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Performance Evaluation of Bread Wheat (*Triticum aestivum* L.) Varieties under Ethiopian Agro-ecological Conditions

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ABSTRACT

The experiment was conducted at four locations over two years, from June, 2023 to December, 2024. The study evaluated the performance of 30 bread wheat (*Triticum aestivum* L.) varieties across seven Ethiopian agro-ecological environments during the 2023–2024 cropping season. The objective of the study was to identify high-yielding, stable, and disease-tolerant bread wheat genotypes suitable for sustainable wheat production across diverse Ethiopian agro-ecological environments. The combined analysis of variance revealed that the environment contributed the largest proportion of the total variation (74.51%), followed by genotype×environment interaction (19.77%), whereas genotypic differences accounted for only 5.71% of the variation. Grain yield ranged from 5.45 t ha^{-1} for Digalu to 7.51 t ha^{-1} for Kulumsa in 2023, with newer wheat varieties consistently outperforming older cultivars. The GGE biplot analysis revealed that the first two principal components explained 71.94% of the genotype×environment interaction (G×E) variation, confirming the reliability of the model for assessing genotype stability and adaptability across environments. Newly released varieties such as Kulumsa, Deka, Honqolo, and Balcha demonstrated superior grain yield and desirable agronomic traits, whereas older varieties such as Digalu, Dashen, and Kubsa showed relatively lower performance. These findings highlight the genetic progress achieved through Ethiopian wheat breeding programs and emphasize the importance of continuous variety evaluation to sustain wheat productivity under changing agro-ecological conditions.

KEYWORDS: Bread wheat, new variety, high-yielding, disease resistance, old variety

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1. INTRODUCTION

Wheat is among the most important staple food crops and a major component of the diet of more than 2.5 billion people globally (Bentley et al., 2022). Wheat is the dominant food crop in its contribution to global nutrition, and production has, and may continue to, increase in line with the increase in the global population (Shewry, 2025). Wheat provides almost 20% of the world's calories (Randhawa et al., 2019) and daily proteins to 4.5 billion people worldwide (Tabbita et al., 2023). Wheat is the second-largest grain worldwide based on grain acreage and the second-largest based on total production volume. The global production volume of wheat came to almost 793 mmt in the marketing year of 2024/25. In Ethiopia, wheat is produced on a total area of 1.87 mha of land with a total production of 5.8 mt with an average productivity of 3.1 t ha^{-1} under rain-fed conditions (Anonymous, 2022), which is relatively lower than the attainable yield of the crop, reaching up to 5 t ha^{-1} (Zegeye et al., 2020). On the other hand, the Ethiopian government is determined to fill the demand gap by producing wheat during the off-season in existing environments using irrigation and by expanding wheat production in nontraditional wheat-growing areas, especially in lowlands (Tadesse et al., 2022). Due to the complexity of its genome, wheat can adapt to a wide range of environmental conditions, making it an incredibly adaptable crop (Kamali, 2008). Wheat is an important crop in Ethiopia. Wheat can grow in the highlands of Ethiopia at altitudes ranging from 1500 to 3000 m.a.s.l. (Adugnaw and Dagninet, 2020). Bale and Arsi, Hadiya and Kenbata, East Gojam, and North Shoa are the main wheat-producing regions of Ethiopia (Ayele et al., 2021). Plant breeders are highly concerned with the development and release of high-yielding, stable, and stress-resistant crop varieties (Akcura et al., 2006). A stable genotype is one possessing constant performance irrespective of changes in environmental conditions (Temesgen et al., 2015). A fruitfully developed new variety should be stable and broadly adaptable over a wide range of environments on top of high-yielding potential (Akcura et al., 2006). In Ethiopia, wheat production and productivity are affected by complex and interactive effects of biotic and abiotic factors and socio-economic challenges. Wheat rust diseases, notably stem and stripe rust, are the most important biotic constraints to wheat production in Ethiopia (Singh et al., 2016), a lack of backward agronomic practices, use of marginal agricultural land, and terminal drought stress, among others (Semahegn et al., 2021), and erratic rainfall pattern, low soil fertility, and high temperature are some of the abiotic yield-limiting factors in wheat (Kılıc et al., 2010). The national wheat research program continued to support countries by releasing new high-yielding and resistant wheat varieties in Ethiopia to help overcome the increasing threat of recurring rust epidemic in the country and help rehabilitate the agricultural sector. Of course, the program is able to release more than 100 wheat varieties for different agroecologies of Ethiopia in five decades of concerted research efforts and endeavors (Tadesse et al., 2022). However, the majority of these varieties are becoming susceptible to rust diseases and are put out of production in a few years after their release. Because yellow and stem rust epidemics have frequently occurred in Ethiopia (Tolemariam et al., 2018). Therefore, the objective of this study is to evaluate the performance of different bread wheat varieties under Ethiopian agro-ecological conditions to identify high-yielding, disease-tolerant, and well-adapted varieties that can improve wheat productivity and support sustainable wheat production in the country.

2. MATERIALS AND METHODS

2.1. Plant materials

The experiment was conducted at 4 locations for two years from June, 2023 to December, 2024. A total of thirty bread wheat varieties were utilized in the experiment. These varieties were selected for their adaptation to various agroecological conditions and were released in different years by the Kulumsa, Sinana, Adet, and Holata Agricultural Research Centers (Table 1).

Table 1: List of bread wheat varieties evaluated in the 2023–24 main cropping season

Entry	Varieties	Year of release
1	Kubsa	1995
2	Biftu	2022
3	Danda'a	2010
4	Digalu	2005
5	Tussie	1997
6	Dashen	1984
7	Hidase	2012
8	Kakaka	2010
9	Abay	2021
10	Wane	2016
11	Deka	2018
12	Dursa	2020
13	Shorima	2011
14	Honqolo	2014
15	Madawalabu	2000
16	Tay	2005
17	Shaki	2021
18	Kulumsa	2023

Table 1: Continue...

Entry	Varieties	Year of release
19	Hawi	2000
20	Balcha	2019
21	Galema	1995
22	Ogolcho	2012
23	Boru	2020
24	Huluka	2010
25	Bika	2014
26	Kingbird	2015
27	Alidoro	2007
28	Lemu	2016
29	Hogana	2011
30	ETBW192369	

2.2. Experimental sites and design

The testing locations included Kulumsa, Asasa, Bekoji, and Holeta. The trial was conducted over two consecutive years, from 2023 to 2024. An alpha lattice design with three replications was employed. Each genotype was planted in a 3 m^2 plot consisting of six rows, each 2.5 m long and spaced 20 cm apart. A total of 150 kg of seed per hectare was utilized. Data were collected on several parameters, including Days to Heading (DTH), Days to Maturity (DTM), Plant Height (PHT), Grain Yield (GYLD), Hundred Kernel Weight (HKW), and Thousand Kernel Weight (TKW) (Table 2).

2.3. Statistical analysis

Data were analyzed using analysis of variance (ANOVA) for each environment separately, and a combined analysis of variance was conducted to determine the effects of environment (E), genotype (G), and the GE interaction on trait expression. The R software was used for a combined ANOVA and GGE biplot. The data were graphically presented for interpreting GE interaction using the GGE biplot software (Yan, 2001).

Table 2: List of test locations and their description

	Latitude	Longitude		Min	Max	
Asasa	07°07'228" N	39° 11'932" E	2360	5.8	23.6	620
Holeta	09°03'414"N	38°30'436"E	2400	6.1	22.4	976
Kulumsa	08°01'10"N	39°09'11"E	2200	10.5	22.8	820

3. RESULTS AND DISCUSSION

Combined analysis of variance concerning grain yield is presented in Table 3. The variance due to environment was significant (p<0.001) for grain yield, indicating the distinct and differential effects of different environmental conditions. The variances due to varieties were significant (p<0.001) for grain yield, indicating the genetic differences of the varieties in the environments. This result was in line with the findings of Kifle et al. (2016), who reported that the combined analysis of variance over the two locations showed highly significant variations among the bread wheat genotypes in all studied traits. The variance due to GEI was significant (p<0.001) for grain yield, showing the differential response of the varieties with different environments. The notable effects of genotype-by-environment interaction (GEI) indicate that specific genotypes may be chosen for their adaptability to particular environments. This aligns with the findings of Gadisa et al. (2019), who reported the grain yield stability of bread wheat genotypes in central Ethiopia through GGE biplot analysis. Hence, the GEI effects demonstrated that genotypes

Table 3: Combined analysis of variance of grain yield for 30 bread wheat varieties evaluated at seven environments

Source of variations	DF	Mean of squares	Sum of square	Percent
Env	6	226.80**	1360.83	74.51
Gen	29	3.60**	104.33	5.71
Env×Gen	174	2.08**	361.15	19.77
PC1	34	5.11	173.73	49.35
PC2	32	2.49	79.53	22.59
PC3	30	1.18	35.50	10.08
PC4	28	1.02	28.48	8.09
PC5	26	0.77	20.03	5.69
PC6	24	0.61	14.75	4.19
PC7	22	0.00	0.00	0.00
Residuals	420	0.80	337.05	0.00

The analysis of variance and principal component breakdown highlights the relative importance of different sources of variation in the multi-environment trial. The environment (ENV) effect is highly significant, accounting for the largest share of variation (74.51%), which indicates that differences among testing sites and years strongly influenced genotype performance. A large sum of squares for environments indicated that the environments were diverse, with large differences among environmental means causing variation in the bread wheat varieties' performance for grain yield. Different researchers (Dawit et al., 2017) reported that the grain yield of bread wheat was significantly affected by different environments. Genotype (Gen) differences, though significant, contributed only 5.71% of the total variation, showing that while genetic variability exists, it is relatively small compared to environmental influence. The genotype×environment interaction (Env*Gen) explained 19.77% of the variation, confirming that genotypes responded differently across environments and underscoring the need for stability analysis.

The decomposition into principal components (PCs) further clarifies the interaction structure. PC1 captured the largest proportion (49.35%) of the interaction sum of squares, followed by PC2 (22.59%), together explaining nearly three-quarters of the G×E variation. This suggests that the first two axes of the GGE bi-plot are sufficient to represent most of the interaction pattern, making them reliable for visual interpretation of mean performance and stability. Subsequent components (PC3–PC6) contributed progressively smaller portions (10.08%, 8.09%, 5.69%, and 4.19%), while PC7 explained nothing, indicating diminishing returns beyond the first few axes. Residual variation was relatively small, confirming that the model captured the majority of meaningful patterns.

In summary, the results emphasize that environmental variability is the dominant factor shaping wheat performance, but genotype × environment interactions are also substantial. The strong explanatory power of PC1 and PC2 validates the use of the bi-plot for identifying genotypes that combine high mean yield with stability, while also distinguishing those adapted to specific environments. This balance between mean performance and stability is crucial for selecting broadly adapted varieties versus those targeted for particular sites.

3.1. GGE bi-plot analysis

3.1.1. Which won where pattern

The visualization of the "which won where" pattern is important to know the existence of different mega-environments within an agro-ecology. It is important because evaluations of test locations and genotypes are most useful when conducted within a mega environment (Yan et al., 2007). The perpendicular lines to the polygon sides divide the bi-plot into sectors, each of which has its own winning cultivar. The winning genotype for a sector is the vertex genotype at the intersection of the two polygon sides whose perpendicular lines form the boundary of that sector; it is usually, but not necessarily, positioned within its winning sector (Yan, 2002). The GGE biplot was constructed by plotting the first two principal components,

Figure 1 presents the polygon view of the GGE bi-plot based on symmetrical scaling, illustrating the "which-won-

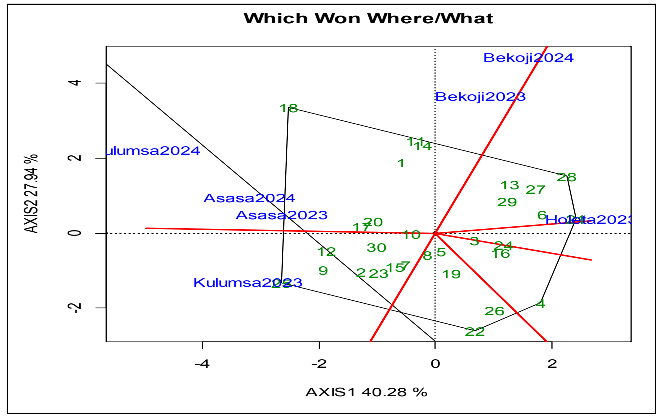

Figure 1: Which genotype won where viewed in the GGE bi-plot

where" pattern of wheat varieties across test environments. In this figure, numbers 1–30 represent the evaluated varieties (see Table 1 for variety abbreviations).

The trials were conducted at four locations: Kulumsa, Bekoji, Asasa, and Holeta, which represent distinct agro-ecological conditions. Kulumsa represents mid-altitude environments, Asasa represents moisture-stressed conditions, while Bekoji and Holeta represent high-altitude areas with significant disease pressure.

The first two principal components (Axis 1 and Axis 2), derived from singular value decomposition of environment-centered yield data (Yan et al., 2000), explained 68.22% of the total G+GE variation in grain yield. Specifically, Axis 1 accounted for 40.28% and Axis 2 for 27.94% of the variation across four environments over two main cropping seasons (2023 and 2024).

The polygon was formed by connecting the outermost (vertex) varieties, which were identified as varieties 18, 28, 4, 22, 21, and 25. These vertex varieties are the most responsive genotypes, meaning they performed best in at least one environment. Each sector of the polygon represents a mega-environment, and the vertex genotype of a sector is the highest-yielding variety in the environments that fall within that sector.

Accordingly, variety 18 (for example, if confirmed from your data) was identified as the winning variety in Kulumsa 2024, Asasa 2024, and Asasa 2023 environments, indicating its specific adaptability and superior performance under those conditions.

3.2. The mean vs stability of environments

Average Environment Coordination (AEC) view of the GGE biplot based on environment-focused scaling, showing the mean performance and stability of wheat varieties. The test environments include Kulumsa (2023 and 2024), Asasa (2023 and 2024), Bekoji (2023 and 2024), and

Holeta (2023). Kulumsa Variety was the best performing genotype at Asasa 2023 and 2024, Bekoji 2023 and 2024, Kulumsa 2024, and Holeta 2023. The vertex genotypes Digalu, Kingbird, Ogolcho, and Tussie were the poorest Variety in almost all of the test environments, since they had the longest distance from the origin of the bi-plot on the opposite side of the environments. Variety Digalu ranked 30th among the seven location Average. In this study, the environments were grouped under three quadrants, while the Varieties were clustered under four quadrants (Figure 2). The first quadrant contained two locations, namely Bekoji 2023 and 2024, and Holeta, 2023.

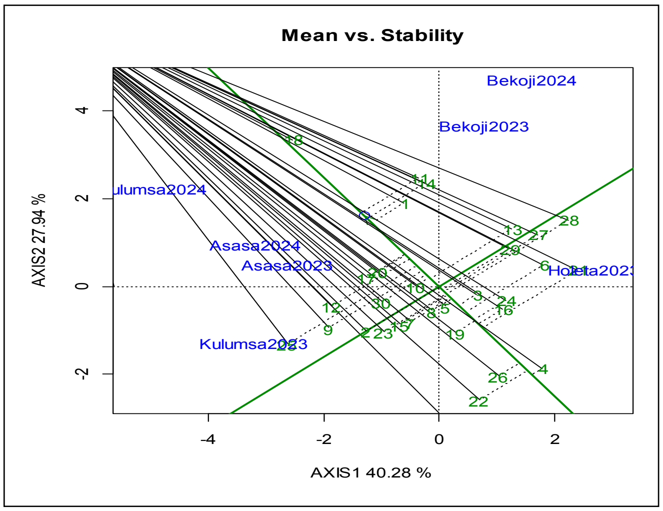

Figure 2: Mean vs Stability

3.3. Discriminating power and representatives of environments

The discriminating power versus representatives' view of the GGE biplot showed that test environments Kulumsa 2024, Bekoji 2023, and 2024, with the longest projection from the biplot origin, were found to be the environments with more discriminating power, which provided much information about the differences among Varieties. On the other hand, Asasa 2023) and Holeta 2023, with their shortest vector from the biplot origin, were found less discriminating of the test Varieties and provide little information on the Varieties. The test environments Kulumsa 2023 and Asasa 2024 were less representative due to the largest angle from the Average Environment Axis (AEA). The environment Asasa can be used to select superior wheat Varieties that have stable performance across environments (generally adapted Varieties) (Figure 3).

3.4. Mean grain yield performance of genotype

The mean performance of agronomic traits among the evaluated bread wheat varieties revealed considerable genetic variation across all measured parameters (Table 4). Days to heading ranged from 63.00 days for Kakaka to 79.53 days for Dashen, with an overall mean of 71.72 days. Varieties

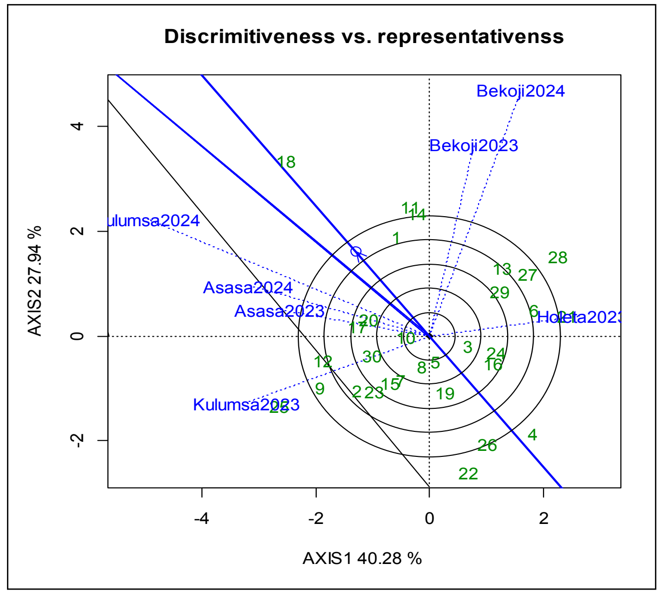

Figure 3: Discriminativeness and representativeness of the test environments

Table 4: The mean performance of agronomic traits

Varieties	DTM	PHT	TKW	DTH	HLW
Kubsa	131.90	87.45	35.09	69.43	68.72
Biftu	133.90	90.52	40.19	70.29	71.20
Danda'a	137.14	105.12	39.35	76.48	68.00
Digalu	140.86	106.67	34.50	78.71	72.12
Tussie	134.52	95.10	32.95	70.62	70.37
Dashen	136.90	93.76	33.31	79.53	68.35
Hidase	133.62	93.19	40.67	67.57	68.67
Kakaka	131.62	95.95	42.55	63.00	70.79
Abay	133.43	97.48	43.52	68.95	70.83
Wane	131.67	91.52	37.43	66.29	66.93
Deka	135.33	98.81	37.87	72.33	68.34
Dursa	133.38	94.26	37.82	67.19	70.17
Shorima	135.14	99.83	35.49	75.81	70.06
Honqolo	134.67	88.26	36.38	74.76	69.55
Madawalabu	132.19	93.05	34.93	68.81	70.39
Tay	135.57	107.62	36.17	74.90	68.82
Shaki	132.24	95.60	45.30	67.24	70.71
Kulumsa	134.19	136.64	38.82	68.90	69.64
Hawi	131.67	88.67	34.33	67.48	67.65
Balcha	133.10	96.52	37.30	69.76	68.59
Galema	136.71	102.71	34.53	78.29	70.00
Ogolcho	133.14	103.81	38.10	71.62	69.10
Boru	132.38	89.90	41.09	72.05	68.14

Table 4: Continue...

Varieties	DTM	PHT	TKW	DTH	HLW
Huluka	137.33	100.88	34.70	79.40	70.40
Bika	134.19	96.21	39.56	66.33	70.48
Kingbird	131.71	91.17	34.86	68.33	68.81
Alidoro	136.76	103.81	37.65	73.19	68.29
Lemu	136.29	96.74	35.75	78.67	68.79
Hogana	137.33	96.29	35.41	75.71	68.76
ETBW192369	133.52	92.50	36.00	70.95	70.23
Mean	134.41	97.67	37.39	71.72	69.43

that headed earlier included Kakaka, Bika, and Wane, while late-heading cultivars were Dashen, Huluka, and Lemu. Days to maturity ranged from 131.6 days (Kakaka and Wane) to 140.9 days (Digalu), with a grand mean of 134.4 days (Table 4). This variation reflects differences in genetic background and adaptation to the growing environments. Plant height varied markedly among varieties, ranging from 87.45 cm (Kubsa) to 136.64 cm (Kulumsa), with an overall mean of 97.67 cm (Table 4). The observed range indicates substantial diversity in plant stature, which can influence lodging resistance and harvest index. Kulumsa (136.64 cm) and Tay (107.62 cm) were the tallest varieties, while Kubsa (87.45 cm) and Honqolo (88.26 cm) were the shortest (Table 1). The moderate height of varieties such as Biftu, Abay, and Balcha suggests a balance between biomass production and lodging tolerance, which is desirable for grain yield stability.

Thousand kernel weight, an indicator of grain size and density, ranged from 32.95 g (Tussie) to 45.30 g (Shaki), with a mean of 37.39 g (Table 4). The varieties Shaki (45.30 g), Abay (43.52 g), and Kakaka (42.55 g) exhibited the heaviest kernels, indicating superior grain plumpness and potential yield advantage. In contrast, older varieties such as Tussie, Kubsa, and Huluka had lower kernel weights. The improvement in kernel weight among recent releases demonstrates breeding progress in enhancing grain quality and yield components. Hectoliter weight (grain density) ranged from 66.93 kg hl^{-1} (Wane) to 72.12 kg hl^{-1} (Digalu), with a mean of 69.43 kg hl^{-1} (Table 4). This trait is important for grain quality and market acceptance. Digalu, Tussie, and Abay exhibited relatively higher HLW values, indicating good grain density and milling quality. The relatively narrow range of HLW among varieties suggests that grain density has been relatively stable across breeding cycles compared to other agronomic traits.

The grain yield data across locations show clear differences between recently released and older varieties, reflecting measurable genetic gain from breeding efforts. The mean grain yield of the evaluated bread wheat varieties across seven environments ranged from 5.45 to 7.51 t ha^{-1}, with an overall mean of 6.23 t ha^{-1} (Table 5). The highest mean yield was recorded for the recently released variety Kulumsa (2023), which produced 7.51 t ha^{-1}, followed by Deka (2018) with 6.88 t ha^{-1}, Honqolo (2014) with 6.67 t ha^{-1}, and Balcha (2019) with 6.66 t ha^{-1} (Table 5). These varieties, all released within the last decade, consistently outperformed older cultivars, indicating the positive impact of recent breeding progress. In contrast, older varieties such as Digalu (2005), Kingbird (2015), and Ogolcho (2012) produced mean yields below the grand mean, with Digalu being the lowest (5.45 t ha^{-1}) (Table 5). This result demonstrates the steady improvement in wheat productivity over time, driven by genetic enhancements and improved agronomic adaptation.

Overall, the results demonstrate substantial genetic variation among the evaluated wheat varieties for key agronomic traits and yield, reflecting both historical and recent breeding achievements. The newer varieties, such as Kulumsa, Shaki, and Abay, combined desirable characteristics including optimal maturity, favorable plant height, high yield, and high kernel weight, indicating superior agronomic potential. Meanwhile, older varieties like Digalu, Dashen, and Kubsa, though still agronomically stable, showed lower performance in yield and several yield-related traits.

3.5. Yield advantage gain of kulumsa variety over other varieties

The results revealed substantial yield variation among the evaluated varieties across seven environments, with mean yields ranging from 5.45 t ha^{-1} (Digalu) to 7.51 t ha^{-1} (Kulumsa). The newly released variety Kulumsa consistently outperformed all other varieties, demonstrating a mean yield of 7.51 t ha^{-1} and an overall yield advantage of 20.55% over the average of the other varieties. This indicates remarkable genetic improvement achieved through breeding efforts focused on yield enhancement and adaptability across diverse agro-ecologies.

Older varieties such as Dashen (1984), Galema (1995), Kubsa (1995), and Tussie (1997) showed relatively low mean yields ranging from 5.92 to 6.72 t ha^{-1}, confirming the gradual yield decline associated with aging germplasm and possible susceptibility to evolving biotic and abiotic stresses. The yield gain of Kulumsa over these older varieties ranged between 11.78% (Kubsa) and 33.97% (Ogolcho), indicating substantial progress in genetic potential and productivity over the past decades. Similarly, mid-aged varieties such as Digalu (2005), Tay (2005), Huluka (2010), and Alidoro (2007) recorded mean yields between 5.45 and 6.44 t ha^{-1}, with Kulumsa showing yield advantages ranging from 16.62% to 37.77% (Figure 1), highlighting significant advances in breeding efficiency over varieties released 10–20 years ago.

Table 5: Mean grain yield of varieties

Varieties	Year of release	Asasa 2023	Asasa 2024	Bekoji 2023	Bekoji 2024	Holeta 2023	Kulumsa 2023	Kulumsa 2024	Mean
Kubsa	1995	6.66	8.38	5.98	8.21	5.77	3.32	8.71	6.72
Biftu	2022	6.00	8.42	4.72	5.45	5.69	3.26	9.10	6.09
Danda'a	2010	4.30	8.70	4.44	7.66	7.10	3.95	7.54	6.24
Digalu	2005	5.29	6.29	4.54	5.99	6.65	2.68	6.71	5.45
Tussie	1997	5.64	7.80	4.68	6.69	5.74	2.80	8.10	5.92
Dashen	1984	4.68	7.21	5.20	7.56	7.36	2.16	7.77	5.99
Hidase	2012	5.90	7.99	5.05	5.83	6.26	3.43	8.52	6.14
Kakaka	2010	6.37	8.29	4.97	6.69	5.50	3.35	7.35	6.07
Abay	2021	5.88	8.13	4.81	5.77	4.94	4.41	9.40	6.19
Wane	2016	5.73	7.94	4.26	7.55	5.09	3.21	8.43	6.03
Deka	2018	6.13	8.31	5.77	8.85	6.56	3.33	9.20	6.88
Dursa	2020	6.96	7.70	4.80	6.39	5.65	4.71	9.40	6.51
Shorima	2011	6.13	6.56	6.40	7.87	6.01	2.53	7.65	6.16
Honqolo	2014	6.57	8.30	6.14	8.45	5.83	2.64	8.78	6.67
Madawalabu	2000	6.33	8.17	3.26	7.60	5.07	3.87	7.85	6.02
Tay	2005	6.34	7.03	4.70	7.50	8.08	4.46	6.96	6.44
Shaki	2021	6.39	8.02	5.50	7.24	5.44	5.20	8.45	6.61
Kulumsa	2023	6.67	9.07	6.58	8.50	6.13	4.46	11.14	7.51
Hawi	2000	5.71	7.84	5.30	6.04	6.39	3.79	7.33	6.05
Balcha	2019	6.15	8.54	5.02	7.89	5.63	5.31	8.08	6.66
Galema	1995	4.85	6.84	5.98	7.92	7.12	3.35	6.26	6.05
Ogolcho	2012	5.57	7.42	3.98	5.66	6.23	3.80	6.57	5.61
Boru	2020	6.37	8.15	4.54	5.97	6.46	4.05	8.59	6.31
Huluka	2010	5.10	7.44	4.63	7.54	6.85	3.41	7.28	6.03
Bika	2014	6.08	8.83	3.64	6.05	5.87	5.37	9.81	6.52
Kingbird	2015	5.38	6.08	3.81	6.64	6.15	4.11	7.02	5.60
Alidoro	2007	5.46	7.11	6.02	8.19	5.84	2.23	7.04	5.98
Lemu	2016	4.56	6.71	5.82	8.66	8.02	3.00	7.68	6.35
Hogana	2011	4.83	7.63	5.11	8.37	5.72	2.62	7.46	5.96
ETBW192369	-	6.02	7.93	4.45	7.22	5.43	4.52	8.53	6.30
Mean		5.80	7.76	5.00	7.20	6.12	3.64	8.09	6.23
CV		12.13	9.13	22.86	8.06	10.21	22.89	8.53	12.44
LSD		1.15	1.56	1.87	0.10	1.03	1.36	1.13	0.23

On the other hand, recently released varieties such as Biftu (2022), Shaki (2021), Dursa (2020), Boru (2020), Balcha (2019), and Deka (2018) displayed improved yield performance (mean yields between 6.31 and 6.88 t ha^{-1}) compared to older cultivars. However, Kulumsa still maintained a noticeable superiority, with yield advantages ranging from 9.16% over Deka to 23.31% over Biftu (Figure 1). These moderate yield differences among recent varieties suggest a plateauing trend in yield gains, likely due to reduced genetic diversity and incremental improvements in the current breeding pool.

The data clearly indicate a significant genetic improvement in yield potential over time, with modern varieties such as Kulumsa demonstrating a notable advantage over older cultivars. The yield difference between Kulumsa, which produces 7.51 t ha^{-1}, and the older standard variety Digalu, which yields 5.45 tons per hectare, corresponds to a 37.77% increase. This reflects the advancements made in the national wheat breeding program.

This progress can be attributed to the incorporation of elite germplasm, improved selection strategies, and enhanced disease resistance, all of which contribute to better adaptability and productivity. These findings highlight the ongoing positive genetic trends in Ethiopian wheat breeding, underscoring the necessity for continued research investment, the replacement of outdated varieties, and the use of new high-yielding cultivars like Kulumsa to achieve national self-sufficiency in wheat and meet food security goals.

4. CONCLUSION

The evaluation of thirty bread wheat varieties across multiple Ethiopian environments demonstrated significant genetic variation and clear yield advantages of recently released cultivars over older ones. The newly released variety Kulumsa (2023) achieved the highest mean yield (7.51 t ha^{-1}), surpassing the grand mean by 20.55% and outperforming both mid-aged and older varieties. Based on these findings, it is recommended that Kulumsa, Deka, Honqolo, and Balcha be prioritized for wider release due to their superior yield and adaptability.

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