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Evaluation of Bread Wheat (*Triticum aestivum* L.) Varieties for Grain Yield and Yield Related Traits in East Gojjam Zone, Northern Ethiopia

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ABSTRACT

Wheat (***Triticum aestivum* L.)** is a major staple and strategic food security crop in Ethiopia. In Ethiopia, research centers have released numerous improved bread wheat varieties; however, these varieties have not been readily accessible to farmers and have not been adequately evaluated for adaptability across the wheat-producing areas.There are just a few varieties in production, making them suscepible to biotic and abiotic stresses. Evaluating and selecting various bread wheat varieties to grain yield and yield related traits is necessary to address yield gap and boost the nation's overall production and productivity of bread wheat. Thus, this experiment was conducted to evaluate bread wheat varieites to grain yield and yield related traits in East Gojjan Zone Northern Amahara specfical awable and enebsi sarmider Farmer Traing Center. Ten bread wheat varieties were evaluated at two locations using a randomized complete block design with three replications for two consecutive years (2022 and and 2023) in main rain season. SAS 9.4 was used to examine their quantitative parameters and showed significant differences in all parameters across years and locations. The combined analysis of variance showed a significant (P <0.01) difference among varieties for all parameters acros year and location. Variety, location, and year interactions significantly influenced all bread wheat varieties. Denda'a (4.9 t ha^{-1}) and Hidase (4.7. t ha^{-1}) varieties best performed to grain yield at both locations. Varieties with high yield and other agronomic parameters performance such as Denda'a (4.9 t ha $^{-1}$) and (4.7 t ha $^{-1}$) Hidase were suitable in wheat-growing areas of northern Amahara. It recommends the promotion of thes varieties to improve bread wheat production and advises ongoing adaptability assessments to sustain crop productivity under varying environmental condations.

Keywords: Adaptability; Bread Wheat; Grain yield, Yield parameters, Wheat production Varietiy.

1. Introduction

Bread wheat (*Triticum aestivum L.*); a hexaploid species (2n=6x=42), is a crucial global crop that originated from natural hybrids of three diploid wild progenitors native to the Middle East (Gebreil & Mohamed, 2023). Currently, there are approximately 25,000 different cultivars of bread wheat globally (Benavente, 2021).

This crop is highly adaptable, thriving in tropical, sub-tropical, and temperate regions. Wheat is cultivated between latitudes of 6–16° N and latitudes of 35–42° E, at altitudes up to 3,300 m.a.s.l. , with an optimal range between 1,900–2,700 m a.s.l. (Watira, 2016). Ideal germination occurs at a temperature of 20–25°C; However, wheat seeds can germinate at temperatures of 3.5 to 35°C. Physiological maturity requires a temperature of 14–15°C (Nahusenay & Kibebew, 2015). It has been the basic staple food of many regions of the world, and it approximately accounts for 20% of the nutritional of people around the world (Khabiri *et al.*, 2012). Globally, wheat provides about 55% of total carbohydrate intake, 20% of daily protein requirements, and contributes up to 21% of caloric intake for approximately 40% of the world's population (Ahamefula *et al.*, 2022).

Wheat ranks second to maize in global area coverage and production, occupying over 220 million hectares with an average yield of 3.5 t ha^{-1} (FAOSTAT, 2024). China, India, and Russia are the top producers. Ethiopia is the leading wheat producer in sub-Saharan Africa, with 689,614 hectares cultivated and an average yield of 2.8 t ha^{-1}(ESS, 2022). Wheat is a major staple and strategic food security crop in Ethiopia, grown under both irrigated and rain-fed conditions. During the 2021/22 cropping season, it was cultivated on 1.87 million hectares, producing 5.8 million tons of grain with an average yield of 3.1 t ha^{-1} under rain-fed conditions (ESS, 2022). However, this yield remains significantly lower than the experimental yield potential of over 5 t ha^{-1} (EAA, 2022). Ethiopia's current annual wheat production, 5.8 million tons (ESS, 2022), is insufficient to meet domestic needs, forcing the country to import a considerable amount of wheat grain either through aid, purchase, or both (Eskezia *et al.*, 2025; Gemechu *et al.*, 2024). This dependency is unsustainable. The existing yield gap of more than 2 t ha^{-1} highlights the potential to boost production through improved agronomic practices and the selection of stable, high-yielding genotypes suited to both low- and high-input environments (Mahmood *et al.*, 2022). Genotypes must be capable of maintaining competitive yields in a range of suboptimal environments, as well as responding to more favorable conditions or increased inputs (Annapurna *et al.*, 2011; Moll & Stuber, 1974). In the Amhara region, had coverage and production of wheat of 689,614.06 hectares and 1.92 million tons production, with a productivity of 2.8 t ha^{-1}(ESS, 2022). In the Amhara region, East Gojjam Zone took the 1st in area coverage (166, 377.99 hectares) and total production (0.53 million tons) of bread wheat, with an average productivity of 3.2 t ha^{-1} among the wheat production zones (ESS, 2022). However, its productivity is very low as compared to improved varieties. This is mainly due to different yield-limiting factors such as use of local varieties, unaccessibility of improved varieties, biotic (diseases, pests) and abiotic factors (climate change, i.e., temperature and rainfall variability, etc.), and less awarness among farmers to improved varieties (Habtamu *et al.*, 2024; Zewdu *et al.*, 2024).

Among wheat production constrating factors, repeated use of old, varieties were low-yielders and highly susceptible to biotic and abiotic stress in the study area. To overcome such constraints, a study was required to increase production and productivity in major bread wheat growing areas of Ethiopia. Therefore, the objective of the experiment was to evaluate and recommend high-yielding and adaptable bread wheat varieties in East Gojjam and beyond.

2. Materials and Methods

2.1. Description of Experimental Site

The field experiments were conducted at Awabel and Enebse-Sar Midir (Merito-Lemariam) farmer traninf center (FTC) of East Gojjam Zone, Amhara region (Fig 1) during the 2022/23 and 2023/24 main cropping seasons under rain-fed conditions. Ten (10) improved bread wheat varieties were used in the study collected from Kulumsa and adet Agricultura research center. The experimental sites were selected based on their history of precursor crops and fertility status. The detailed agroecological data of environments and the description of genotypes are listed in Tables 1 and 2, respectively.

Table 1. Description of the Experimental Locations

Location	Altitude (m.a.s.l.)	Geographical Location		Soil type	Weather data		
		Latitude	Longitude		Rainfall (mm)	Temperature (°C)	
						Max	Min
Awabel	800-2220	$10^0$22'N	$37^0$47' E	Nitosol	1150	18.0	27.0
Enbise-Sar Midir	950-3360	$11^0$04'N	$38^0$14'E	Vertisol	900-1200	10.0	20.0

Source = Climatic and edaphic information was obtained from their respective District administrative office

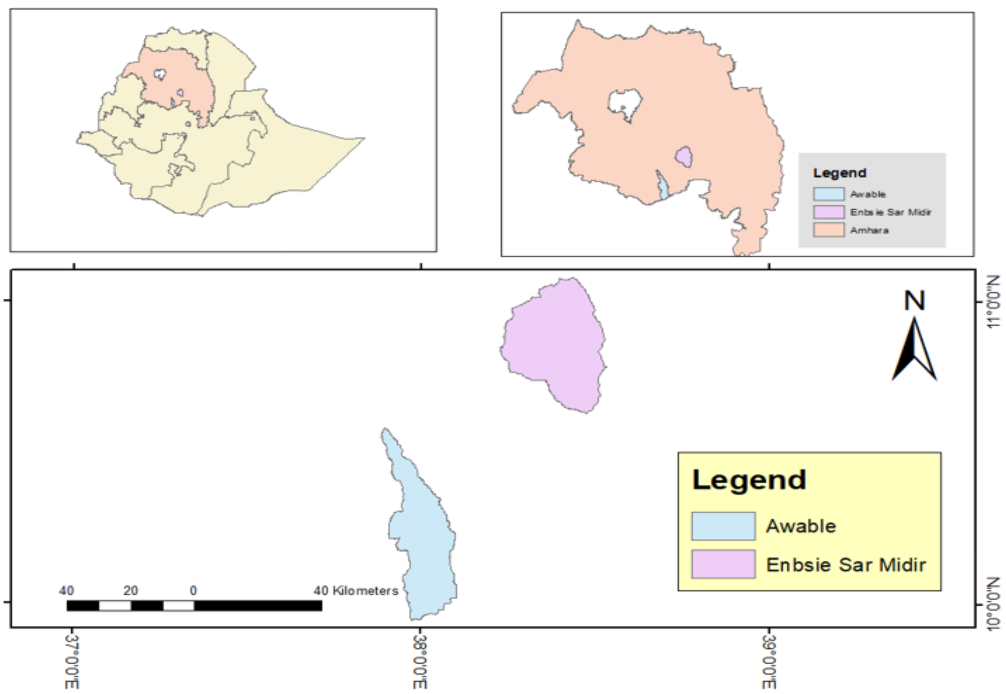

Figure 1. study area map

2.2.Experimental Design and Procedure

The land was prepared by plowing three times and manually labeled during planting time . Treatments were laid out in a randomized complete block design with three replications with six rows per plot. Planting was done in the first up to the second week of July. Each plot comprised nine rows, 2 m in length and spaced 0.2 m apart, with 0.5 m between plots and 1 m between blocks. Urea and NPS fertilizers as a source of nitrogen and phosphorous were applied with a blanket recommendation at the rates of 100 and 200 kg ha^{-1} for both Awabel and Enbise Sar Midir. The total amount of NPS and one-third of urea were applied at planting time, while the remaining two-thirds of urea was applied at tillering after the first weeding. Weeding was done manually twice at the tillering and boosting stages, depending on the weed infestation at the trial site. Other agronomic practices were done based on crop recommendation which is recommended by national agricultura office of Ethiopia

2.3.Data Collection

Data were collected on a plant-and-plot basis for nine traits. Data on a plot basis were taken based on all plants in the central rows of each plot, leaving one border row from each side of the plots. Days to heading, days to maturity, dry shoot biomass, grain yield, thousand seed weight, and harvest index were recorded on a whole-plot basis.

Plant height (cm), spike length (cm), number of seeds per spike, and tiller number were taken from the five individual samples of plants, which were randomly taken from the central rows of each plot, and the averages of the five sample plants were used for analysis. The mean values of the five random samples of plants were considered to estimate the performance of each genotype and for the analysis of different traits in each plot.

2.3.1. Phenological data collection

Days to heading (days): The number of days from sowing to when the tips of the spike first emerged from the main shoot in 50% of the plant population within a plot was recorded.

Days to 90% maturity (days): The number of days from sowing to physiological maturity was recorded. Physiological maturity was determined when 90% of the crop stands in a plot showed a light yellow (straw) color in their stems, leaves, and floral bracts.

2.3.2. Yield and yield related traits

Number of productive tillers (no): The number of productive tillers was determined at maturity by counting all spike-producing tillers of 10 plants per plot.

Number of spikelets per spike (no): The number of spikelets per spike was counted from ten representative spikes per plant, and the average was calculated.

Plant height (cm) was measured from the base of the main stem to the tip of the spike from an average of ten randomly selected plants in the central four rows in each plot.

Number of seeds per spike (no): The number of seeds per spike was determined after harvesting by counting the seeds on each individual spike.

Spike length (cm): This was recorded at the physiological maturity stage by measuring the middle rows of 10 randomly tagged plants from the base of the spike to the tip of the spike (excluding the awns), and the average length of the plant was calculated.

Table 2. Ten released bread wheat varieties were used for field evaluation

No	Variety	Pedigree Name	Breeder Center	Released Year	Altitude (m.a.s.l.)	Days to maturity	Productivity t ha-1	
							On station	On-farm
1	Hidase	YANAC/3/PRL/SARA/TSI/VEE#CROC-I/AE.SQUAOSA(224)//OPATTA	Kulumsa	2012	2200-2600	121	4.4-7.0	3.5-6.0
2	Denda	KIRITATI/2*PBW65/2SERI.1B	Kulumsa	2010	2200-2600	110-145	3.5-5.5	2.5-5.0
3	Wetera	NA	Holeta	2007	Na	Na	Na	Na
4	Dambal	AGUIL/3/PYN/AU//MILAN=AGUILAL/FLAG-3	Sinana	2015	2000-2400	142	5.6-6.4	3.4-4.2
5	Huluka	UTQUE96/3/PYN/BAU//MILAN.TBW5496	Kulumsa	2012	2200-2600	133	4.4-7.0	3.8-6.0
6	Wane	SOKOLL/EXCALIBUR	Kulumsa	2016	2100-2700	125	5.0-6.0	4.0-5.0
7	Shorima	UTQE96/3/PYN/BAU//Milan	Kulumsa	2011	1900-2600	105-150	2.9-7.1	2.3-4.3
8	Oglocho	WORRAKATTA/2*PASTOR	Kulumsa	2012	1600-2100	102	2.8-4.0	2.3-3.5
9	Tay	ET-12D4/HAR604(1)	Adet	2005	1900-2800	104-130	2.5-6.1	3.4-5.8
10	Kakaba (Check)	KIRITATI/SERI/RAYO	Kulumsa	2010	1500-2200	90-120	3.3-5.2	4.0

Source, (EAA, 2022), and Amhara Regional Agricultural Research Institute (ARARI) and Ethiopian Institute of Agricultural Research (EIAR).

Where: Alt: altitude, masl: meter above sea level, RF: rainfall, Long: Latitude:, lati: Longitude and Na= not available

Biomass yield (t ha^{-1}): Aboveground total biomass was recorded after sun-drying, attained constant weight, and then converted to t ha^{-1}.

Grain yield (t ha^{-1}): The weight of air-dried seeds harvested from each plot was recorded. Then, the yield from the net plot area was converted into t ha^{-1}

Harvest index (%): The ratio of grain yield per plot to biological yield per plot is expressed as a percentage.

$$\text{HI (\%)} = \frac{\text{Grain Yield}}{\text{Biomass Yield}} \times 100$$

2.4.Data Analysis

The data collected for each trait were analyzed using Proc GLM procedures of SAS version 9.4 (SAS Institute, 2013). To demonstrate the existence of significant variations across varieties for various parameters with year and location, the Combined Analysis of Variance (CANOVA) was computed. Additionally, the validity of the combined analysis of variance and the homogeneity of error variance between environments were assessed using the Bartlett's homogeneity and Shapiro-Wilk normality tests. Fisher's least significant difference (LSD) test was used for mean separation. This means that at the 5% level, the LSD test was used to separate the means of the different varieties to determine which ones were significantly different from each other.

3. Result and Discussion

3.1.Combined Analysis of Variance (ANOVA)

The combined ANOVA for grain yield of two cropping years with four location-year environments result of the traits was highly significant ($P \leq 0.01$) among the tested bread wheat varieties (Table 3).

A combined analysis of variance (CANOVA) was run to test the significance of genotype, location, and year and their interaction effect on grain yield. A result of the CANOVA of grain yield of genotypes across locations is given in Table 3. The proportion of total variation explained was 2.31 % for environment, 72.56 % for genotype, 0.546 % for year, 4.96 % for genotype by location, 3.54 % for genotype by year, and 6.81 % for the three combinations (Table 3). Highly significant (p <0.001) genotypic effects were observed in the grain yield of the evaluated genotypes, indicating that there is a difference among genotypes in their yield performance at a given location. Likewise, the location effect was found to be highly significant, indicating the presence of significant differences among testing locations in temperature, soil type, rainfall, and other environmental factors, as also reported by (Ewunetu *et al.*, 2023). Similar results have been reported for the combined analysis of variance across locations by many authors (Tesema *et al.*, 2024; Zarei *et al.*, 2012).

3.2.Analysis of variance of yield and yield-related traits over locations

According to the combined ANOVA across two cropping years and two locations (Table 3), the majority of bread wheat traits exhibited highly significant differences (P < 0.01). In particular, varietal effects were highly significant for harvest index (HI), tiller number (TN), spike length (SL), days to heading (DH), days to maturity (DM), and thousand seed weight (TSW). Year effects were also highly significant (P < 0.01) for biomass yield (BY), spike length (SL), number of spikelets per spike (NSPS), days to maturity (DM), and significant (P <

0.05) for plant height (PH). Location effects strongly influenced grain yield (GY), biomass yield (BY), harvest index (HI), days to heading (DH), plant height (PH), spike length (SL), and days to maturity (DM), all at a highly significant level (P < 0.01). These results highlight the substantial impact of genetic, temporal, and environmental factors on the key agronomic traits of bread wheat.

The combined effect of location and year was highly significant for days to heading (DH), days to maturity (DM), plant height (PH), biomass yield (BY), and grain yield (GY), while it was significant for tiller number (TN). The interaction between location and variety significantly affected DH, DM, harvest index (HI), and GY, with PH and BY also showing significant responses to this interaction. Variety by year interactions were highly significant for DH, PH, HI, and GY, and significant for TN and number of spikes per plant (NSPS). Moreover, the three-way interaction among year, variety, and location was extremely significant for DH, DM, PH, BY, GY, and HI, and significant for spike length (SL) (Table 3). These results highlight the complex and significant influence of environmental and genetic factors, as well as their interactions, on key agronomic traits.

These significant correlations indicate that annual variability and environmental conditions substantially influence the performance of bread wheat varieties. This underscores the critical importance of conducting evaluations across multiple locations and growing seasons to identify cultivars that demonstrate consistent and stable performance. The combined analysis revealed that bread wheat genotypes exhibited significant variation across most of the traits assessed. These findings align with previous studies, such as (Rozbicki *et al.*, 2015; Yong *et al.*, 2004), which reported considerable differences among wheat varieties in days to heading, maturity, plant height, and yield components.

The critical importance of genetic diversity in crop improvement is underscored by the significant differences observed in agronomic traits among bread wheat genotypes. Notable variations were identified in traits such as tiller number, spike length, plant height, phenology, grain and biomass yield, and harvest index, highlighting the potential to select cultivars tailored to diverse environmental conditions. Furthermore, the study demonstrated that both location and year exerted a substantial influence on variety performance, suggesting that some cultivars possess greater adaptability, while others may be region-specific. This diversity emphasizes the necessity of extensive multi-environment and multi-year testing to identify cultivars with consistently high-yielding performance an essential requirement for effective breeding programs (Mulugeta *et al.*, 2022; Nadim *et al.*, 2025).

The coefficient of variation (CV) values for most traits fell within acceptable ranges, indicating strong experimental precision. The highly significant varietal effects observed are consistent with findings from previous studies (Habib *et al.*, 2024; Rashid *et al.*, 2017).

Table 3. Combined ANOVA for All triats and explained variance of ten bread wheat varieties tested at different environments during the 2022 and 2023 main cropping season

			Traits									
Source of variation	DF	Explained variance (%)	DH	DM	PH	SL	NSPS	TN	TSW	BM	GY	HI
Locations	1	2.31	193.19*	807.51**	502.99ns	0.10ns	430.5ns	0.26ns	4.80ns	0.40ns	1.74**	20.27ns
Year	1	0.546	1.89ns	207.90**	6.46**	1.89**	81.2ns	1.51**	45.63ns	3.81**	0.85ns	17.12ns
Varieties	9	72.56	191.44**	1048.01**	132.37ns	4.16**	285.3ns	3.04**	195.06**	9.12**	6.12ns	43.54**
Blocks (Env)	4	0.55	42.21ns	19.21ns	3.97**	0.13ns	112.6ns	0.11ns	4.07ns	0.22ns	0.10**	2.30ns
Varieties × location	9	4.96	115.82*	70.44**	62.03ns	1.84**	246.4ns	0.60**	39.33*	1.55**	0.41**	14.07**
Varieties × Year	9	3.54	64.21ns	20.35ns	20.26*	0.50**	147.0ns	0.13ns	7.12ns	0.50ns	0.85**	11.91**
Location × year	1	2.12	1.40ns	174.12**	0.01ns	0.21ns	142.4ns	0.06ns	28.23ns	1.35ns	2.71**	19.78ns
V× L× Y	9	6.81	35.23ns	73.50**	41.25**	1.18**	144.8ns	0.22ns	7.26ns	0.22ns	0.32**	19.46ns
Error	76	6.73	39.09	10.67	8.50	0.12	193.0	0.08	4.52	0.295	0.05	3.44
R^2			0.89	0.92	0.89	0.95	0.87	0.88	0.93	0.89	0.94	0.91
Mean			66	104	90.1	7.8	18.3	3.8	39.2	10.7	3.7	34.8
CV (%)			3.2	3.2	3.4	6.5	8.6	9.5	5.7	8.5	7.9	10.7

Note: CV= coefficient of variation, R^2= Coefficient of determination, DF= degree of freedom, SS= sum square, MS= mean square

3.3.Combined Performance of Varieties for Yield-Related Traits

The evaluated bread wheat cultivars showed notable variation in several important traits. The average days to heading was 66, with some cultivars like Dembele taking longer to head at 70.3 days, while others such as Kakaba headed earlier at 60.3 days. The time to maturity averaged 104 days, ranging from the earliest maturity at 92.5 days in Wane to the latest at 116.5 days in Wetera. Plant height varied from 85.0 cm in Huluka to 94.9 cm in Oglocho, with an overall average of 90.1 cm. Spike length ranged between 6.9 cm and 8.6 cm, averaging 7.8 cm, with the longest spikes found in Hidase, Denda'a, and Oglocho. The number of spikelets per spike averaged 18.3, with Wetera having the highest count at 20.3 and Huluka the lowest at 16.8. Productive tillers averaged 3.8 per plant, with Hidase and Denda'a producing more tillers (4.7) and Kakaba fewer (3.1). Thousand seed weight varied from 31.3 g in Kakaba to 44.8 g in Hidase, averaging 39.2 g. Dry shoot biomass ranged from 9.4 to 12.0 tons per hectare, with an average of 10.7 t/ha. Grain yield showed considerable differences, from 2.7 t ha^{-1} in Kakaba to 4.9 t ha^{-1} in Denda'a, averaging 3.7 t ha^{-1}. The harvest index, which reflects the efficiency of converting biomass into grain, averaged 34.8%, with the highest value of 41.4% in Denda'a and the lowest of 29.2% in Kakaba. These variations demonstrate the diversity among the cultivars and provide valuable information for selecting and breeding wheat varieties with improved growth, yield, and adaptation characteristics (Mengistu *et al.*, 2019; Tadesse *et al.*, 2019). With the exception of dry shoot biomass, which was not significantly affected by environmental factors, genotype variability was significant ($P \leq 0.01$) for every parameter assessed. Except for dry shoot biomass, the environment had a significant impact on every attribute. For the majority of characteristics, the genotype-by-environment interaction was significant, suggesting that varieties perform differently across locations and years. While Kakaba consistently performed worse across most parameters, Hidase and Denda'a outperformed the other examined varieties in terms of grain yield and harvest index. The findings imply that cultivars with higher yield potential and better adaptation to the testing conditions include Hidase, Denda'a, and Oglocho. Both Denda'a and Hidase demonstrated significantly superior yield performance compared to the local check (*Kakaba*), with up to 1.8-fold increase in yield. Their overall agronomic advantage, high harvest index, and adaptability make them promising varieties for enhancing wheat productivity in Ethiopia.These results emphasize the necessity of promoting high-performing cultivars like Hidase and Denda'a in bread wheat production systems in the East Gojjam Zone, as well as the importance of multi-location trials in identifying broadly adapted cultivars.

3.4.Mean performance of grain yield in each test locations and years

The analysis of variance revealed a significant difference ($P<0.01$) in grain yield among bread wheat varieties tested at the two locations during the 2022/23 and 2023/24 main cropping seasons, which is presented in Table 4. This indicates that it is possible to identify high -yield genotypes for possible use in these locations.

Table 4. Mean performance of bread wheat cultivars for yield and yield-related traits combined across four location-year environments

No.	Wheat Cultivars	DTH	DTM	PH (cm)	SL (cm)	NSPS	TN	TSW	BY (tha^{-1})	GY (tha^{-1})	HI
1	Hidase	70.1	114.1	93.6	8.6	19.3	4.7	44.8	12.0	4.7	39.9
2	Denda'a	67.3	106.4	92.9	8.6	19.7	4.7	39.5	11.8	4.9	41.4
3	Wetera	69.8	116.5	91.7	7.7	20.3	4.5	41.8	12.0	4.5	37.4
4	Dembele	70.3	108.3	90.0	8.3	18.8	4.1	43.9	11.0	3.7	33.7
5	Huluka	62.8	104.7	85.0	6.9	16.8	3.2	36.3	9.9	3.2	32.2
6	Wane	62.2	92.5	88.9	7.3	16.8	3.4	35.5	10.4	3.2	30.4
7	Shorma	66.8	98.9	85.3	7.4	16.6	3.3	37.8	9.8	3.5	35.8
8	Oglocho	62.0	105.6	94.9	8.6	19.2	3.7	41.9	10.9	3.8	35.5
9	Tay	67.7	102.1	91.9	7.7	18.7	3.6	39.0	10.1	3.3	32.4
10	Kakaba	60.3	90.8	86.9	7.2	17.3	3.1	31.3	9.4	2.7	29.2
	Mean	66	104	90.1	7.8	18.3	3.8	39.2	10.7	3.7	34.8
	CV (%)	3.2	3.2	3.4	6.5	8.6	9.5	5.7	8.5	7.9	10.7
	LSD (5%)	1.9	3.0	2.49	0.4	1.29	0.3	1.8	0.74	0.24	3.03
	Genotype (G)	<.001	<.001	<.001	0.001	<.001	<.001	<.001	<.001	<.001	<.001
	Environment(E)	0.001	<.001	<.001	<.001	0.002	<.001	0.002	0.06	<.001	0.002
	G*E	<.001	<.001	<.001	<.001	0.075	<.001	<.001	0.08	<.001	<.001

Note: **, NS= highly significant & non-significant, DTH= days to heading, DTM= days to maturity, PH= plant height, SL= spike length, NSPS=number of seed per spike, TN=tiller number, TSW=thousand seed weight, DSB= dray shoot biomass, GY= grain yield, HI=harvest index

The results of this study are in agreement with the previous studies of (Geleta et al., 2021; Kizilgeci *et al.*, 2019; Misganaw, 2016) who indicated a significant difference (P <0.05) among bread wheat genotypes for grain yield at all the individual test locations in multi-environment trials.

The mean yields of varieties across environments ranged from 2.7 to 4.9 t ha^{-1}, with a grand mean of 3.7 t ha^{-1} (Table 4). The mean yield of bread wheat varieties in the different environments ranged from 2.5 t ha^{-1} for Kakaba at Debre-Elias in 2023/24 to 5.4 t ha^{-1} for Denda at Awabel in 2022/23 (Table 5). Even though the ranking of genotypes was different from one environment to another, the three highest mean yields across environments were recorded by Denda, Hidase, and Wetera, with respective overall mean yields of 4.9, 4.7, and 4.5 t ha^{-1}. On the other hand, Kakaba, Wane, and Huluka exhibited the lowest overall mean yield across environments, with values of 2.7, 3.2, and 3.2 t ha^{-1}, respectively (Table 5). The high variation in grain yield among the ten bread wheat varieties at the four location-year environments might be due to extensive variability in climatic and soil conditions. Similarly, inconsistent grain yield performances of variety have been found across locations (Mengistu *et al.*, 2019; Seyoum, 2021).

Table 5. Mean grain yield (t ha^{-1}) performance of bread wheat variety evaluated across four environments during 2022/23 and 2023/24 main cropping season

No	Wheat Variety	Enbise Sar Midir 2022/23	2023/24	Mean	Debre-Elias 2022/23	2023/24	Mean	Overall mean
1	Hidase	4.3	4.6	4.5	5.2	4.8	5.0	4.7
2	Denda'a	4.6	4.3	4.5	5.4	5.1	5.3	4.9
3	Wetera	4.7	3.8	4.3	4.9	4.4	4.6	4.5
4	Dembele	3.4	4.4	3.9	3.7	3.3	3.5	3.7
5	Huluka	2.9	3.6	3.2	3.1	3.1	3.1	3.2
6	Wane	2.6	3.3	2.9	3.8	3.0	3.4	3.2
7	Shorma	3.4	3.4	3.4	4.1	3.2	3.7	3.5
8	Oglocho	3.8	3.3	3.5	4.2	4.1	4.2	3.8
9	Tay	3.0	3.4	3.2	3.5	3.1	3.3	3.3
10	Kekeba (check)	2.7	2.9	2.8	2.8	2.5	2.7	2.7
	Mean	3.5	3.7	3.6	4.1	3.7	3.9	3.7
	CV(%)	6.4	7.9	7.3	5.6	11.6	8.6	7.9
	LSD(5%)	0.39	0.5	0.3	0.39	0.73	0.39	0.24

3.5.Trait correlation analysis

In bread wheat, grain yield is a complex, polygenic trait influenced by several interconnected agronomic characteristics. Effective wheat improvement programs aimed at increasing productivity require an understanding of the relationships between grain yield and yield-related traits, especially in regions where wheat is a staple crop, such as Ethiopia. Breeders can streamline selection efforts by using this information to identify traits that contribute most significantly to yield gains.

Grain yield (GY) and several important traits, including days to heading (DTH), days to maturity (DTM), plant height (PH), spike length (SL), number of spikelets per spike (NSPS), number of seeds per spike (TN), dry shoot biomass (DSB), and thousand seed weight (TSW), were found to be significantly positively correlated in our correlation analysis (Fig 2). Grain yield and dry shoot biomass showed the strongest positive correlation (r = 0.84), suggesting that higher grain yields are often produced by cultivars that accumulate more biomass. This implies that a key factor influencing yield performance is biomass production, which reflects the plant's photosynthetic capacity and resource use efficiency.

Grain yield and plant height also have a substantial positive correlation (r = 0.82), suggesting that taller plants may support more productive tillers or spikelets, thereby increasing potential yield. However, breeders must weigh the potential risks associated with greater height against this characteristic. Longer growing periods may provide varieties with more time for biomass formation and grain filling, which can increase yield. Phenological traits such as days to heading (r = 0.42) and days to maturity also show a positive correlation with grain yield. Nevertheless, when considering these traits, adaptation to local growing seasons and climatic conditions remains crucial.

Moderate but positive correlations were found between spike length (r = 0.20) and the number of seeds per spike (r = 0.18), indicating that these yield components, although individually contributing to a lesser extent, collectively influence the ultimate grain output. Their cumulative impact affects production as a whole. These results support the significance of biomass and phenological features in determining wheat production and are consistent with earlier studies (Alemayehu *et al.*, 2025; Desta *et al.*, 2025). Indirect selection for biomass has the potential to increase yield stability and adaptation, as evidenced by the substantial correlation between biomass-related characteristics and grain output.

Breeding programs can increase selection efficiency by concentrating on variables that have substantial positive correlations with grain yield, including phenology, plant height, and dry shoot biomass. By optimizing yield components and enhancing spike attributes, such as spike length and the number of seeds per spike, efforts to increase yield will be supported. In summary, this correlation study provides important new insights into the interactions between yield and associated characteristics in bread wheat. This knowledge is essential for developing stable, high-yielding cultivars that are well-adapted to a variety of agro-ecological conditions (Kebede *et al.*, 2024; Mohammed *et al.*, 2022; Zarei *et al.*, 2012).

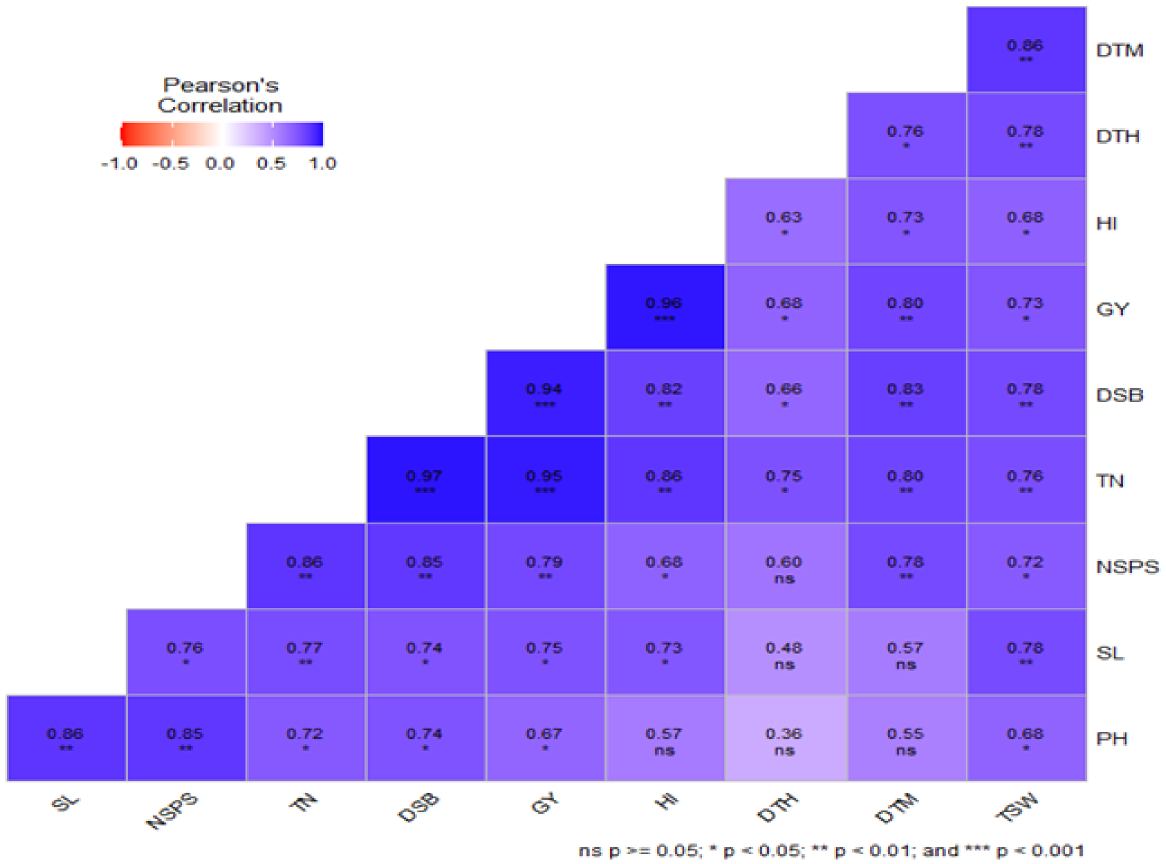

Figure 2. Correlation Heat Map. Note: DTH= days to heading, DTM= days to maturity, PH= plant height, SL= spike length, NSPS=number of seed per spike, TN=tiller number, TSW=thousand seed weight, DSB= dray shoot biomass, GY= grain yield, HI=harvest index

4. Conclusion and Recommendation

This study demonstrated significant genetic variability among bread wheat varieties tested across different locations and years. Genotypic, environmental, and genotype-by-environment interactions had significant effects on grain yield and related traits. The varieties Denda'a, Hidase, and Wetera consistently outperformed others, with Denda'a achieving the highest average grain yield (4.9 t ha^{-1}), followed by Hidase (4.7 t ha^{-1}). These varieties also showed superior performance in agronomic traits like tiller number, thousand seed weight, and harvest index. In contrast, the local check Kakaba had the lowest yield (2.7 t ha^{-1}), indicating poor adaptation and productivity. Grain yield showed strong positive correlations with biomass, plant height, and phenological traits, suggesting these traits can be used in indirect selection for yield improvement. The findings highlight the importance of evaluating genotypes across environments to identify broadly adapted and high-yielding varieties.

It is recommended to replace old varieties, and the promotion of high-yielding cultivars like Denda'a and Hidase for production is among the recommendations. Agronomic optimization and ongoing multi-environment testing are essential to reducing the yield gap and raising wheat production in Northwestern Ethiopia.

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Conflict of Interest

The authors have not declared any conflict of interest.

Authors' contribution statement
Alemnesh Eskezia: Wrote the original draft, edited the manuscript, analyzed, investigated, revised, and Restructured, **Atinkut Fentahun**: Reviewed, edited the manuscript, and collected the data.

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