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Genetic Variability in Bread Wheat (*Triticum aestivum* L.) Genotypes under Irrigated Condition

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Abstract

Bread wheat (*Triticum aestivum* L.) is a major grain crop and staple in many regions of the world. The objective of this research is to discover high-yielding genotypes while also analyzing gene variation, heritability, and progress of yield-determining variables related to bread wheat genotypes. As a result, this study assesses the production potential, genetic diversity, and heritability of bread wheat genotypes produced under irrigated settings in Ginchi, Ethiopia. Sixty-four bread wheat advanced pure lines and standard checks were evaluated using a simple lattice (8X8) design. The results show considerable phenotypic and genotypic variations among the tested genotypes for all considered traits. Traits such as grain yield per hectare, biomass yield, number of kernels per spike, and thousand kernels weight showed moderate phenotypic coefficients of variation. Broad sense heritability ranged from 30% for biomass yield to 91% for days to 50% heading. Expected genetic advance as percent of means values ranged from 3.73% for days to 50% emergence to 16.91% for thousand kernel weight. The identified high-yielding genotypes, G31, G11, G51, G6, G3, G34, G23, G5, G41, and G59, have shown promising potential for advancing the breeding objectives in the field of irrigated wheat. The study concludes that the use of these traits for direct selection would bring advancement. The future scope of this research lies in the confirmation of the identified high-yielding genotypes in multi-location and season trials to further advance the breeding objectives in the field of breeding programs.

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Introduction

Bread wheat is one of the most important cereal crops in the world, farmed both irrigated and rain-fed, and serves as a reliable food source for many populations.[9] The study of bread wheat is crucial due to its value as a cash crop, high level of production per unit area, and its role in meeting the dietary needs of society.[17] The major producers of wheat worldwide are China, India, and Russia, whereas South Africa and Ethiopia are Africa's major producers.[14] Even though wheat has been grown in Ethiopia since time immemorial, bread wheat, the third-most important cereal crop of the country, is a newly introduced crop.[4] Wheat roughly accounts for 17% of the nation's annual grain production.[2] Any breeding population's performance improvement depends on available and created genetic variability.[13]

Previous research has been conducted on the production and major producers of wheat globally, as well as its importance in Ethiopia. There is a lack of research on the yield potential, genetic variability, and heritability of bread wheat genotypes grown under irrigated conditions in the central highlands of Ethiopia. The development of high-yielding adaptive genotypes for off-season cropping in the central highlands of Ethiopia is in high demand, and this study aims to evaluate the yield potential, genetic variability, and heritability of bread wheat genotypes grown under irrigated conditions in Ginchi, Ethiopia. What are the yield potential, genetic variability, and heritability of bread wheat genotypes grown under irrigated conditions in the central highlands of Ethiopia? This study aims to evaluate the yield potential, genetic variability, and heritability of bread wheat genotypes grown under irrigated conditions in the central highlands of Ethiopia. It is hypothesized that the bread wheat genotypes grown under irrigated conditions in the central highlands of Ethiopia will have high yield potential, genetic variability, and heritability.

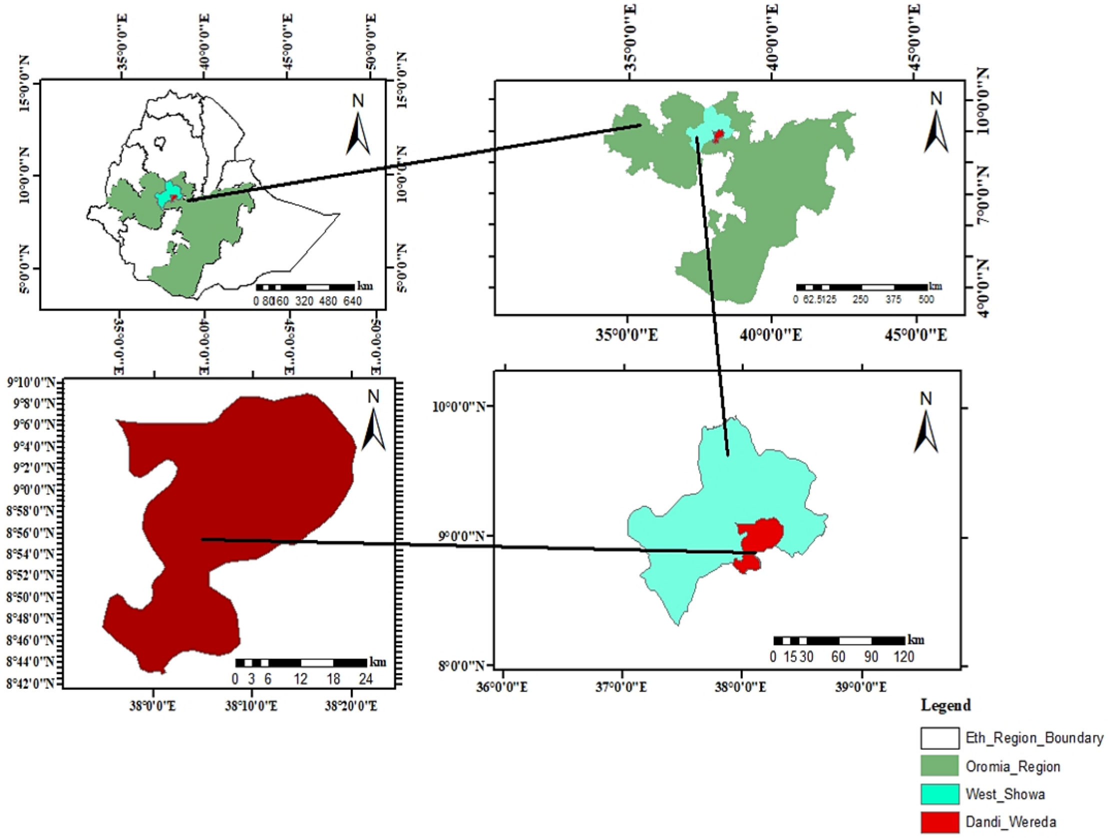

Fig. 1: Study Area Map

Materials and Methods

Description of Study Area

The study was carried out in the Ginchi sub-station Ambo Agricultural Research Center experimental field during the off-season (November twenty-one to April twenty, 2021). The site is located at an altitude of 2304 meters above sea level at 9° 01' 2.2" N latitude and 38° 06' 11.8" E longitude. The region has average minimum and maximum temperatures of 11°C and 21°C, and a relative humidity of 64.4% as well as the region has 1050 mm of regular annual rainfall. The major soil type of the area is heavy vertisol with a pH of 7.8 for the uppermost topsoil. (0–30 cm).[7]

Table 1: A list of bread wheat genotypes that were evaluated in the study

Code	Genotype	Source	Code	Genotype	Source	Code	Genotype	Source
G1	BW174382	KU18BWOE-5-26	G28	BW172582	KU18BWOE-3-6	G55	BW174421	KU18BWOE-7-35
G2	BW172655	KU18BWOE-3-27	G29	BW172580	KU18BWOE-7-10	G56	BW174424	KU18BWOE-1-20
G3	BW172683	KU18BWOE-4-36	G30	BW172596	KU18BWOE-4-35	G57	BW174416	KU18BWOE-10-25
G4	BW172653	KU18BWOE-6-20	G31	BW172598	KU18BWOE-4-9	G58	BW174397	KU18BWOE-6-33
G5	BW172682	KU18BWOE-1-23	G32	BW174101	KU18BWOE-10-4	G59	BW174399	KU18BWOE-3-25
G6	BW172661	KU18BWOE-3-35	G33	BW172581	KU18BWOE-3-16	G60	BW174420	KU18BWOE-9-20
G7	BW172726	KU18BWOE-10-14	G34	BW172575	KU18BWOE-7-34	G61	BW174393	KU18BWOE-9-17
G8	BW172750	KU18BWOE-5-34	G35	BW172592	KU18BWOE-5-10	G62	BW174390	KU18BWOE-5-22
G9	BW172712	KU18BWOE-9-29	G36	BW172576	KU18BWOE-7-2	G63	Obora	Sinana
G10	BW172719	KU18WOE-9-31	G37	BW120131	KU18BWOE-3-30	G64	Liben	Bako
G11	BW172722	KU18BWOE-3-29	G38	BW120097	KU18BWOE-6-4			
G12	BW172711	KU18BWOE-3-28	G39	BW120094	KU18BWOE-3-2			
G13	BW172710	KU18BWOE-6-26	G40	BW120103	KU18BWOE-10-34			
G14	BW172695	KU18BWOE-5-31	G41	BW120136	KU18BWOE-3-17			
G15	BW174395	KU18BWOE-2-2	G42	BW120124	KU18BWOE-10-18			
G16	BW172646	KU18BWOE-2-25	G43	BW120113	KU18BWOE-4-33			
G17	BW172631	KU18BWOE-2-1	G44	BW120091	KU18BWOE-6-12			
G18	BW172650	KU18BWOE-4-27	G45	BW120117	KU18BWOE-3-22			
G19	BW172642	KU18BWOE-4-1	G46	BW120151	KU18BWOE-1-18			
G20	BW172640	KU18BWOE-1-33	G47	BW120074	KU18BWOE-2-21			
G21	BW172638	KU18BWOE-1-24	G48	BW174386	KU18BWOE-2-10			
G22	BW172623	KU18BWOE-6-21	G49	BW120078	KU18BWOE-10-27			
G23	BW172618	KU18BWOE-4-7	G50	BW120075	KU18BWOE-7-3			
G24	BW172632	KU18BWOE-1-36	G51	BW120081	KU18BWOE-9-30			
G25	BW172624	KU18BWOE-5-18	G52	BW120076	KU18BWOE-1-29			
G26	BW172626	KU18BWOE-8-5	G53	BW174455	KU18BWOE-5-36			
G27	BW172583	KU18BWOE-10-15	G54	BW174342	KU18BWOE-4-30			

Experimental Materials and Design

Experimental materials were constituted of sixty-two bread wheat advanced pure lines in Table 1, obtained from Ambo Agricultural Research Center (AARC) and two released varieties from Sinana and Bako Agricultural Research Center used as standard checks. The advanced lines were originally sourced from the International Maize and Wheat Improvement Center and advanced by the Kulumsa National Wheat Program located at Kulumsa Agricultural Research Center (Table 2). The experiment was laid out in an 8 × 8 simple lattice design in two replications with a plot size length of 2.5 m x 1.2 m =3m². Total plot 128; Spacing between rows, adjacent plots, blocks, and replication were 20 cm, 1 m, 1 m, and 2 m respectively. The seed rate for irrigated conditions was 125 kg ha^{-1}, and NPS was applied by drilling at sowing time. While urea fertilizers were employed at a rate of 100 kg ha^{-1}, urea was applied in equal parts during the tillering and heading stages. Weeds were manually managed as necessary. The data were collected from a net plot area of 2m².

Data Collected

Data was collected using the International Plant Genetic Resources Institute procedure.[3] The following plant-based data were recorded: the number of tillers per plant (NTPT), plant height (PH), spike length (SL), number of spikelets spike^{-1} (SPS), and number of kernels spike^{-1} (KPS). Total net plot:- Data on days to 50% emergence (DTE), days to 50% heading (DTH), grain filling period (GFP), days to 90% physiological maturity (DM), thousand kernel weight (TKW), Hectoliter weight(HLW), Grain protein content (GPC), biomass yield (BY), grain yield (GY), and harvest index (HI) traits were collected.

Table 2: Mean squared analysis of variance for fourteen parameters of 64 bread wheat genotypes examined in Dandi District.

Traits	Means square				CV%
	Rep	Block within Rep (Adj.)	Genotypes (Adj.)	Residual (inter-block)	
	(DF=1)	(DF=14)	(DF=63)	(DF=49)	
Days to 50% emergency	4.5**	0.29**	0.25**	0.087	2.7
Days to 50% heading	2.53	1.82	37.78**	1.82	1.3
Days to 90% maturity	5.28	4.39	49.54**	4.309	1.2
Grain filling period	0.5	4.5	18.41**	3.6036	2.5
Plant height(cm)	47.37**	24.04**	49.79**	5.16	1.8
Number of tillers plant-1	0.0001	0.22	0.198ns	0.152	9.5
Spike length (cm)	0.206	0.39**	0.63**	0.14	2.8
Number of spikelets spike-1	0.67	0.89	3.66**	0.66	2.9
Number of kernels spike-1	3.85	30.83**	48.47**	12.38	4.7
Thousand kernels weight	2.51	6.23	56.72**	10.02	4.2
Hectoliter weight (Kg)	7.5	6.48	10.027**	1.55	1.63
Biomass yield (Kg/ha)	9098114	2612827	3009801**	1321392	10.9
Grain yield (kg/ha))	28375**	5180*	9664**	4139	6.2
Harvesting index (%)	0.0007	13.691	22.58**	7.365	5.2
Grain protein content (%)	0.18	0.699**	2.43**	0.178	1.08

Key ***, **, * Significant at P<0.001, 0.01 and 0.05 levels, respectively, SV=source of variation, DF=degree of freedom CV=coefficient variation,

Data Analysis

PBIB design analysis of variance, Tukey's honest significance difference means performance test, and variability analysis were done using agricolae, and variability packages of R software (version 4.1.0).

Results and Discussion

Analysis of Variance

Analysis of variance revealed significant differences (P<0.01) across genotypes for every trait except the number of tillers per plant (Table 2). Similarly,[1,6] discovered extremely significant variations between genotypes in those mentioned traits. These include the number of days to heading, days to maturity, grain filling period, thousand kernel weight, plant height, spike length, number of spikelets spike^{-1}, and number of grains plant^{-1}, as well as the amount of grain produced plot^{-1}, harvest index, and hectoliter weight. Analysis of variance reveals that the tested genotypes differed in the majority of traits. Thus, it might be exploited in future breeding efforts.

Mean Performance of Genotypes

The mean grain yield numbers varied from 3763 kg ha^{-1} for G45 to 6811 kg ha^{-1} for G31. The total population mean was 5561 kg ha^{-1} (Table 3). G31 (6811 kg ha^{-1}) and G11 (6806 kg ha^{-1}) were the highest grain yields. For the left genotypes yield next to above their order, which was chosen for the materials as good yielders as follows: G51 (6797 kg ha^{-1}), G6 (6575 kg ha^{-1}), G3 (6556 kg ha^{-1}), G34 (6548 kg ha^{-1}), G23 (6430 kg ha^{-1}), G5 (6325 kg ha^{-1}), G41 (6304 kg ha^{-1}), G59 (6213 kg ha^{-1}), G36 (6177 kg ha^{-1}), G46 (6157 kg ha^{-1}), and G25 (6153 kg ha^{-1}). The lowest yield values were reported for genotype G45 (3763 kg ha^{-1}), followed by G19 (3913 kg ha^{-1}), G29 (4126 kg ha^{-1}), and G14 (4231 kg ha^{-1}). When compared to check varieties, thirteen genotypes showed higher mean grain yield values than the standard check Liben, whereas forty genotypes outperformed the standard check Obora.

The grain protein content values for the examined genotypes ranged from 10.4% to 14.9%, with a population mean of 12.34% (Appendix Table 1). The grain protein content was highest for G17, followed by G14, G20, G4, G19, G55, G27, G18, and G29. Low grain protein content was found for the Obora variety, followed by G42, G5, and G34. All genotypes showed higher mean grain protein content than the standard check, Obora. Aside from this, sixteen genotypes showed a higher mean grain protein content than the normal check Liben. This conclusion was consistent with that of,[11] who found an average wheat grain protein content of 12%. Hectoliter weight readings varied from 66.95 kg ha^{-1} to 76.8 kg ha^{-1}, with an average value of 71.83 kg ha^{-1}. According to the analyzed data, the maximum hectoliter weight was observed on G55 (76.8 kg ha^{-1}). The left genotypes were the following: G12 (76.4), G54 (76), G57 (75.6), G62 (75.6), G9 (75.1), and G1 (75.0). The lowest hectoliter weights were observed for G41 (74.8), G48 (74.8), G59 (74.4), G40 (74.3), and G23 (74.2). In general, sixty genotypes had a greater hectoliter weight than the standard check, Liben.

According to earlier research, nine genotypes were classified as early maturing based on their mean performance(Appendix Table 1). These include G17, G35, G29, G8, G19, G3, G4, G25, and G11. The G63 has been shown to mature at approximately 136 days, making it the latest mature genotype. Next to this, G45, G43, G41, and G40 have a similar value of days to maturity at 129.5 days. The top ten most promising genotypes were chosen for comparison with the check varieties based on their performance outcomes across all variables (Table 3 Appendix Table 1). These genotypes performed above average on attributes of interest. These include days to 50% heading, number of kernels spike^{-1}, thousand kernel weight, biomass yield, the yield of grain hectare^{-1}, and harvesting index. In addition, they had intermediate values for days to maturity, grain filling duration, plant height, and hectoliter weight.

Furthermore, they found lower values for days to 50% emergence, spike length, number of spikelets, and grain protein content. This finding was consistent with,[5,12] who reported similar results on traits such as days to maturity, plant height, grain filling period, thousand kernel weight, hectoliter weight, spike length, number of spikes per spike, grain spike spike^{-1}, biomass yield, harvest index, and grain yield. As a result, the selected genotypes can go to the next stage of the bread wheat advancement program.

Table 3 Mean performance of top ten genotypes along with standard checks evaluated at Dandi District 2021 off-season

GENO	DTH	DTM	GFP	PH(cm)	SL(cm)	SPS	KPS	TKW/g	HLW	BY(kg ha^{-1})	GY kg ha^{-1}	HI (%)	GPC (%)
G31	70.5^{k-q}	124^{c-k}	53.5^{b-g}	86.07^{c-m}	9.98^{a-c}	20.05^{b-n}	56.9^{a-c}	56.2^{a-h}	70.8^{j-w}	11844^{a-g}	6811^{a}	57.42^{ab}	11.6^{o-w}
G11	71.5^{j-o}	117.5^{m-s}	46^{lm}	87.02^{c-l}	9.09^{c-p}	17.1^{r-u}	53.65^{a-l}	50^{f-s}	71.2^{i-u}	12223^{a-e}	6806^{ab}	55.75^{a-e}	12.15^{h-s}
G51	72.5^{h-m}	119.5^{j-q}	47^{k-m}	80.97^{j-r}	8.99^{c-q}	20.55^{a-k}	55.1^{a-i}	53.5^{c-m}	69.2^{r-x}	11580^{a-i}	6797^{ab}	58.73^{a}	10.8^{t-w}
G6	69^{n-s}	125.5^{b-h}	56.5^{a-c}	87.97^{b-j}	9.87^{a-e}	18.55^{j-u}	48.7^{c-o}	52.65^{c-o}	72.7^{d-p}	12741^{a-d}	6575^{a-c}	51.8^{a-j}	12.7^{e-q}
G3	70^{l-r}	117^{n-s}	47^{k-m}	86.13^{c-m}	9.24^{b-o}	19.25^{e-q}	54.45^{a-j}	58.35^{a-e}	67.8^{wx}	11939^{a-f}	6556^{a-d}	55.08^{a-g}	12.15^{h-s}
G34	73^{g-l}	126^{b-g}	53^{c-h}	88.15^{b-j}	10.2^{ab}	20.85^{a-i}	62.75^{ab}	49^{h-s}	70.1^{m-w}	11564^{a-i}	6548^{a-d}	56.61^{a-d}	10.7^{u-w}
G23	72.5^{h-lm}	121^{g-n}	48.5^{h-m}	95.25^{ab}	8.54^{i-r}	19.7^{c-p}	55.95^{a-f}	51.4^{e-r}	74.2^{a-i}	12897^{a-c}	643^{a-e}	49.88^{d-j}	12.7^{e-q}
G5	71^{k-p}	121^{g-n}	50^{f-m}	87.2^{c-k}	9^{c-q}	17.7^{o-u}	45.65^{h-o}	54.4^{b-k}	71.2^{i-u}	11075^{a-k}	6325^{a-f}	57.32^{a-c}	10.65^{u-w}
G41	78.5^{b-d}	129.5^{b}	51^{e-k}	91.66^{b-f}	9.73^{a-h}	20.6^{a-j}	50^{c-o}	45.4^{o-t}	74.8^{a-g}	11754^{a-g}	6304^{a-g}	53.64^{a-h}	10.75^{t-w}
G59	71^{k-p}	120^{i-p}	49^{g-m}	87.72^{c-j}	9.28^{a-o}	22.15^{a}	57.05^{a-c}	46.6^{l-t}	74.4^{a-h}	11580^{a-i}	6213^{a-h}	53.74^{a-h}	12.9^{d-o}
G63 check	89^{a}	136^{a}	47^{k-m}	92.62^{bc}	9.83^{a-f}	19.6^{c-p}	50.9^{c-o}	42.7^{s-w}	69.8^{p-x}	11032^{a-k}	5233^{c-n}	47.44^{h-j}	10.4^{w}
G64 check	69.5^{m-r}	128^{b-e}	58.5^{a}	82.47^{h-r}	9.46^{a-l}	21.95^{ab}	54.15^{a-k}	51.1^{e-r}	68 v-x	13548a	6099^{a-h}	45.1^{i-k}	13.05^{c-m}
Min	64	113	44	70.52	7.6	16.65	41	34.65	66.95	93.67	3763	31.85	10.4
Max	89	136	58.5	99.17	10.4	22.15	68.5	62	76..8	16532.7	6811	59.63	14.9
Mean	72.31	123.58	51.27	85.23	9.05	19.26	49.9	50.44	71.83	10582.7	5561	52.7	12.34
SEM +	0.96	1.47	1.39	2.23	0.32	0.6	2.87	2.14	0.88	896.7	4.03	2.1	0.38
CD (5%)	0.73	2.69	3.92	4.16	6.29	8.12	1.69	0.89	6.05	1137	2534.3	5.92	1.08

Key Genotypes code =see table 1, MD= Days to 90% physiological Maturity, DH= Days to 50% Heading, GFP=Grain Filling Period, PH= plant height(cm), NKPS=Number of Kernels Spike^{-1}, SPS= Number of Spikelets Spike^{-1}, SL =Spike length(cm), TKW= Thousand kernels weight (g.), GY Ha^{-1}= Grain Yield per Hector, BY kg ha^{-1}=Biomass Yield per hector, HI = harvest index, GPC%=protein content and HLW kg hl^{-1} =hectoliter weight, SEM =standard error of the mean, CD= Critical Difference, super script = showed written scientific paper format.

Estimation of Variance Components

Genotypic and phenotypic variances were more than 20%. For multiple traits that were investigated. These include days to maturity, plant height, thousand kernel weight, number of kernels spike^{-1}, biomass yield, and grain yield. For these traits, genotypic differences were higher than environmental variances. The lowest genetic variation was seen for days to 50% emergence, grain protein content, and spike length.

Genotypic and Phenotypic Coefficients Variation

Grain yield, biomass yield, thousand kernel weight, and number of kernel spike^{-1} characteristics all showed moderate phenotypic coefficients of variation (PCV). The features with the lowest PCV were days to 50% heading, 50% grain filling period, days to maturity, plant height, and spike length (Table 4). The genotypic coefficient variation (GCV) was less than 20% for all characteristics except grain yield. The previous results were in line with those of Haydar.[10] Because grain yield exhibited low GCV, it must be considered when using grain yield as a selection measure for improving these genotypes. In general, the PCV estimation was somewhat higher than the matching GCV, showing the importance of external factors in character expression. This was consistent with the findings of.[5,10]

Table 4: Variability, heritability, and genetic advance estimation for traits of the genotype in the study

Characters	Range	Mean	Sem	σ^2e	σ^2g	σ^2p	ECV (%)	GCV (%)	PCV (%)	H^2 (%)	GA	GAM
DTE	7-80	7.34	0.26	0.13	0.06	0.19	0.50	3.29	5.99	31	0.28	3.73
DTH	64-89	72.31	0.96	1.83	17.98	19.80	1.87	5.86	6.15	91	8.32	11.5
DTM	113-136	123.58	1.47	4.33	22.59	26.92	1.68	3.85	4.20	84	8.97	7.26
GFP	44-58.50	51.27	1.39	3.85	7.28	11.13	3.83	5.26	6.51	65	4.49	8.77
PH (cm)	70.52-99.17	85.23	2.23	9.92	20.21	29.59	3.59	5.27	6.38	68	7.66	8.98
SL (cm)	7.6-10.40	9.05	0.32	0.20	0.22	0.42	4.95	5.17	7.16	52	0.70	7.70
SPS	16.65-22.15	19.26	0.60	0.71	1.47	2.19	4.38	6.31	7.68	67	2.05	10.70
KPS	41-68.50	49.90	2.87	16.48	16.00	32.48	8.14	8.02	11.42	49	5.78	11.60
TKW (g)	34.65-62	50.44	2.14	9.18	23.77	32.95	6.01	9.67	11.38	72	8.53	16.90
HLW (Kg hl^{-l})	66.95-76.8	71.83	0.88	1.55	4.24	5.79	1.73	2.87	3.35	73	3.63	5.06
BY(kg ha^{-1})	7293.67-16532.7	10582.70	896.7	1608377.80	700711	2309089.5	11.98	7.90	14.35	30	949.9	8.90
GY (kg ha^{-1})	3763-6811	5561	4.03	324107	321124.9	645232	10.24	10.19	14.44	50	824	14.81
HI (%)	31.85-59.63	52.70	2.10	8.78	6.90	15.70	5.60	4.99	7.52	44	3.59	6.80
GPC (%)	10.4%-14.90%	12.34	0.38	0.29	0.07	1.36	4.39	8.37	9.45	78	1.88	15.27

Key: σ2e environment variance, σ^2g genotypic variance, σ^2p phenotypic variance, ECV, environmental coefficient variance, GCV genotypic coefficient of variation, PCV phenotypic coefficient of variation, H^2 broad sense heritability, GA genetic advance, GAM genetic advance as percentage of the mean; DE= Days to 50% Emergence, DH=Days to 50% Heading, GFP=Grain Filling Period, DTM= Days to 90% Maturity, PH (cm) =Plant Height, KPS=Number of Kernels Spike^{-1}, SPS=Spikelets Spike^{-1}, SPL (cm) =Spike length, TKW (g) = Thousand kernel weight, GY (kg ha^{-1}) = Grain Yield, BY (kg ha^{-1}) =Biomass Yield, HI = harvest index, GPC= Grain protein content, HLW(Kg hl^{-l})=hectoliter weight

Heritability and Genetic Advance as Percent of Mean

The majority of the traits: days to 50% heading, grain filling period, days to maturity, plant height, number of spikelets spike^{-1}, thousand kernels weight, grain protein content, and hector liter weight; lay on high heritability class. The other four traits: number of kernels spike^{-1}, spike length, grain yield hector^{-1}, and harvesting index; were moderately heritable and the remaining two (days to emergence and biomass yield) traits showed low heritability results (Table 4). Similar findings were reported by[15] also observed high heritability for spike length, kernel spike^{-1}, and grain yield. These research findings of heritability showed traits of consideration are least influenced by the test environment.

Expected genetic advance as a percentage of the mean (GAM) values ranged from 3.73% for days to 50% emergency to 16.90% for thousand kernel weight (Table 4). Moderate GAM was observed in thousand kernels weights followed by grain protein content, grain yield hector^{-1}, number of kernels spike^{-1}, days to 50% heading, and number of spikelets spike^{-1}. This result is similar to[8,16] for grain yield hector^{-1} and number of kernels spike^{-1}. Whereas, genetic advance as a percent of mean values was low for days to 50% emergency, hectoliter weight, harvest index, days to maturity, spike length, grain filling period, biomass yield, and plant height. Comparable results were reported on days to 50% of emergency, plant height, and days to 90% maturity.[18] Those characteristics with moderate genetic progress as a percentage of mean values also had high to moderate heritability (i.e. thousand kernel weight, grain protein content, and grain yield ha^{-1}). It demonstrated that the phenotypes accurately described their genotypes, and that selection based on phenotypic performance would be reliable for improving bread wheat.

Conclusion

In conclusion, the results of this study demonstrate the significant variations among the tested bread wheat genotypes for all considered traits. The study successfully identified high-yielding genotypes and determined the variation in genes, heritability, and advancement of yield-determining variables in bread wheat genotypes under irrigation conditions in Ethiopia. The identified high-yielding genotypes, G31, G11, G51, G6, G3, G34, G23, G5, G41, and G59, have shown promising potential for advancing the breeding objectives in the field of irrigated wheat. The findings of this study can be used to guide future breeding programs aimed at developing high-yielding and adaptive bread wheat genotypes for low-altitude areas and off-season irrigated farming in Ethiopia.

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Conflict of Interest

The authors declare that they have no known financial or interpersonal conflicts that might have looked to have influenced the research presented in this study.

Authors' Contribution

Proposed proposal, study conception and design, Data collection and data management, Data analysis and interpretations of result and manuscript wrote
2nd. Author. Ermias Estifanos Desalegn
Interpretation of results, Reviewed and comment, Written paper comment, Field supervisor and advise way of data collection
3rd. Author. Negash Galata Ayena
Interpretation of results, Reviewed and comment, Written paper comment, Field supervisor and advise way of data collection.

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Appendix Table 1

GENO	DTH	DTM	GFP	PH	SL	SPS	NKPS	TKW	HLW	BY	GY	HI (%)	GPC (%)
G1	72.5 $^{h-m}$	125b^{-i}	52.5^{c-i}	76.33 ^{rs}	8.25 $^{n-r}$	19.95^{b-n}	51.5^{c-n}	48.5 $^{i-s}$	75 $^{a-f}$	8912^{f-k}	48.29 $^{h-o}$	54.25^{a-h}	12.35 $^{g-r}$
G2	72.5 $^{h-m}$	124.5^{b-j}	52^{c-j}	85.1 $^{c-n}$	8.18 $^{o-r}$	19.5^{d-p}	50.95^{c-o}	54.9 $^{a-j}$	72.2 $^{e-r}$	10944^{a-k}	59.44 $^{a-j}$	54.52^{a-h}	12.45 $^{f-r}$
G3	70 $^{l-r}$	117^{n-s}	47^{k-m}	86.13 $^{c-m}$	9.24 $^{b-o}$	19.25^{e-q}	54.45 $^{a-j}$	58.35 $^{a-e}$	67.8 ^{wx}	11939^{a-f}	65.56 $^{a-d}$	55.08^{a-g}	12.15 $^{h-s}$
G4	70 $^{l-r}$	117^{n-s}	47^{k-m}	83.87^{g-q}	8.42 $^{k-r}$	19.65^{c-p}	44.25 $^{k-o}$	47.7 $^{j-t}$	69.1 $^{s-x}$	9800^{c-k}	48.67 $^{h-o}$	49.76^{d-j}	14.05 $^{a-d}$
G5	71 $^{k-p}$	121^{g-n}	50^{f-m}	87.2 $^{c-k}$	9 $^{c-q}$	17.7^{o-u}	45.65 $^{h-o}$	54.4 $^{b-k}$	71.2 $^{i-u}$	11075^{a-k}	63.25 $^{a-f}$	57.32^{a-c}	10.65 $^{u-w}$
G6	69 $^{n-s}$	125.5^{b-h}	56.5^{a-c}	87.97 $^{b-j}$	9.87 $^{a-e}$	18.55^{j-u}	48.7 $^{c-o}$	52.65 $^{c-o}$	72.7 $^{d-p}$	12741^{a-d}	65.75 $^{a-c}$	51.8^{a-j}	12.7 $^{e-q}$
G7	68 $^{p-s}$	120.5^{h-n}	52.5^{c-i}	89.52 $^{b-i}$	8.73 $^{f-q}$	18.95^{h-s}	47.95 $^{c-o}$	54 $^{c-l}$	70.9 $^{j-v}$	10717^{a-k}	57 $^{a-k}$	53.4^{a-h}	12.8 $^{d-p}$
G8	64 ^{tv}	114.5^{rs}	50.5^{e-l}	83.15 $^{g-r}$	9.03 $^{c-q}$	16.65^{u}	47.8 $^{c-o}$	55.6 $^{a-i}$	72.2 $^{e-r}$	11459^{a-i}	59.26 $^{a-j}$	51.73^{a-j}	13.25 $^{b-i}$
G9	73 $^{g-l}$	126^{b-g}	53^{c-h}	81.92 $^{i-r}$	8.81 $^{e-q}$	17.65^{o-u}	45.6 $^{h-o}$	52.5 $^{c-o}$	75.1 $^{a-e}$	9967^{c-k}	58 $^{a-i}$	58.03^{a}	13 $^{c-m}$
G10	73.5 $^{f-k}$	121^{g-n}	47.5^{j-m}	89.7 $^{b-h}$	9.55 $^{a-j}$	18.3^{m-u}	50.7 $^{c-o}$	49.4 $^{f-s}$	71.2 $^{i-u}$	11067^{a-k}	57.67 $^{a-j}$	52.24^{a-i}	10.8 $^{t-w}$
G11	71.5 $^{j-o}$	117.5^{m-s}	46l^{m}	87.02 $^{c-l}$	9.09 $^{c-p}$	17.1^{r-u}	53.65 $^{a-l}$	50 $^{f-s}$	71.2 $^{i-u}$	12223^{a-e}	68.06 ^{ab}	55.75^{a-e}	12.15 $^{h-s}$
G12	70.5^{kl-q}	122.5^{f-m}	52^{c-j}	92.05 $^{b-e}$	9.02 c-q	18.4^{l-u}	50.6 $^{c-o}$	48.6 $^{i-s}$	76.4 ^{ab}	10376^{b-k}	54.76 $^{a-m}$	52.99^{a-h}	12.8 $^{d-p}$
G13	73.5 $^{f-k}$	127.5^{b-f}	54^{a-f}	79.4 $^{l-r}$	8.93 c-q	17.6^{p-u}	43.4 $^{m-o}$	52.8 $^{c-o}$	71.4 $^{h-u}$	10801^{a-k}	51.84 $^{c-m}$	47.42^{h-j}	11.55 $^{p-w}$
G14	68^{p-s}	120^{i-o}	52^{c-j}	84.85 $^{d-o}$	9.21 b-p	18.6^{j-u}	47.8 $^{c-o}$	51.2 $^{e-r}$	70.3 $^{k-w}$	8481^{h-k}	42.31 $^{l-o}$	49.92^{c-j}	14.45 ^{ab}
G15	72.5 $^{h-m}$	128.5^{b-d}	56^{a-d}	83.87 $^{g-q}$	9.38a-m	20.05^{b-n}	55.85 $^{a-g}$	44.7 $^{p-t}$	73 $^{c-n}$	10515^{a-k}	54.82 $^{a-m}$	52.09^{a-i}	10.75 $^{t-w}$
G16	67 $^{r-t}$	125^{b-i}	58^{ab}	83.02 $^{g-r}$	9.52a-k	19.45^{d-q}	43.1 $^{m-o}$	61.5 ^{ab}	73.1 $^{c-m}$	11007^{a-k}	59.24 $^{a-j}$	53.82^{a-h}	13.2 $^{b-j}$
G17	67^{rstu}	113^{s}	46^{lm}	84.77 $^{e-o}$	9.25 b-o	16.95^{s-u}	46.45 $^{e-o}$	58.9 $^{a-d}$	68.4 $^{u-x}$	9526^{e-k}	45.42 $^{j-o}$	47.9^{g-j}	14.9 ^{a}
G18	70 $^{l-r}$	123^{e-l}	53^{c-h}	85.92 $^{c-m}$	8.88 c-q	17.4^{q-u}	50.8 $^{c-o}$	51.36 $^{e-r}$	71.1 $^{j-u}$	9680^{d-k}	51.13 $^{e-o}$	52.83^{a-h}	13.65 $^{a-g}$
G19	64^{v}	115^{o-s}	51^{e-k}	76.47 $^{q-s}$	8.29 m-r	17.15^{r-u}	43.4 $^{m-o}$	62 ^{a}	68.9 $^{t-x}$	80978252^{k}	39.13 ^{no}	48.59^{e-j}	13.95 $^{a-e}$
G20	69 $^{n-s}$	120^{i-o}	51^{e-k}	84.55 $^{e-p}$	8.99 c-q	19.25^{f-q}	46.65^{d-o}	50.4 $^{f-r}$	73 $^{c-o}$	10157^{b-k}	51.41 $^{d-n}$	50.52^{b-j}	14.25 $^{a-c}$
G21	67.5 $^{q-s}$	121^{g-n}	53.5^{b-g}	83.92 $^{g-q}$	8.87 c-q	19.6^{c-p}	47.75^{c-o}	56.5 $^{a-h}$	70.8 $^{j-w}$	9110^{e-k}	48.93 $^{g-o}$	53.97^{a-h}	13.4 $^{b-h}$
G22	68 $^{p-qrs}$	119.5^{j-q}	51.5^{d-k}	84.47 $^{e-p}$	8.84 d-q	19.6^{c-p}	49.05 $^{c-o}$	52.2 $^{d-p}$	71.6 $^{h-t}$	10091^{b-k}	52.24 $^{c-n}$	51.47^{a-j}	13.4 $^{b-h}$
G23	72.5^{h-lm}	121^{g-n}	48.5^{h-m}	95.25 ^{ab}	8.54 i-r	19.7^{c-p}	55.95 $^{a-f}$	51.4 $^{e-r}$	74.2 $^{a-i}$	12897^{a-c}	64.3 $^{a-e}$	49.88^{d-j}	12.7 $^{e-q}$
G24	68.5 $^{o-s}$	119.5^{j-q}	51^{e-k}	77.69 $^{n-r}$	7.96 qr	17.6^{p-u}	45.35 $^{i-o}$	49.1^{g-s}	68.9 $^{t-x}$	10898^{a-k}	57.98 $^{a-j}$	53.19^{a-h}	13.15 $^{b-k}$
G25	69.5 $^{m-r}$	117^{n-s}	47.5^{j-m}	86.11 $^{c-m}$	9.32 a-n	18.15^{n-u}	43.55 $^{i-o}$	59.7 $^{a-c}$	70.6 $^{j-w}$	11453^{a-i}	61.53 $^{a-h}$	53.57^{a-h}	13.45 $^{b-h}$
G26	71 $^{k-p}$	127.5^{b-f}	56.5^{a-c}	81.63 $^{j-r}$	9.55 a-j	18.25^{n-u}	51.95 $^{c-m}$	48.2 $^{i-s}$	71.2 $^{i-u}$	9642^{d-k}	51.75 $^{c-n}$	53.68^{a-h}	12.95 $^{c-n}$
G27	67.5^{qrs}	120 $^{l-P}$	52.5^{c-i}	87.15 $^{c-k}$	9.375 a-m	19.85^{c-n}	47.75 $^{c-o}$	56.9 $^{a-f}$	71 $^{j-v}$	8252^{jk}	43.36 $^{k-o}$	52.68^{a-h}	13.7 $^{a-f}$
G28	69.5^{m-r}	124.5^{b-j}	55^{a-e}	88.5 $^{b-j}$	9.1b-p	20.1^{b-n}	52.35 $^{c-m}$	49.4 $^{f-s}$	69.6 $^{q-x}$	10476^{a-k}	56.09 $^{a-l}$	53.56^{a-h}	13.1 $^{c-l}$
G29	68 $^{p-s}$	113.5^{s}	45.5^{m}	84.02 $^{f-p}$	8.67 g-r	19.55^{d-p}	41^{o}	59.7^{a-c}	69.9 $^{n-x}$	82428252^{jk}	41.26 $^{m-o}$	50.09^{b-j}	13.65 $^{a-g}$

G30	70.5^{k-q}	124^{c-k}	53.5^{b-g}	82.72^{g-r}	8.38^{l-r}	18.05^{n-u}	45.8^{f-o}	49.5^{f-s}	72.6^{d-q}	8763^{g-k}	49.29^{f-o}	56.29^{a-d}	12.8^{d-p}
G31	70.5^{k-q}	124^{c-k}	53.5^{b-g}	86.07^{c-m}	9.98^{a-c}	20.05^{b-n}	56.9^{a-c}	56.2^{a-h}	70.8^{j-w}	11844^{a-g}	68.11^{a}	57.42^{ab}	11.6^{o-w}
G32	76.5^{c-f}	127^{b-f}	50.5^{e-l}	77.35^{o-r}	8.43^{j-r}	16.85^{tu}	41.4^{no}	53.2^{c-n}	72.1^{e-s}	10470^{a-k}	58.53^{a-j}	55.9^{a-e}	11.55^{p-w}
G33	73^{g-l}	128^{b-e}	55^{a-e}	80.96^{j-r}	8.2^{o-r}	19.55^{d-p}	46.2^{ab}	51.4^{e-r}	72^{f-s}	9963^{c-k}	55.96^{a-l}	56.18^{a-d}	11.8^{l-v}
G34	73^{g-l}	126^{b-g}	53^{c-h}	88.15^{b-j}	10.2^{ab}	20.85^{a-i}	62.75^{ab}	49^{h-s}	70.1^{m-w}	11564^{a-i}	65.48^{a-d}	56.61^{a-d}	10.7^{u-w}
G35	66^{s-v}	113^{s}	47^{k-m}	89.81^{b-h}	9.77^{a-g}	21.15^{a-g}	46.6^{d-o}	56.3^{a-h}	69.2^{r-x}	11217^{a-k}	58.34^{a-j}	52.11^{a-i}	13.55^{b-g}
G36	69^{n-s}	118.5^{i-r}	49.5^{f-m}	86.92^{c-l}	8.92^{c-q}	19.35^{e-q}	46.7^{d-o}	45.7^{n-t}	70.3^{k-w}	12026^{a-f}	61.77^{a-h}	51.48^{a-j}	11.65^{n-w}
G37	76.5^{c-f}	125^{b-i}	48.5^{h-m}	90.17^{b-g}	9.68^{a-h}	18.5^{j-u}	43^{m-o}	50.2^{f-s}	72.7^{d-p}	10131^{b-k}	51.98^{c-n}	51.55^{a-j}	11.65^{n-w}
G38	76.5^{c-f}	129^{bc}	52.5^{c-i}	88.1^{b-j}	9.84^{a-f}	20.8^{a-i}	50.4^{c-o}	44.45^{q-t}	73.4^{c-k}	10800^{a-k}	52.17^{c-n}	48.32^{f-j}	11.35^{r-w}
G39	72.5^{h-m}	124^{c-k}	51.5^{d-k}	89.9^{b-h}	8.82^{d-q}	16.8^{tu}	54.35^{a-k}	46.3^{m-t}	70.3^{k-w}	11198^{a-k}	58.98^{a-j}	52.94^{a-h}	10.9^{s-w}
G40	76.5^{c-f}	129.5^{b}	53^{c-h}	99.17^{a}	9.64^{a-i}	18.15^{n-u}	44.6^{j-o}	56.6^{a-g}	74.3^{a-h}	12250^{a-e}	60.84^{a-i}	49.84^{d-j}	12.05^{i-t}
G41	78.5^{b-d}	129.5^{b}	51^{e-k}	91.66^{b-f}	9.73^{a-h}	20.6^{a-j}	50^{c-o}	45.4^{o-t}	74.8^{a-g}	11754^{a-g}	63.04^{a-g}	53.64^{a-h}	10.75^{t-w}
G42	76^{c-g}	128.5^{b-d}	52.5^{c-i}	92.41^{ab-d}	9.16^{b-p}	19.25^{e-q}	48.9^{c-o}	51.3^{e-r}	72.7^{d-p}	11471^{a-i}	60.87^{a-i}	53.13^{a-h}	10.5^{vw}
G43	77.5^{c-e}	129.5^{b}	52^{c-j}	87.47^{c-k}	9.425^{a-l}	21.65^{a-c}	55^{a-i}	48.6^{i-s}	73.4^{c-k}	10429^{a-k}	52.96^{c-n}	51.38^{a-j}	12.35^{g-r}
G44	77^{c-e}	129^{bc}	52^{c-j}	86.9^{c-l}	9.32^{a-n}	21.3^{a-f}	53.1^{b-m}	48.6^{i-s}	70.8^{j-w}	10591^{a-k}	58.24^{a-j}	55.07^{a-g}	11.3^{r-w}
G45	81^{b}	129.5^{b}	48.5^{h-m}	86.91^{c-l}	8.79^{e-q}	20.45^{a-l}	55.65^{a-h}	37.3^{u-x}	69.2^{r-x}	8413^{i-k}	37.63^{o}	44.74^{jk}	11.95^{i-u}
G46	81^{b}	129^{bc}	48^{i-m}	87.85^{b-j}	9.94^{a-d}	20.4^{a-m}	51.9^{c-m}	47.25^{k-t}	72.8^{d-p}	11408^{a-j}	61.57^{a-h}	53.95^{a-h}	10.8^{t-w}
G47	69^{n-s}	119^{k-r}	50^{f-m}	82.67^{g-r}	8.85^{d-q}	18.75^{i-t}	52.35^{c-m}	52.2^{d-p}	73.2^{c-m}	8992^{f-k}	50.76^{e-o}	56.42^{a-d}	13.05^{c-m}
G48	75.5^{d-h}	126.5^{b-f}	51^{e-k}	77.13^{p-s}	8.23^{n-r}	19.25^{e-q}	49^{c-o}	47^{k-t}	74.8^{a-g}	10458^{a-k}	58.75^{a-j}	56.35^{a-d}	11.8^{l-v}
G49	79^{bc}	129^{bc}	50^{f-m}	92.5^{bc}	10.4^{a}	19.9^{b-n}	48.1^{c-o}	47.15^{k-t}	73.6^{b-j}	10534^{a-k}	55.33^{a-m}	52.58^{a-h}	11.9^{j-u}
G50	76.5^{c-f}	126.5^{b-f}	50^{f-m}	84.5^{e-p}	9.01^{c-q}	18.45^{k-u}	49^{c-o}	51.7^{d-q}	66.95^{x}	8922^{f-k}	46.72^{i-o}	52.3^{a-i}	11.75^{m-v}
G51	72.5^{h-m}	119.5^{j-q}	47^{k-m}	80.97^{j-r}	8.99^{c-q}	20.55^{a-k}	55.1^{a-i}	53.5^{c-m}	69.2^{r-x}	11580^{a-i}	67.97^{ab}	58.73^{a}	10.8^{t-w}
G52	73^{g-l}	119^{k-r}	46^{lm}	86.99^{c-l}	8.63^{h-r}	18.35^{l-u}	45.35^{i-o}	49.7^{f-q}	70.7^{j-w}	10489^{a-k}	58.05^{a-j}	55.37^{a-f}	12.4^{f-r}
G53	74.5^{e-k}	125.5^{b-h}	51^{e-k}	87.1^{c-k}	8.68^{g-r}	18.2^{n-u}	43.45^{m-o}	51.8^{d-q}	71.8^{g-t}	10930^{a-k}	59.13^{a-j}	54.13^{a-h}	12.15^{h-s}
G54	71^{k-p}	120^{i-p}	49^{g-m}	70.52^{s}	8.1^{q-r}	19.75^{c-o}	45.7^{g-o}	47.8^{j-t}	76^{a-c}	10139^{b-k}	56.22^{a-l}	55.45^{a-f}	12.45^{f-r}
G55	71.5^{j-o}	128^{b-e}	56.5^{a-c}	88.12^{b-j}	8.64^{h-r}	19.45^{d-q}	50.25^{c-o}	40.5^{t-x}	76.8^{a}	13230^{ab}	49.97^{f-o}	39.74^{k}	13.95^{a-e}
G56	75^{d-h}	127.5^{b-f}	52.5^{c-i}	81.22^{j-r}	7.62^{r}	19.1^{g-r}	49.65^{c-o}	44^{r-u}	71.8^{g-t}	9796^{c-k}	51.8^{c-n}	52.82^{a-h}	11.85^{k-u}
G57	72^{i-n}	123.5^{c-l}	51.5^{d-k}	78.1^{n-r}	9.12^{b-p}	20.9^{a-h}	56.65^{a-d}	49.2^{g-s}	75.6^{a-d}	10119^{b-k}	53.69^{c-m}	52.9^{a-h}	12.05^{i-t}
G58	74.5^{e-j}	128^{b-e}	53.5^{b-g}	82.95^{g-r}	9.06^{c-q}	19.15^{g-r}	55.65^{a-h}	49.6^{f-s}	71.4^{h-u}	9784^{c-k}	53.84^{b-m}	55.01^{a-g}	11.4^{q-w}
G59	71^{k-p}	120^{i-p}	49^{g-m}	87.72^{c-j}	9.28^{a-o}	22.15^{a}	57.05^{a-c}	46.6^{l-t}	74.4^{a-h}	11580^{a-i}	62.13^{a-h}	53.74^{a-h}	12.9^{d-o}
G60	74.5^{e-j}	128.5^{b-d}	54^{a-f}	78.87^{m-r}	9.17^{b-p}	21.35^{a-e}	63.45^{a}	34.65^{x}	73.4^{c-l}	9966^{c-k}	52.33^{c-n}	52.51^{a-h}	12.8^{d-p}
G61	73.5^{f-k}	125.5^{b-h}	52^{c-j}	79.9^{k-r}	8.9^{c-q}	19.95^{b-n}	53.85^{a-k}	43.9^{r-v}	70.4^{k-w}	9732^{c-k}	54.32^{a-m}	55.82^{a-e}	11.45^{q-w}

G62	76.5 $^{c-f}$	128.5 $^{b-d}$	52^{c-j}	86.3 $^{c-m}$	9.27 $^{a-o}$	21.5^{a-d}	56.55 $^{a-e}$	44.9 $^{p-s}$	75.6 $^{a-d}$	11625^{a-h}	60.75 $^{a-i}$	52.26^{a-i}	10.85 $^{s-w}$
G63	89 ^{a}	136 ^{a}	47^{k-m}	92.62 ^{bc}	9.83 $^{a-f}$	19.6^{c-p}	50.9 $^{c-o}$	42.7 $^{s-w}$	69.8 $^{p-x}$	11032^{a-k}	52.33 $^{c-n}$	47.44^{h-j}	10.4 ^{w}
G64	69.5 $^{m-r}$	128 $^{b-e}$	58.5^{a}	82.47 $^{h-r}$	9.46 $^{a-l}$	21.95^{ab}	54.15 $^{a-k}$	51.1 $^{e-r}$	68 $^{v-x}$	13548^{a}	60.99 $^{a-h}$	45.1^{i-k}	13.05 $^{c-m}$
Min	7	113	64	44	70.52	41	16.65	7.6	34.65	7293.67	31.85	0.104	3763
max	8	136	89	58.5	99.17	68.5	22.15	10.4	62	13230	59.63	0.149	6811
GM	7.34	123.58	72.31	51.27	85.23	49.9	19.26	9.05	50.44	10582.7	52.7	12.34	5561
SEM	0.26	1.47	0.96	1.39	2.23	2.87	0.6	0.32	2.14	896.7	2.1	0.38	4.03
CV%	2.7	1.3	2.5	1.2	1.8	4.7	2.9	2.8	4.2	6.2	10.9	5.2	1.08
LSD (5%)	0.73	2.69	3.92	4.16	6.29	8.12	1.69	0.89	6.05	1137	2534.3	5.92	1.08