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Genotype by Environmental Interaction on Grain Quality of Bread Wheat (*Triticum aestivum* L.) Genotypes at Southern Ethiopia

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Abstract: Information on the nature and magnitude of the genotype by environment interaction that affects performance of genotypes is essential to enhance the quality improvement of wheat. This study was conducted at five locations in southern Ethiopia using 4 replications of randomized complete block design to evaluate the nature and magnitude of genotype by environment interaction and its effect on grain quality of bread wheat genotypes. The objective of this study was to determine genotype x environment interaction (GEI) in wheat production in southern Ethiopia for some grain quality traits (grain protein content (GPC), grain gluten content (GLTN), grain zeleny index (LI), TKW and HLW). In this study twenty genotypes at five locations were conducted. Combined analysis of variance showed highly significant differences ($P < 0.001$) among environments, genotypes and their interactions in all quality traits included in this study. The significant GEI indicated that performance of the genotypes in quality traits was not consistent over environments; some genotypes performed well at some locations but poorly at other locations. The GEI (40.20%), the genotype (29.89%) and the environment (14.55%) made contribution to total treatment SS of HLW in which major variation is due to genotype x environment interaction for this trait. For GPC, GEI, environment and genotype made a contribution of 34.61%, 17.32% and 13.59% of variation respectively. For ZI, environment (51.10%), GEI (18.84%) and genotype (11.24%) contribution was observed. For this quality trait, high variation is made by environment. For GLTN, environment (33.31%), GEI (28.14%) and genotype (14.10%) contribution was made. In this quality trait, high variation is contributed due to environment as well and less contribution is made due to genotypes. Unsimilar proportional contribution from G, E and GEI was observed in TKW which was 40.32%, 26.35% and 12.72% for GEI, G and E respectively. Almost similar protein content was recorded at all tested locations numerically with the lowest (12.64%) at Bore and highest (13.81%) at A/Sorra. The highest TKW (60.33) from genotype Hidase, Zeleny Index (69.36ml) from Wane, grain protein content (14.38%) and gluten content (33.24%) from ETBW8407, and HLW (83.55) from Shorima was obtained. The lowest TKW (46.34) from old variety Kubsa, Zeleny Index (56.99ml) from Alidoro, grain protein conten (12.34%) from PBW-34, gluten content (27.00%) from PBW-34 again and the lowest HLW (74.83) from Kubsa was obtained. The variations observed to these quality traits among genotype across location, is due to year-to-year variation in factors such as rainfall, temperature and disease of the growing season.

Keywords: Bread Wheat, Environment, Grain Quality, GEI, Guji Zone

1. Introduction

Grain quality is defined by a range of physical and chemical composition properties where threshold requirements are set according to end-use requirements. For staple grains such as wheat, whole grain physical properties such as size and shape influence milling yield and screening losses, which determine the processing efficiency and value of the grain. Whole-grain quality encompasses the physical characteristics which are influenced by both genotype and environment.

The quality of wheat grain depends on several characteristics, among which grain hardness, protein content and composition of high molecular weight gluten in subunits are the most important [14]. Test weight is one of the simplest criteria used to determine quality of grain and measure of grain bulk density. Test weight of wheat is considered the most common and easiest way to quantify wheat. It is an indicator of general grain quality and primary grain specification, normally the higher the test weight the higher the quality, and the lower the test weight the lower the quality, and grain quality decreases dramatically as grain deteriorates [2]. Genotype, environment and their interaction play an important role in the final expression of grain yield and quality attributes [9].

The protein is a primary quality component of cereal grains. The protein concentration is influenced by both environmental and genotypic factors that are difficult to separate. The protein content of wheat grains can vary from 6% up to as much as 25%, depending upon the growing conditions noted that protein content varied more widely among locations than among varieties at the growing location [4]. Differences among cultivars tended to be greatest under optimum growth conditions [16]. Protein content and protein quality have been also shown to be significant for baking quality. The protein content is positively correlated with gluten content [6], which is strongly influenced by the growing environment [8].

Protein content and gluten content were greatly influenced by environment, although they were also significantly influenced by genotype and GEI [13]. Similarly, many other studies demonstrated that environmental conditions have a larger effect on protein content than the genotype [14, 15]. It appears that GEI effects, although were higher than the effects of genotype and environment, for all of the traits, but lower than environment for zeleny index. Similar finding was reported by [10].

The identification and examination of key genetic and environmental components that affect quality and GEI have proven successful in breeding and cultivating good-quality crop cultivars [10]. Environmental variables have important effects on wheat grain protein accumulation and processing quality, although wheat quality is a genotype-dependent trait.

In general, moderately high temperature, proper soil moisture (resulting from rainfall and irrigation), and sufficient solar radiation may improve wheat quality [10]. Some ecological factors, including soil physiological and chemical properties and geographic latitude, can also affect wheat quality. Wheat quality may be improved by breeding elite varieties, improving crop/farming management practices and exploiting the synergism between genotype and the environment. Wheat quality is directly affected by diverse environmental factors [10].

2. Materials and Methods

Twenty genotypes (15 released and 5 advanced lines) of bread wheat genotype were evaluated across five locations in 2018 / 2019 main cropping seasons. Description of test locations and wheat genotype is provided in Table 1 and Table 2, respectively.

The field experiment was laid out in RCBD with three replications. The experimental field plot was 6 rows of 2.5 m long with a 0.2 m inter-row spacing. Each plot was planted at a rate of 125 kg ha^{-1}. The fertilizer application and other crop management practices were done as per recommendations of each test locations.

2.1. Data Collection

Data was collected from the following traits; grain protein content, grain gluten content, zeleny index, HLW and TKW.

2.2. Stastical Analysis

The grain quality traits data for twenty bread wheat in five environments were used to combine analysis of variance (ANOVA) using GenStat software 17th edition to determine the effects of environment, genotype and GEI. Before combine the data Bartlett's test was used to determine the homogeneity of variances between environments to determine the validity of the combined ANOVA on the data and the data collected was homogenous.

2.3. Quality Assessment

Grain protein content, gluten content and zeleny index was determined by using MININFRA SmarT Infracont Grain Analyzer. While HLW was determined using the approved method of the American Association of Cereal Chemists 55-10 [1].

Table 1. *Description of the locations used.*

Location	Altitude (masl)	Lat/long.	Average annual rainfall (ml)	Average Annual T (oC)	Soil type
Bore	2775	5°57'N/38°25'E	>1227	15	Nitosols
A/Sorra	2675	5°52'N/38°29'E	1000	20	OrthicAcrosol
Adola	1754	5°44'N/38°45'E	665	25	Chromic, orthic
Liben	1575	5°20'N39°35'E	655	25	Nitosols
L/Farm	2450	33°299N37°E	702.2	13.5	Silty Clay & Sandy Loam

Table 2. *Lists of bread wheat genotypes included in the study.*

SN	Genotype	Pedigree	Year of release
1	Lemu	WAXWING*2/HEILO	2016
2	Wane	SOKOLL/EXCALIBUR	2016

SN	Genotype	Pedigree	Year of release
3	Hawi	CHIL/PRL	2000
4	Shorima	UTQUE96/3/PYN/BAU//MILAN	2011
5	Honqolo		2014
6	Dashen	VEE #17, KVZ/BUHO"S"//KAL/BB	1984
7	Hidase	YANAC/3/PRL/SARA//TSI/VEE#5/4/CROC-1/AE.SQUAROSA(224)//OPATTA	2012
8	Tuse	COOK/VEE"S"//DOVE"S"/SERI	2004
9	Danda'a	KIRITATI//2*PBW65/2*SERI.1B	2010
10	Kakaba	KIRITATI//SERI/RAYON	2010
11	Kubsa	ATTILA	1994
12	Alidoro	HK-14-R251	2007
13	Galama	4777(2)//FKN/GB/3/PVN"S"	1995
14	Digalu	SHA7/KAUZ	2005
15	Ogolcho	WORRAKATTA/2*PASTOR	2012
16	ETBW8407		Advaced breeding line
17	ETBW8415		Advaced breeding line
18	ETBW8420		Advaced breeding line
19	ETBW8369		Advaced breeding line
20	PBW-343		Advaced breeding line

3. Result and Discussion

According to the result of combined analysis of variance (table 3) for genotype, environment and GEI were very highly significant differences for all quality traits included in this study.

Table 3. *ANOVA for grain quality of 20 bread wheat genotypes over five locations.*

Traits	Source of variation					Means	CV%
	Env't (4)	Rep (evn't) (10)	Genotype (19)	GEI (76)	Error (198)		
HLW	163.741***	3.133	70.821***	23.813**	3.460	80.35	2.3
TKW	522.89***	15.10	228.13***	87.25**	16.97	52.12	6.17
GPC	22.8239***	0.0985	3.7706***	2.4003***	0.9168	13.347	7.2
ZI	3225.07***	46.87	149.31***	62.56***	23.53	64.67	7.5
GLTN	392.22***	10.569	34.946***	17.437***	5.707	30.26	7.9
GY	118.04***	0.73	8.04***	1.56***	0.26	2.52	21.1

*** Highly significant at (P < 0.00)

Where HLW=hectoliter weight, TKW=thousand kernel weight, GPC=protein content, GLTN= grain gluten content, GY = grain yield (ton^{-ha}) and CV=coefficient of variations.

This indicated that quality traits of bread wheat were highly influenced by environmental factors. This significance of environment on quality traits of wheat is in agreement with results of previous investigations Alemu G. *et al* [7], Drezner *et al*. [5] and Williams *et al*. [17] who reported that environment had significant effect on grain quality of bread wheat genotypes. The greater significance of environmental variation for protein content in bread wheat, in this study, is in agreement with the results of Drezner *et al*. [5] and Bilgin *et al*. [3], who stated strong environmental impact on bread wheat protein content. Many other studies demonstrated that environmental conditions have a larger effect on protein content than the genotype [12, 15]. The greater significance of environmental variation for gluten content in bread, in this study, is in agreed with the results of [5, 3] stating that strong environmental impact on bread wheat grain gluten content and also in line with other finding of [11, 18] those reported that grain gluten content significantly depended on environment, cultivar and their interactions. In this result genotype as source of variation was least important than environmental and GEI variation except for TKW. Highly significant genotype x environment interaction was found for all quality traits studied. This would mean that evaluation of bread wheat genotype of several environments would give a more accurate estimate of their quality potential.

3.1. Mean Comparison of the Genotypes for Grain Quality

The differences among the genotype were important. The highest mean values of TKW was observed from genotype Hidase (#7), Zeleny Index from Wane (#2), grain protein content from ETBW8407 (#16), gluten content from ETBW8407 (#16), HLW from Shorima (#4). The lowest TKW was obtained from old variety Kubsa (#11), Zeleny Index from Alidoro (#12), grain protein conten from PBW-34 (#20), gluten content from PBW-34 (#20), HLW from Kubsa (#11) (Table 4).

Table 4. *Mean values of yield and quality traits of bread wheat genotypes tested at five locations.*

SN	Genotypes	GY	TKW	ZI	GPC	GLTN	HLW
1	Lemu	2.72	49.18	67.14	13.673	31.30	81.83
2	Wane	3.54	55.03	69.36	13.600	31.11	81.91
3	Hawi	1.75	52.61	66.97	13.653	31.00	79.33
4	Shorima	2.98	47.89	68.67	13.573	31.65	83.55
5	Honqollo	3.16	51.16	64.75	13.300	30.03	81.60
6	Dashen	2.53	46.62	62.11	13.280	28.89	79.05
7	Hidase	2.97	60.33	64.09	12.433	29.25	80.61
8	Tuse	2.99	49.97	67.10	12.980	30.33	83.25
9	Danda'a	2.42	53.39	64.41	13.587	30.65	77.64
10	Kakaba	1.77	53.37	64.62	13.367	29.37	78.04
11	Kubsa	1.22	46.34	59.63	13.200	27.59	74.83
12	Alidoro	2.73	59.45	56.99	13.727	31.76	79.36
13	Galama	1.12	49.68	65.69	13.873	31.43	78.64
14	Digalu	1.20	48.24	64.93	13.467	30.85	79.84
15	Ogolcho	3.10	48.85	63.11	12.867	29.53	81.16
16	ETBW8407	2.48	55.22	67.89	14.380	33.24	82.35
17	ETBW8415	2.63	50.45	63.05	12.773	28.50	81.40
18	ETBW8420	2.80	54.83	67.77	13.827	31.63	78.57
19	ETBW8369	2.86	55.12	64.39	13.033	30.13	82.00
20	PBW-34	3.49	51.767	60.63	12.340	27.00	82.12
	Means	2.52	52.12	64.67	13.347	30.26	80.35
	LSD%	0.09	3.02	7.810	1.5417	3.847	1.34

Where: GY = grain yield (ton^{-ha}), TKW = thousand kernel weight, ZI = zeleny index, HLW = hectoliter weight GPC = grain protein content, GLTN = gluten content, LSD = Least Significance differences.

3.2. Difference Between Environments for Grain Quality

When locations were compared, the highest hectoliter weight was obtained from Liben, while lowest from Bore. Liben and Adola had greater than over all mean of HLW and Bore, Anna Sorra and Lole Farm had low HLW less than over all mean. There was the difference in TKW between all five locations. Anna Sorra had high TKW when compared to other location followed by Bore and Adola had low TKW. The highest grain protein content recorded from Anna Sorra and Liben, and the lowest was from Bore and Lole Farm. The highest zeleny index is from Liben followed by Adola and the lowest was from bore. The highest gluten content was from Liben and the lowest from Bore (Table 5). These indicate that, the performance for quality traits varied across environments.

Table 5. *Mean values of quality traits of bread wheat at five locations.*

Traits	Locations							
	Bore	A/Sorra	Adola	Liben	L/Farm	Means	CV%	LSD%
HLW	75.25	78.36	81.47	82.89	80.03	80.35	2.3	1.34
TKW	54.68	55.48	49.06	49.51	51.14	51.98	7.9	3.02
GPC	12.64	13.81	13.77	13.8	12.71	13.35	7.2	1.54
ZI	55.88	64.14	71.47	72.56	59.28	64.67	7.5	7.81
GLTN	26.91	31.08	32.5	32.55	28.27	30.26	7.9	3.85

Where: HLW = hectoliter weight, TKW = thousand kernel weight, GPC = grain protein content, ZI = zeleny index, GLTN = gluten content.

4. Conclusions

Bread wheat genotypes are generally evaluated in multi-environment trials to test their performance across environments and to select the best genotypes for specific environments. GEI is a differential genotypic expression across environments or generally the inconsistency of relative performance of genotypes over environments. The large occurrence of GEI causes the relative ranking of genotypes to change from location to location and/or from year to year.

In the present study ANOVA revealed significant difference between the 20 genotypes in quality traits such as, hectoliter weigh, protein content, gluten content, zeleny index and TKW at all five environments.

Combined analysis of variance showed highly significant differences (P<0.001) among environments and among genotypes. The GxE interaction was also significant for all quality traits. The significant GxE interaction indicated that performance of the genotypes in quality traits was not consistent over environments; some genotypes performed well at some locations but poorly at other locations. The GEI (40.20%), the genotype (29.89%) and the environment (14.55%) made contribution to total treatment SS of HLW in which major variation is due to genotype x environment interaction for this trait. For GPC, GEI, environment and genotype made a contribution of 34.61%, 17.32% and 13.59% of variation respectively. For ZI, environment (51.10%), GEI

(18.84%) and genotype (11.24%) contribution was observed. For this quality trait, high variation is made by environment. For GLTN, environment (33.31%), GEI (28.14%) and genotype (14.10%) contribution was made. In this quality trait, high variation is contributed due to environment as well and less contribution is made due to genotypes. Unsimilar proportional contribution from G, E and GEI was observed in TKW which was 40.32%, 26.35% and 12.72% for GEI, G and E respectively. Almost similar protein content was recorded at all tested locations numerically with the lowest (12.64%) at Bore and highest (13.81%) at A/Sorra. The highest HLW (82.89) and the lowest (75.25) was obtained from Liben and Bore respectively. While highest ZI (72.56ml) at Liben and the lowest (55.88) at Bore. The highest GLTN (32.5%) at Liben and Adola and the lowest (26.91%) at Bore was obtained. The highest TKW (60.33) from genotype Hidase, Zeleny Index (69.36ml) from Wane, grain protein content (14.38%) and gluten content (33.24%) from ETBW8407, and HLW (83.55) from Shorima was obtained. The lowest TKW (46.34) from old variety Kubsa, Zeleny Index (56.99ml) from Alidoro, grain protein conten (12.34%) from PBW-34, gluten content (27.00%) from PBW-34 again and the lowest HLW (74.83) from Kubsa was obtained. The variations observed to these quality traits among genotype across location, is due to year-to-year variation in factors such as rainfall, temperature and disease of the growing season.

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