

3 Results and discussion

3.1 Farmers' bread wheat variety evaluation criteria

Grain yield was ranked first, followed by earliness and disease tolerance (Table 3). Farmers gave priority to the grain yield because it is the goal of production in areas where food security is the first concern. Adapting improved varieties is compulsory, mainly for higher productivity. Seed yield is the most preferred trait of bread wheat varieties in the drought-prone agroecology of Ethiopia [37]. Early maturity was also the most important bread wheat trait identified by farmers, where early set-off rainfall is a common phenomenon [38]. In areas where prolonged rainfall is prevalent, farmers do not consider early maturity in their selection criteria [39]. Earliness is one breeding criterion to escape the effects of late season stress [40]. Farmers identified the disease tolerance trait as an important character, knowing its significant negative effect on yield. Farmers mentioned that yellow rust is the most important wheat disease in the area. Yellow rust adversely impacts the growth and production of bread wheat [41, 42]. It is the most common wheat disease that triggers considerable destruction worldwide [43] and in Ethiopia [44, 45].

Moreover, tillering capacity, spike length, and biomass yield were also traits preferred by farmers. Studies show that both tillering [46, 47] and spike length [46, 48] are positively correlated with grain yield. Biomass was the least preferred trait by farmers. There are several combined wheat traits that farmers would like to have when selecting varieties. However, in most cases, it may be difficult to find all the traits in a single variety or in some varieties. Farmers' preferred traits were different at the different growth stages of the crop. In general, grain yield and disease tolerance were identified as the top priority traits of bread wheat producers in the different parts of the country [37, 39, 49]. Moreover, studies show that the commercial behaviors of farmers determine the type of bread wheat varieties they use [50], which is mainly based on the different agronomic and quality attributes of the varieties.

3.2 Farmers' evaluation of bread wheat varieties

Farmers' evaluation of twelve bread wheat varieties based on the six selection criteria is presented in Table 4. *Tay* was selected as the best preferred variety by farmers, followed by *Danda'a*, *Alidoro*, and *Dambal*. *Tay* is recommended by the Adet ARC for the northwestern highlands of the country [51] where the study area is located. This variety is also known for its tolerance to yellow, stem, and leaf rust [52]. Farmers in the Arsi area of Ethiopia also preferred varieties *Tay* and *Danda'a* for their good tillering capacity, large seed size, and higher grain yield [39].

Wane and *Kakaba* were early mature varieties, but these varieties showed poor performance for other selection criteria. *Kakaba* is one of the widely cultivated early mature bread wheat varieties in the country and is recommended for the low to mid-highlands of Ethiopia. It is moderately resistant to stem rust [52] but has become susceptible to yellow rust. As a result, this variety has shown poor performance [53] and is becoming out of production in most potential wheat-producing areas of the country [54]. Farmers' evaluation confirmed the susceptibility of this variety, as it ranked the lowest in terms of disease tolerance. Varieties *Hulluka*, *Wane*, *Kakaba* and *Bulluq* were found to be the least preferred bread wheat varieties by farmers. According to farmers' evaluations, *Wane* and *Hulluka* found with poor performance for spike length and tillering capacity, which directly affect the yield. Studies show that better tillering capacity influences grain yield [48, 55]. Higher yield was also determined by higher spike length [56, 57]. Farmers found all except *Obora* and *Tay* to be poor in biomass yield.

Table 3 A pair-wise ranking of farmers selection criteria at Sekela district, Ethiopia

Criteria	Early maturity	Spike length	Tillering capacity	Disease tolerance	Biomass yield	Grain yield	Total	Rank
Early maturity	x	Early maturity	Early maturity	Early maturity	Early maturity	Seed yield	4	2
Spike length		x	Tillering capacity	Disease tolerance	Spike length	Seed yield	1	5
Tillering capacity			x	Disease tolerance	Tillering capacity	Seed yield	2	4
Disease tolerance				x	Disease tolerance	Seed yield	3	3
Biomass yield					x	Seed yield	0	6
Grain yield						x	5	1

Table 4 Direct matrix ranking bread wheat varieties for selected traits by farmers (n = 24)

Criteria	Relative weight	Bread wheat varieties											
		Wane	Obora	Lemu	Tay	Danda'a	Kakaba	Alidoro	Dambal	Ogolcho	Liben	Bulluq	Hulluka
Early maturity	2	(1) **2**	(3.5) **7**	(1.5) **3**	(2) **4**	(2) **4**	(1) **2**	(2) **4**	(1.5) **3**	(1.5) **3**	(2) **4**	(3) **6**	(1) **2**
Spike length	5	(3.5) **17.5**	(2.5) **12.5**	(2.5) **12.5**	(1) **5**	(1) **5**	(3) **15**	(1) **5**	(1.5) **7.5**	(1.5) **7.5**	(2) **10**	(2) **10**	(3.5) **17.5**
Tillering capacity	4	(3.5) **14**	(1) **4**	(1) **4**	(1) **4**	(1) **4**	(1) **4**	(1) **4**	(1) **4**	(1) **4**	(1.5) **6**	(1.5) **6**	(3) **12**
Disease tolerance	3	(1.5) **4.5**	(1) **3**	(1.5) **4.5**	(1) **3**	(1.5) **4.5**	(4) **12**	(1) **3**	(1) **3**	(2) **6**	(1) **3**	(1) **3**	(3.5) **10.5**
Biomass yield	6	(3) **18**	(1) **6**	(2) **12**	(1) **6**	(1) **6**	(2) **12**	(1.5) **9**	(1.5) **9**	(1.5) **9**	(1.5) **9**	(2) **12**	(3) **18**
Grain yield	1	(3) **3**	(2) **2**	(1.5) **1.5**	(1) **1**	(1) **1**	(3.5) **3.5**	(1) **1**	(1) **1**	(2) **2**	(2) **2**	(2) **2**	(4) **4**
Total		59	34.5	37.5	23	24.5	48.5	26	27.5	31.5	34	39	64
Rank		11	7	8	1	2	10	3	4	5	6	9	12

Numbers in parenthesis are mean scores given by farmers (1 = very good; 2 = good; 3 = average; 4 = poor; 5 = very poor); Numbers in bold case are the product of relative weight of the selection criterion and the mean score of a variety given by farmers. Ranks are in ascending order

3.3 Grain yield of bread wheat varieties

The yield performance of the tested varieties with the application of lime was better than without liming (Fig. 2). Higher grain yields were recorded for varieties *Obora*, *Lemu*, *Tay*, *Alidoro*, and *Liben* with and without lime application. A higher yield with liming application was observed for varieties *Wane* and *Dambal* than without the application of lime. The findings show the availability of additional varieties for the SPCs to diversify their portfolios. *Hulluka* was found to be the only tested variety with a lower yield than the average national bread wheat of 31.1 tons/ha [34], both for liming and non-liming. In contrast with this study, the variety *Hulluka* showed higher yields in the central and southeast parts of Ethiopia [39]. For other varieties, including *Danda'a*, *Kakaba*, and *Ogolcho*, the performance was similar regardless of lime application.

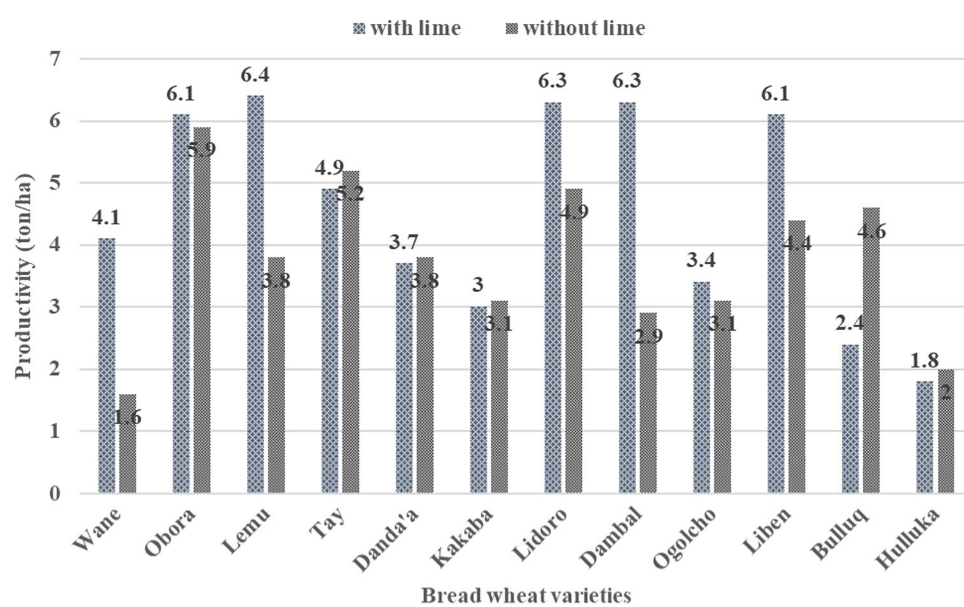

Fig. 2 Grain yield performance of bread wheat varieties

Table 5 Mean values of yield component traits of bread wheat varieties with and without liming

Varieties	No of tillers/plant	Spike length (cm)	Plant height (cm)	TSW (gm)	HLW (gm)
Wane	3.6 (3.6)	5.9 (5.1)	83.1 (79.5)	31.7 (43.1)	75.2 (72.8)
Obora	8.4 (8.3)	9.4 (9.4)	96 (86.5)	36.2 (37.8)	78 (78.3)
Lemu	7.3 (5.5)	8.4 (8.4)	94 (77.5)	37.6 (40)	77.2 (77.6)
Tay	9.3 (6.2)	9.5 (9.5)	102.5 (96)	33.2 (39.4)	74 (77.2)
Danda'a	5.3 (4.4)	8.4 (7.4)	94 (86)	33.8 (38.8)	70 (73.2)
Kakaba	5.5 (3.8)	7.7 (6.5)	86.5 (84)	29.2 (35.8)	68.6 (75.6)
Alidoro	8.7 (7.8)	10.4 (8.8)	106 (93.5)	38.4 (38.5)	77.6 (78.3)
Damball	6.2 (6.2)	8.1 (7.1)	101.5 (82.5)	40.4 (41.6)	79.2 (79.6)
Ogolcho	5.7 (5.6)	9.1 (8.6)	100.5 (88)	30.8 (35)	69.8 (74.4)
Liben	6.1 (4.4)	9.1 (7.7)	87 (70.3)	38.2 (39)	81.6 (82)
Bulluq	7.7 (7.5)	9.9 (9.4)	91 (89.5)	37.1 (37.7)	76 (79.6)
Hulluka	5.4 (4.1)	7.4 (6.3)	81.5 (72.5)	22.4 (25.2)	66.3 (69)

Numbers with parenthesis are results without lime application

Table 6 Mean comparison of bread wheat traits with and without liming

Variable	Application		Two sample *t*-test results		Effect size
	Lime (n = 12) Mean (SD)	No-lime (n = 12) Mean (SD)	*t* (df = 11)	*P* value	
No of tillers per plant	6.6 (1.7)	5.6 (1.6)	3.504	0.005	1.0
Spike length (cm)	8.6 (1.2)	7.9 (1.4)	4.751	0.001	0.7
Plant height (cm)	93.6 (8.0)	83.8 (7.8)	5.883	0.000	10.2
1000 seed weight (g)	34.1 (5.0)	37.7 (4.5)	− 3.752	0.003	− 3.6
Hectoliter weight (g)	74.5 (4.8)	76.5 (3.6)	− 2.772	0.018	− 2.0
Grain yield (tons/ha)	4.5 (1.7)	3.8 (1.3)	1.680	0.121	0.70

n number of varieties tested, *SD* standard deviation, *df* degree of freedom, *g* gram, *cm* centimeter, *ha* hectare

3.4 Yield components of bread wheat varieties

The detailed performance of the tested bread wheat varieties for different traits with and without the application of lime is described in Table 5. There were variations in lime response among varieties. The higher number of tillers was observed from varieties *Tay*, *Obora*, *Lemu*, and *Alidoro* with lime application, and the lower from *Hulluka* non-liming. This was reflected in the higher yield potential of the former varieties and the lower yield potential of the latter variety. The higher number of tillers of bread wheat is associated with a higher yield [48].

The higher hectoliter weight (HLW) was recorded from varieties *Liben*, *Dambal*, *Obora*, *Alidoro*, and *Lemu*, and the lower from *Hulluka*, *Ogolcho*, and *Kakaba*. The HLW values varied from 66.3 with lime and 69 without liming (*Hulluka*) to 81.6 with lime and 82 without liming (*Liben*). HLW is one physical quality parameter important in determining flour yield in wheat [58, 59]. The main purpose of the HLW measure is to predict the flour yield of a grain. According to Protic et al. [60], high-quality wheat is generally above 76 kg/ha, while a value below this limit implies wheat of low quality. Genetic differences among varieties can potentially determine HLW. Moreover, other stress factors such as extremely high temperatures, nutrient deficiencies, physical damage, and lodging also affect the HLW negatively [61].

3.5 Comparison of bread wheat traits with and without liming

Table 6 compares the traits with and without the application of lime. The results show that significant variations were observed between lime and non-liming for the number of tillers per plant ($p = 0.000$), spike length per plant ($p = 0.001$), plant height ($p = 0.000$), thousand seed weight ($p = 0.003$), and hectoliter weight ($p = 0.018$). This implies that most of the yield components were significantly influenced by liming. Previous reports showed that most of the yield components of bread wheat were positively and significantly affected by liming [62].

The largest differences were observed for plant height. Liming increases pH in acidic soil, which favors root proliferation, and increases nutrient availability, which might contribute to higher plant height in wheat [63]. The lowest differences were observed both for spike length and moisture content. Interestingly, non-significant difference was recorded for grain yield ($p=0.121$) due to the application of lime. Unlike previous studies [64], we found non-significant variations in yield with and without liming. This may be associated with the slow reaction of the lime in the first year to release fixed plant nutrients and magnesium which are not directly absorbed by the plant [65]. A recent study reported that the maximum wheat yields were obtained during the second year after the application of lime, confirming that lime efficiency is greater in the succeeding years than the first years of its application [66]. The soil pH increased, and exchangeable acidity reduced after amending the soil with lime [64, 66], which is the main factor for better performance for yield and yield components.

3.6 Correlations among bread wheat traits

Grain yield was positively correlated with thousand seed weight ($r=0.78$; $p<0.01$) and hecolitre weight ($r=0.82$; $p<0.01$) with liming and with number of tillers ($r=0.76$; $p<0.01$), spike length ($r=0.88$; $p<0.01$), and hectoliter weight ($r=0.65$; $p<0.05$) with non-liming (Table 7). Studies show a positive association between grain yield and yield-related traits, including the number of tillers and spike length [67, 68]. The number of tillers was positively and significantly associated with spike length and plant height, both with and without liming. Previous studies reported similar findings [69]. Interestingly, a negative and significant correlation was observed between spike length and plant height with the application ($r=-0.69$; $p<0.05$) of lime that was contradicted with the previous reports [70, 71], but a positive and significant association ($r=0.6$; $p<0.05$) with non-liming. Hectoliter weight showed positive association with grain yield in the Canadian winter wheat [59] and in the Ethiopian bread wheat varieties [72].

4 Conclusions

The present study identified the main evaluation criteria of farmers for bread wheat varieties, namely grain yield, early maturity, disease tolerance, tillering capacity, spike length, and biomass yield. Hence, the promotion of new bread wheat varieties should consider these criteria. The study also centered on the SPC for effective participatory variety evaluation, which was conducted with the collaboration of research institutes, local-level government offices, and development partners with clear role and responsibility. The idea of variety evaluation originally came from the seed cooperative, and there was high involvement from the cooperative regarding trial management and cost-sharing, which was one reason for successful implementation. Working on participatory development activities with an organized group of farmers, including cooperatives, is a good strategy for proper and successful implementation of development interventions and ensuring sustainability. Development partners should always work with farmers or producing organizations to maximize their contributions and ensure the ultimate benefit of the interventions.

Tay, *Alidoro*, and *Dambal* were identified as the best bread wheat varieties in the study area based on both the farmers' evaluation criteria and the research findings. Therefore, researchers and development practitioners should promote these varieties in large-scale seed production. The study also identified the positive effect of liming on many of the bread

Table 7 Correlations among bread wheat varieties evaluated under lime application and no lime application

Traits	1	2	3	4	5	6
Number of tillers/plant (1)	1	0.82**	0.61*	0.17	0.54	0.76**
Spike length (cm) (2)	0.85**	1	0.60*	0.09	0.55	0.88**
Plant height (cm) (3)	0.67*	−0.69*	1	0.26	0.15	0.52
Thousand seed weight (g) (4)	0.45	0.49	0.55	1	0.57	0.22
Hectoliter weight (g) (5)	0.38	0.33	0.31	0.89**	1	0.65*
Grain yield (tons/ha) (6)	0.43	0.30	0.53	0.78**	0.82**	1

NB: with liming (below diagonal) and without liming (above diagonal)

*significant at 0.1; **significant at 0.01

wheat agronomic and quality traits. In the study area where soil acidity is a challenge, the application of lime is advisable to improve soil fertility and increase yield.

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Author contributions DTS analyzed the data and wrote the main manuscript; GS, BG, AD and EA managed the trial and collected the data; RG, TD, AR, DM, SZ and CAG reviewed the manuscript.

Data availability Data are not publicly available. However, data can be available from the first author upon reasonable request.

Declarations

Ethics approval Not applicable.

Consent of publication Not applicable.

Competing interests The authors declare that they have no competing interests.

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