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Evaluation of bread Wheat (*Triticum aestivum* L.) Genotypes under Moisture Deficit Conditions

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ABSTRACT

Wheat is one of the most important cereal crop grown in the highland areas of Wollo. The grain yield remains extremmly low as compared to other wheat grower countries due to different production constraints like the use of low yielder varieties across different agro-ecologies of the country. The objective of the study was to identify stable and high yielding, early maturing bread wheat genotypes for moisture stress conditions. Sixteen bread wheat genotypes including the standard and local checks were evaluated using Randomized Complete Block Design at Geregera, Kon, Dihana and Lalibela during 2010 and 2011 main cropping seasons. The genotypes were evaluated using different yield related traits like days to heading and maturity, plant height, biomass yield, grain yield and 1000 kernels weight. Data were analyzed using additive main effects and a multiplicative interaction and genotype by environment interactions biplot stability measuring techniques, grain yield stability performances of genotypes. The results revealed that "Vorobeycmss96y02555-040Y-020m" genotype was the best among the tested genotypes on its earliness, gave high yield (3341 Kg ha^{-1}). The selected genotype (Vorobeycmss96y02555-040Y-020m) showed yield advantage of 18.4% and 36.6% over recently released variety and farmers' variety, respectively. This variety was highly adaptable to moisture deficit areas and resistant to yellow rust. In conclusion, this variety was suitable for moisture deficit wheat growing areas and recommended in the tested districts and similar agro ecological zones of the region in particular and in the country in general.

Keywords: Additive main effects and a multiplicative interaction, Bread wheat, Genotype by environment interactions biplot, Grain yield, Moisture deficit.

INTRODUCTION

Bread wheat (*Triticum aestivum L.*) is one of the major cereal crops grown in the middle and high lands of Ethiopia (Solomon et al., 1995). It grows in Ethiopia, in the altitude range of 1500 to 3000 m.a.s.l (Bekele et al., 2000), however, the most suitable agro-ecological zones for wheat production fall between 1900 and 2700 m.a.s.l (Hailu, 1991). Ethiopia is the major producer of wheat in Sub-Saharan Africa which ranks first in crop area coverage as well as production (Food and Agriculture Organization, 2016). In terms of grain crop area wheat ranked fourth after teff, maize, and sorghum and in terms of production ranked fourth after maize, teff and sorghum. About 1.6 million ha of land was covered by wheat, from which about 4.22 million tons wheat grain was produced (Central Statistical Agency, 2016).

Wheat is one of the most important food grain crops in Amhara region. people used the grain for food utilization in different forms like bread, porridge, soup and roasted grain ("Kolo"), enjira, dabokolo, nifro, tella, arki. In addition to this, farmers used wheat grain for marketing (selling purpose) to generate income and cover other required costs. Its straw also important for animals feed, thatching house roof and bedding. The popularity of wheat comes from the variability of its use in production of variable food products (Pena, 2002). It has different important nutritive value such as protein (>10%), lipid (2.4%), and carbohydrate (79%); thus, it accounts about 20% of the calorie intake of human diet (Khanna, 1991; Gooding & Davies, 1997).

Amhara region shares 32.8% (545,106.1 ha.) and 28.96 % (1.22 million tons) of the total wheat growing area and production of the country, respectively (Central Statistical Agency, 2016). Thus, the region has 2.24 tons production of wheat per unit area which is lower than the national average. Of the total wheat area coverage in the region, 27.13% was found in eastern Amhara region: South Wollo, North Wollo, and Waghimra Administrative Zones (Central Statistical Agency,

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2016**)** while its productivity is low (1.87 ton ha^{-1}). Some of the possible reasons for low yielding of wheat are using of low yielding bread wheat varieties, moisture stress, and wheat rust disease (Arega & Setu, 2014). In recent times, in 2010, yellow rust epidemics were reported in the Central and West Asia and North Africa region which causing yield losses of up to 80% (Solh et al., 2012). Stem rust epidemics can cause up to 100% yield loss on Digalu variety as witnessed recently in the Bale region of Ethiopia (Olivera et al., 2015). Yellow rust can cause 60 to 100% yield losses especially when the spikes are infected with the pathogen at higher altitudes (Ayele et al., 2008).

By conducting various breeding research, different bread wheat varieties were developed to alleviate the wheat production constraints, in Ethiopia as well as in eastern Amhara region, however, genotypes growing in different environments shows variable in grain yield performances; this may be due to the effects of genotype by environment interaction. According to Ceccarelli (1989), GEI must be either exploited by selecting best genotypes for each specific environment or avoided by selecting widely adapted and stable varieties for wide range of environments. Therefore, this experiment was conducted to select; high yielding and stable, disease resistance and early maturing bread wheat varieties for moisture stress areas of eastern Amhara region.

MATERIALS AND METHODS

Experimental design:

Sixteen bread wheat genotypes including the the released variety as standard **"Dinknesh"** and farmers' varietities were evaluated in four wheat growing districts (Geregera, Kon, Dihana and Lalibela) of eastern Amhara region in 2010 and 2011 main cropping seasons. The improved variety 'Dinknesh' which released by Sirinka Agricultural Research Center for eastern Amhara region, was used as a standard check. A total of eight enviroments (four locations and two seasons) were used. The individual location in each year considered as separate environment. The testing locations represent high land moisture stress area of north-eastern part of Ethiopia and their climatic and soil characteristics showed in Table 1. Rainfall distribution was generally erratic and uneven. It often started late (first to mid-week of July) and terminate earlier (first week of September). Usually large amount of annual rainfall was received in July and August while in the rest months the availability of rainfall was scanty. Sowing date ranged from first to mid week of July for both cropping seasons depending on the on set of rainfall and effective soil mositure of testing locations.

Table 1. Altitude, rainfall and soil types of experimental locations

Location	Mean annual rainfall (mm)	Altitude (masl)	Soil Texture	Soil colour	p^H
Geregera	1104	2650	Lithosol	Brown	6.0
Kon	1054	2800	Lithosol	Red	6.5
Lalibela	940	2400	Lithosol	-	-
Dahana		2400	Lithosol	-	-

Sources: Yosef et al. (2006); Kehaliew et al. (2014)

The experiment was laid-out in Randomized Complete Block Design with three replications. The materials were planted in 1.2 m by 2.5 m plot size using 20 cm spacing between rows. Blanket recommendation fertilizer rates of 41/46 kg ha^{-1} N/ P_2O_5 were used for all locations and cropping seasons. Two to three times weeding practices were done depending on the frequency and density of weed in each environment. The genotypes were evaluated for days to heading and maturity, plant height, biomass yield, grain yield, 1000 kernels weight and yellow rust. The field data were taken from the central four rows, excluding the two most border rows. In each plot five tagged plants were used for disease recording and the diseases were recorded when emergency of ear completed. The top most leaves were used for recording yellow rust disease. The response of tested bread wheat genotypes for yellow rust were recorded using Modified Cobb's scale (Peterson et al., 1948); reported as no visible infection on plants (0), resistant (R), moderately resistant (MR), moderately susceptible (MS), and Susceptible (S). Post harvesting data (grain yield and 1000 kernels weight) were taken at laboratory.Thousand kernels were counted randomly from each experimental plot. Grain yield and thousand kernels weight were measured using analytical balance, and then the results were adjusted to the standard moisture contents of cereal crops (12.5%) using the following formula. Adjusted X = Actual X measure × [(100%-Actual moisture content %) / (100%-Standard moisture content %)], where, X is either grain yield or thosand kernels weight.

Statistical analysis:

The analysis of variance for each location and combined analysis of variance over locations and years were performed using "Genstat 18^{th} statistical software. Bartlett's chi-square test was performed to determine the validity of the combined analysis of variance and homogeneity of error variance between environments for each measured traits (Steel & Torrie, 1980). All traits have homogeneous error variances. Then, data for days to heading and maturity, 1000 kernels weight, plant height, biomass and grain yield were pooled to perform the analysis of variances across locations and locations by years. To examine the presence and magnitude of genotypic stability across environments, the two multivariate analysis methods: Additive Main effect and Multiplicative Interaction (AMMI) model and Genotype plus Genotype by Environment interactions (GGE) biplot for grain yield were applied using Genstat 18th edition software.

RESULTS

The combined analyses of variance over locations in 2010 cropping season showed that except for biomass yield, there were highly significant differences (P<0.01) among genotypes in days to heading and maturity, plant height and 1000 kernels weight (Table 2). There was also significant difference among genotypes for grain yield (P<0.05). Among the tested bread wheat genotypes, Parus/pastorcmss96y….38m and Skoll-cmss97moo3165-0p10m-0p10m1 headed delayed (75 days) as compared with the rest genotypes while genotype Vorobeycmss96y02555-040Y-020m headed earlier (67 days). Genotype Uress/jun//kau2/3/babaxcmss97moo3395 and farmers' variety were scored the lowest number of days for physiological maturity (122 days); considered as early maturing genotypes. Maximum plant height was recorded from farmers' variety (98 cm) and PASTOR/SITE/MO/3/chen/ (91cm). Genotype Vorobeycmss96y02555-040Y-020m and Skoll-cmss97moo3165-0p10m-0p10m1 showed maximum 1000 kernels weight (42 g) followed by genotype Berkut cmss96M05638-040Y-5M (41 g). Significantly high mean grain yields were recorded in Parus/pastorcmss96y…48m (3208 kg/ha), Vorobey cmss96y02555-040Y-020m (3170 kg/ha), Rubei/PRINIACMSS96Y026825040Y(3125kg/ha) andUress/jun//kauz/3/babaxcmss97moo3395 (3095kg/ha) (Table 2). Location by genotype interaction revealed that there were significant difference (P<0.05) for days to heading and maturity and non-significant difference for biomass, grain yield, plant height and 1000 kernels weight. This indicated that, different genotypes had different performances across different locations in days to heading and maturity but showed consistent performance in the other yield and yield related traits. In 2011 cropping season, the combined analyses of variance over location showed significantly high difference (P<0.01) among genotypes for all parameters except biomass yield (Table 3).

Table 2. Mean grain yield and other important agronomic traits of 16 bread wheat genotypes tested at four locations in 2010 cropping season

Genotype pedigree	DH	DM	PH	GY	BMY	TKW
PASTOR/SITE/MO/3/chen/	73^{ef}	125^{cd}	92^{a}	2659^{ab}	7688	35^{f}
Munia/chto/3/pfau/bow/……………..	72^{d}	127^{de}	73^{g}	2595^{ab}	7667	36^{f}
Berkut cmss96M05638-040Y-26M……..	74^{fg}	128^{ef}	77^{ef}	2689^{ab}	6722	39^{bc}
Berkut cmss96M05638-040Y-5M…….	74^{fg}	127^{de}	78^{de}	2918^{ab}	8146	41^{ab}
Vorobeycmss96y02555-040Y-020m……	67^{a}	124^{bc}	84^{bc}	3170^{a}	8854	42^{a}
Parus/pastorcmss96y…..48m	72^{d}	127^{de}	84^{bc}	3208^{a}	8438	37^{de}
Parus/pastorcmss96y…..46m	71^{d}	126^{cd}	81^{bc}	2843^{ab}	8052	36^{f}
Parus/pastorcmss96y…..38m	75^{g}	130^{f}	83^{bc}	2687^{ab}	7812	38^{cd}
Rubei/PRINIACMSS96Y026825-040Y……	70^{c}	123^{ab}	75^{fg}	3125^{a}	8167	35^{fg}
Uress/jun//kauz/3/babaxcmss97moo3395…	68^{ab}	122^{a}	84^{bc}	3095^{a}	8444	36^{ef}
Srma/tui/ babaxcmss97moo3905…..	74^{fg}	130^{f}	86^{b}	2844^{ab}	7875	38^{cd}
Croc-1/aesquarrosa….	69^{bc}	125^{cd}	85^{bc}	2619^{ab}	7198	38^{cd}
Mtrwa92-155….	69^{bc}	127^{de}	80^{cd}	2248^{c}	6296	33^{cd}
Skoll-cmss97moo3165-0p10m-0p10m1…	75^{g}	127^{de}	82^{bc}	2378^{ab}	7542	42^{a}
Dinknesh	68^{ab}	123^{ab}	79^{cd}	2440^{ab}	6896	38^{cd}
Farmers' variety	72^{d}	122^{a}	98^{a}	2313^{c}	7896	39^{bc}
Mean	71	126	83	2740	7731	38
Genotype(G)	***	***	***	*	NS	***
Location * G (5%)	***	***	NS	NS	NS	NS
CV (%)	2.3	1.8	8	28.9	26.2	5.8

*Significant at 5% probability level, ***Significant at 0.1% probability level, NS = Non significant, DH=days to heading, DM=days to maturity, PH=plant height (cm), GY=grain yield (Kg ha^{-1}), BMY=biomass yield (Kg ha^{-1}), TKW=thousand kernels weight (g), CV = coefficient of variation, values with same letters in a column are not significantly different most desired parameter, grain yield

The minimum number of days for heading (67 days) was recorded in Dinknesh (released variety) but the maximum (75 to 76 days) was recorded from genotype parus/pastorcmss96y……38m, Berkutcmss96M05638-040Y-5M, Srma/tui/babaxcmss97moo3905 and Skoll-

Table 3. Mean grain yield and other important agronomic traits of 16 bread wheat genotypes tested at four locations in 2011 cropping season.

Genotype	DH	DM	PH	GY	BM	TKW
PASTOR/SITE/MO/3/chen/	74^{fg}	130^{ab}	99^{b}	3392^{ab}	10333	34.8^{gh}
Munia/chto/3/pfau/bow/……………..	72de	132^{cd}	79^{g}	3017^{bc}	9313	35.7^{ef}
Berkut cmss96M05638-040Y-26M……..	74^{gh}	135^{fg}	84^{ef}	2865^{cd}	8875	37.8^{cd}
Berkut cmss96M05638-040Y-5M…….	75^{h}	132^{cd}	84^{ef}	3081^{bc}	9417	38.3^{cd}
Vorobeycmss96y02555-040Y-020m……	70^{c}	129^{ab}	90^{cd}	3513^{a}	10125	42.0^{a}
Parus/pastorcmss96y…..48m	73de	133de	87^{cd}	2933^{cd}	9667	37.1^{cd}
Parus/pastorcmss96y…..46m	73^{ef}	133de	89^{cd}	2884^{cd}	10542	35.3^{fg}
Parus/pastorcmss96y…..38m	76^{h}	135^{ef}	87^{cd}	3488^{a}	10667	38.0^{cd}
Rubei/PRINIACMSS96Y026825-040Y……	72^{d}	129^{ab}	82^{fg}	3020^{bc}	9542	33.2^{h}
Uress/jun//kauz/3/babaxcmss97moo3395…	68^{b}	128^{a}	86de	3091^{bc}	8875	36.5^{de}
Srma/tui/ babaxcmss97moo3905…..	75^{h}	137^{g}	92^{c}	3359^{ab}	9958	38.5^{cd}
Croc-1/aesquarrosa….	70^{c}	130^{ab}	90^{cd}	3100^{bc}	9917	38.5^{cd}
Mtrwa92-155….	69^{bc}	129^{ab}	88^{cd}	3010^{bc}	9250	33.0^{h}
Skoll-cmss97moo3165-0p10m-0p10m1…	75^{h}	131^{bc}	88^{cd}	2691de	9625	42.0^{a}
Dinknesh	67^{a}	128^{a}	91^{cd}	3203^{ab}	10042	39.5^{bc}
Farmers' variety	73^{ef}	128^{a}	104^{a}	2579^{e}	9625	37.7^{cd}
Mean	72	131	89	3077	9736	37.3
Genotype (G)	***	***	***	***	NS	***
Location *G (5%)	***	***	**	***	NS	NS
CV (%)	1.9	2	6	13.3	15.7	7.2

**Significant at 1% probability level, ***Significant at 0.1% probability level NS=Non significant. DH=days to heading, DM=days to maturity, PH=plant height, GY=grain yield (Kg ha^{-1}), BMY =biomass yield (Kg ha^{-1}), TKW=thousand kernels weight (g), CV = coefficient of variation, values with same letters in a column are not significantly different

Table 4. Mean grain yield and other important agronomic traits of 16 bread wheat genotypes tested at four locations over two years (2010 and 2011)

Genotype (pedigree)	DH	DM	PH	GY	BMY	TKW
PASTOR/SITE/MO/3/chen/	73^{f}	128^{cd}	96^{b}	3026^{ab}	9010	35^{ef}
Munia/chto/3/pfau/bow/……………..	72^{e}	129de	76^{g}	2806^{bc}	8490	37de
Berkut cmss96M05638-040Y-26M……..	74^{g}	131^{hi}	81^{ef}	2777^{bc}	7798	38^{bc}
Berkut cmss96M05638-040Y-5M…….	74^{g}	129^{ef}	81^{ef}	3000^{ab}	8781	39^{b}
Vorobeycmss96y02555-040Y-020m……	68^{a}	127^{bc}	87^{cd}	3341^{a}	9490	42^{a}
Parus/pastorcmss96y…..48m	72^{e}	130^{gh}	86^{d}	3070^{ab}	9052	37^{cd}
Parus/pastorcmss96y…..46m	72^{e}	130^{fg}	85^{d}	2864^{bc}	9297	36de
Parus/pastorcmss96y…..38m	75^{g}	132^{ij}	85^{d}	3088^{ab}	9240	38^{bc}
Rubei/PRINIACMSS96Y026825-040Y……	71^{d}	126^{ab}	78^{fg}	3072^{ab}	8854	34^{fg}
Uress/jun//kauz/3/babaxcmss97moo3395…	68^{a}	125^{a}	85^{d}	3093^{ab}	8660	36de
Srma/tui/ babaxcmss97moo3905…..	75^{g}	133^{j}	89^{c}	3102^{ab}	8917	38^{bc}
Croc-1/aesquarrosa….	69^{c}	128^{cd}	87^{cd}	2859^{bc}	8557	38^{bc}
Mtrwa92-155….	69^{bc}	128^{cd}	84de	2629^{cd}	7773	33^{g}
Skoll-cmss97moo3165-0p10m-0p10m1…	75^{g}	129de	85^{d}	1534^{d}	8583	42^{a}
Dinknesh	68^{a}	125^{a}	85^{d}	2822^{bc}	8469	39^{b}
Farmers' variety	73^{ef}	125^{a}	101^{a}	2446^{cd}	8760	38^{bc}
Grand mean	72	128	86	2908	8733	38
CV%	2.1	2	7	21.9	20.7	6.6

DH = days to heading, DM = days to maturity, PH = plant height (cm), GY = grain yield (Kg ha^{-1}), BMY = biomass yield (Kg ha^{-1}), TKW = thousand kernels weight (g), CV= coefficient of variation, values with same letters in a columun are not significantly different cmss97moo3165-0p10m-0p10m1. Among the tested bread wheat genotypes Uress/jun//kauz/3/babaxcmss97moo3395…, biomass yield and 1000 kernels weight, i.e. genotypes were performed differently in different

Table 5. Additive main effects and multiplicative interaction (AMMI) ANOVA for grain yield (Kg ha^{-1}) of bread wheat genotypes over eight environments

Source of variations	DF	SS	MS	Sum of square explained (%)		
				Total variation explained	GxE explained	GxE comulative
Replications/E	16	42640716	2665045***			
Treatments	127	363673145	2863568***			
Genotypes (G)	15	20100179	1340012***	5.5		
Environments (E)	7	273385693	39055099***	75.2		
GEI	105	70187272	668450***	19.3		
IPCA-1	21	32951818	1569134***		46.9	46.9
IPCA-2	19	20393013	1073316***		29.06	75.96
Residuals	65	16842441	259114^{ns}			
Error	240	61501324	256256			

*** Significant at 0.1% probability level, DF = dgree of freedom, SS = sum square, MS = mean square

farmers' variety, Dinknesh, Vorobeycmss96y02555040Y20m, Rubei/PRINIACMSS96Y026825-040Y, Mtrwa92-155…., and Croc-1/aesquarrosa….were recorded the minimum number of maturity days (128 to 130 days) which were considered as early maturing suitable for moisture stress areas. Genotype Srma/tui/babaxcmss97moo3905 was recorded the maximum number of days for physiological maturity (137days). Genotype Vorobeycmss96y02555040Y20m and Skoll-cmss97moo3165-0p10m-0p10m1… were recorded the maximum 1000 kernels weight (42g) as compared with the rest genotypes. Maximum (104 cm) and minimum (79 cm) plant heights were location for the most desired trait, grain yield.

The combined analyses of variances (ANOVA) over eight environments (four locations by two cropping seasons) revealed that there were highly significant difference (P<0.05) among bread wheat genotypes for all measured traits except for biomass yield (Table 9). As the result depicted in Table 4; Vorobey cmss96y02555-040Y 20m, Uress/jun//kauz/3/babaxcmss97moo3395 and standard check Dinknesh were headed earlier (68 days) than the rest bread wheat genotypes. Maximum numbers of days for heading (ranging from 74 to 75 days) were recorded from genotypes Berkutcmss96M05638-040Y-26M, Berkutcmss96M05638-040Y-5M,

Table 6. First four bread wheat genotypes AMMI selections per environment

Environments	Mean grain yield (kg ha^{-1})	IPCA-1 scores	Rank			
			1	2	3	4
Dahina10	2280	15.3	G6	G9	G10	G5
Dahina11	3061	-13.7	G1	G15	G11	G2
Geregera10	2095	1.9	G5	G11	G6	G9
Geregera11	2558	2.5	G5	G11	G9	G10
Kon10	4411	-32.4	G5	G12	G4	G8
Kon11	4154	-16.9	G5	G6	G4	G11
Lalibela10	2172	39.2	G9	G16	G11	G3
Lalibela11	2534	4.1	G9	G5	G8	G10

recorded from farmers' variety and genotype Munia/chto/3/pfau/bow/……………, respectively. GenotypeVorobeycmss96y02555040Y20m, Parus/pastorcmss96y…..38m,andPASTOR/SITE/ MO/3/chen/ were identified as high yielder with mean grain yield of 3513 kg ha^{-1}, 3488 kg ha^{-1} and 3392 kg ha-1, respectively. In this season, location by genotype interaction showed that there were significant differences for all parameters except Parus/pastorcmss96y…..38m,Srma/tui/babaxcmss97moo3905 and Skoll-cmss97moo3165-0p10m-0p10m1. Among the tested bread wheat genotypes; Uress/jun//kauz/3/babaxcmss97moo3395,"Dinknesh", Farmers' variety were the earliest maturing genotypes which needed 125 days for its physiological maturity, while, genotype Srma/tui/ babaxcmss97moo3905 was recorded 133 days considered as late maturing genotype. Maximum

(101 cm) and minimum (76 cm) plant heights were recorded from farmers' variety and Munia/chto/3/pfau/bow/ genotypes, respectively.

Genotype Vorobeycmss96y02555-040Y-020m and Skoll-cmss97moo3165-0p10m-0p10ml recorded maximum 1000 kernels weight (42 g) whereas the minimum (33 g) was recorded from genotype Mtrua92-155. From tested bread wheat genotypes; Vorobeycmss96y02555-040Y-5M, Srma/tui/babaxcmss97moo3905 and Uress/jun//kauz/3/babaxcmss97moo3395 recorded maximum mean grain yield of 3341 kg ha^{-1}, 3102 kg ha^{-1} and 3093 kg ha^{-1}, respectively. The minimum (1534 Kg ha^{-1}) mean grain yield was recorded from genotype Skoll-cmss97moo3165-0p10m-0p10ml.Genotype Vorobeycmss96y02555-040Y-020 has a yield advantage of 36.6% and 18.4% over the farmers' variety and released bread wheat variety, Dinknesh, respectively (Table 8).

The genotypes by locations interaction showed that (Table 9) there were highly significant difference (P<0.05) for all measured traits except 1000 kernels weight. Genotype by year interaction revealed that there was significant difference (P<0.05) for days to heading but non-significant difference for plant height, biomass yield, grain yield , days to maturity and 1000 kernels weight. Therefore, bread wheat genotypes were performed differently in different locations for all parameters except 1000 kernels weight, while, over years genotypes were performed consistently for all parameters except days to heading.

Genotype by location by year interaction revealed that (Table 9) there were significant differences (P<0.05) for days to heading and grain yield traits while the differences were non-significant for days to maturity, plant height, biomass yield, and 1000 seeds weight. Therefore, for the most important parameter; grain yield, genotypes performed differently in different environments, which showed that we need to recommend different bread wheat varieties for the respective environments.

As shown in Figure1; perpendicular lines were drawn to each side of the polygon divides the biplot into six sectors, each testing location falling inevitably into one of the sectors. Two of the sectors did not contain any location while the other four sectors contain locations.

Vorobeycmss96y02555-040Y-020m was the winner genotype at Kon and Geregera in 2010 and 2011 cropping seasons and at Lalibela in 2011 cropping season. Genotype Parus/pastorcmss96y…..48m won in Dahana in 2010. Genotype Rubei/PRINIACMSS96Y026825-040-Y won in Lalibela2010 and genotype Dinknesh (standard check) won in Dahana 2011. Since we have tested the genotypes over eight environments, the analysis clustered them in to

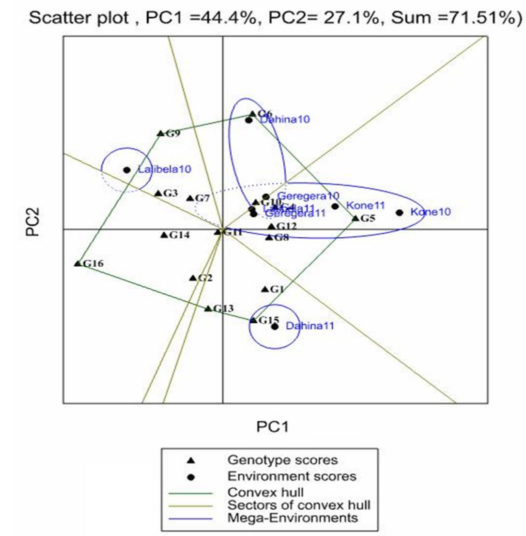

Figure 1: Genotype by Genotype by environment interaction (GGE), which won where in different environment and with mega-environment (for grain yield). G1 = PASTOR/SITE/MO/3/chen/, G2 = Munia/chto/3/pfau/bow/, G3 = Berkut cmss96M05638-040Y-26M, G4 = Berkut cmss96M05638-040Y-5M,G5=Vorobeycmss96y02555-040Y-020m,G6=Parus/pastorcmss96y…..48m,G7= Parus/pastorcmss96y…..46m, G8 = Parus/pastorcmss96y…..38m, G9 = Rubei/PRINIACMSS96Y026825-040Y, G10 = Uress/jun//kauz/3/babaxcmss97moo3395, G11 = Srma/tui/ babaxcmss97moo3905, G12 = Croc-1/aesquarrosa, G13 = Mtrwa92-155, G14 = Skoll-cmss97moo3165-0p10m-0p10m1, G15 = Dinknesh, G16 = Local (Farmers' variety)

four mega-environments. Therefore, locations are divided into four groups (mega-environments) based on the winner genotypes. The biplot showed that there was a huge variability of season at Dahana and Lalibela, while consistency of season at Geregera and Kon.

Based on which-won-where analysis of GGE-biplot analysis of grain yield, for most of environments, genotype Vorobeycmss96y02555-040Y-5M was the winner even if other options such as genotypes Parus/pastorcmss96Y…38, Croc-1/aesquarrosa,Berkutcmss96m05658-040Y-5M and Uress/jun//kauz/3/babaxcmss97moo3395 were available. For Dahina 2011, the standard check variety Dinkinesh was performed well. Thus, it is possible to grow this bread wheat variety in such environments.

The analysis of variance using AMMI model for grain yield (Kg ha^{-1}) revealed that the three sources of variation (environments, genotypes, and GEI) were significant (P<0.001) (Table 5). AMMI model indicated that additive effects (both genotype and environments) and non-additive effects (GE interaction) explained 80.7%, and 19.3 % of the total treatment variations (G+E+GE), respectively. Environment was the predominant source of variation which had big effect on the grain yield performances of bread wheat genotypes (Table 5). The partitioning of the GE interaction sum square using AMMI ANOVA showed that the first two interaction principal component axis (IPCAs) were significant (P<0.001), explaining 76% of the total GE interaction sum square and the remaining 24% considered as noise (residual). The first and second IPCA was explained 46.9%, 29.06% of GE interaction sum of square, respectively (Table 5).

The AMMI-1 biplot (Zobel et al., 1988) is the most well-known and appealing component of AMMI analysis (Figure 2). Its abscissa represents main effects (mean grain yield of genotypes and environments) and its ordinate represents IPCA-1 scores of both genotypes and testing environments.

Therefore, it provided a means of visualization for mean performances and stability of genotypes and environments simultaneously. The AMMI-1 biplot

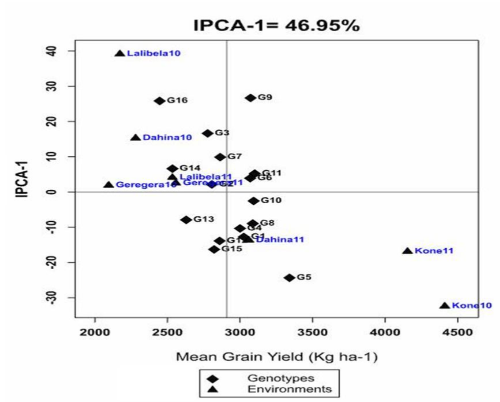

Figure 2: Biplot with abscissa (X-axis) plotting means from 2446 to 4411 Kg ha^{-1} and with Ordinate (Y-axis) plotting IPCA-1 from -32.4 to 39.2, Genotypes plotted as G1, G2, G3... and G16, Environments as Kon10, Kon11, Geregera10, Geregera11, Lalibela10, Lalibela11, Dahana10 and Dahana11. G1 = PASTOR/SITE/MO/3/chen/, G2 = Munia/chto/3/pfau/bow/, G3 = Berkut cmss96M05638-040Y-26M, G4 = Berkutcmss96M05638-040Y-5M, G5 = Vorobeycmss96y02555-040Y-020m, G6 = Parus/pastorcmss96y…..48m, G7 = Parus/pastorcmss96y…..46m,G8 = Parus/pastorcmss96y…..38m,G9 = Rubei/PRINIACMSS96Y026825-040Y, G10 = Uress/jun//kauz/3/babaxcmss97moo3395, G11 = Srma/tui/ babaxcmss97moo3905, G12 = Croc-1/aesquarrosa, G13 = Mtrwa92-155, G14 = Skoll-cmss97moo3165-0p10m-0p10m1, G15 = Dinknesh, G16 = Local (Farmers' variety)

explained 89.8% of the total treatment variations (G+E+GE), which is reasonably enough to explained main effects and GE interaction.

Vorobeycmss96y02555-040Y-5M genotype exhibited high mean grain yield and plotted with Dahana11, Kon10, and Kon11; indicating its adaptability for these environments (Figure 2). Parus/pastorcmss96y…..48m,Uress/jun//kauz/3/babaxcmss97moo3395,Srma/tui/babaxcmss97moo3905 and Parus/pastorcmss96y….38m genotypes scored above average mean grain yield with IPCA scores near to zero which plotted near to the origin (Figure 2); indicating its wide adaptability for all testing environments. However, Pasrus/pastorcmss96y….38m,Srma/tui/babaxcmss97moo3905andParus/pastorcmss96y…..48m genotypes were late maturing; not fit for moisture stress environments (Table 4).In addition as shown in Table 6, AMMI model selected the first four bread wheat genotypes per environment; thus, genotype Vorobeycmss96y0255-040Y-5M was selected in most of environments than the rest bread wheat genotypes. As shown in Figure 2, environments showed variation for both interaction and main effects. Among the testing environments Kon 2010 recorded the highest negative IPCA-1 scores and the highest mean grain yield (4411 Kg ha^{-1}) while Lalibela10 scored the minimum mean grain yield (2172 Kg ha^{-1}) and the highest positive IPCA-1 scores. These two environments were highly interactive environments which contributed the largest interaction effects. On the other hand Lalibela11, Geregera10, and Geregera11 scored the minimum IPCA-1 scores but recorded less than average mean grain yield. Environment Dahana showed huge seasonal variation, because the mean grain yield of Dahana in 2010 cropping season was below the average while in 2011 cropping season recorded mean grain yield of above the average (Figure 2).

In the AMMI-2 biplot (Figure 3), the environmental scores are joined to the origin by side lines called vectors. Environments located near to the origin did not exerted strong interaction effects while environments located far away from the origin exert strong interaction effects. Thus, Kon10, Lalibela10, Dahana10, and Dahana11 contributed large amount of interaction effects while the rest environments contributed less interaction effects. In terms of genotypes; farmers' variety, Rubei/PRINIACMSS96Y026825-040Y, Parus/pastorcmss96y…..48m, and Dinknesh scored high IPCA scores; considered relatively less stable genotypes.

In this experiment the response of tested genotypes for yellow rust depicted in Table 7, genotype Berkut cmss96M05638-040Y-26M and "Dinknesh" had no visible infection on it. Genotype Vorobeycmss96y02555-040Y-020m

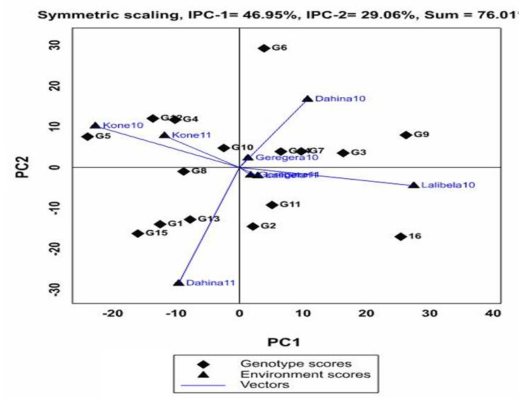

Figure 3: AMMI-2 biplot for grain yield (Kgha^{-1}) showing the interaction of IPCA-1 againstIPCA-2 scores of 16 bread wheat genotypes and 8 environments.

G1 = PASTOR/SITE/MO/3/chen/, G2 = Munia/chto/3/pfau/bow/, G3 = Berkut cmss96M05638-040Y-26M, G4 = Berkutcmss96M05638-040Y-5M, G5 = Vorobeycmss96y02555-040Y-020m, G6 = Parus/pastorcmss96y…..48m, G7 = Parus/pastorcmss96y…..46m, G8 = Parus/pastorcmss96y…..38m, G9 = Rubei/PRINIACMSS96Y026825-040Y, G10 = Uress/jun//kauz/3/babaxcmss97moo3395, G11 = Srma/tui/ babaxcmss97moo3905, G12 = Croc-1/aesquarrosa, G13 = Mtrwa92-155, G14 = Skoll-cmss97moo3165-0p10m-0p10m1, G15 = Dinknesh, G16 = Local (Farmers' variety)

Table 7. Responses of tested bread wheat genotypes for yellow rust disease across environments

passport code)	Pedigree	Yellow rust reaction
G1	PASTOR/SITE/MO/3/chen/	30S
G2	Munia/chto/3/pfau/bow/……………..	15S
G3	Berkut cmss96M05638-040Y-26M……..	0
G4	Berkut cmss96M05638-040Y-5M…….	5MS
G5	Vorobeycmss96y02555-040Y-020m……	10MR
G6	Parus/pastorcmss96y…..48m	5MS
G7	Parus/pastorcmss96y…..46m	5MS
G8	Parus/pastorcmss96y…..38m	5MS
G9	Rubei/PRINIACMSS96Y026825-040Y……	80S
G10	Uress/jun//kauz/3/babaxcmss97moo3395…	80S
G11	Srma/tui/ babaxcmss97moo3905…..	20S
G12	Croc-1/aesquarrosa….	30MR-MS
G13	Mtrwa92-155….	40MS
G14	Skoll-cmss97moo3165-0p10m-0p10m1…	15S
G15	Dinknesh	0
G16	Farmers' variety	30S

scored moderately resistant reaction with low percent of severity (10%) and Croc-/aesquarrosa had response of moderately resistant with high percentage of severity (30%) and some moderately susceptible response (Table 7). However, most of the rest bread wheat genotypes showed susceptibility response with medium to very high percentage of severity.

DISCUSSION

In this experiment, the significant effects of tested bread wheat genotypes across environments for the value of heading and maturity, plant height, 1000 kernels weight, and grain yield revealed that there were possibilities to select best performed genotypes for the target environments. In agreement with the result, Geleta et al. (2015) and Kumar et al. (2018) reported that significant variability were observed among the evaluated bread wheat genotypes for days to heading and maturity, plant height, grain yield and 1000 kernels weight traits.

Therefore, to determine the stability performances of bread wheat genotypes across different environments the two stability models such as genotype plus GGE biplot and AMMI analyses were performed for grain yield.

GGE biplot graphically displays Genotype by Environment Interactions (GEI) of a multi-environment trial that facilitate visual genotype evaluation and mega-environment identification (Yan et al., 2000). The GGE biplot for grain yield of testing genotypes; represent a polygon view of the five vertex genotypes and the rest genotypes found inside the polygon. The vertex bread wheat genotypes are supposed to be the most responsive

Table 8. Yield of candidate genotype (G5) as percent of the standard and local checks

Genotypes	Grain yield ($kg\ ha^{-1}$)	Over the local check	Over the standard check
Vorobey cmss96y02555-040Y-020m (Sorra)	3341	36.6 %	18.4 %
Standard check (Dinknesh)	2822		-
Farmers' variety	2446	-	-

Table 9. Mean square values of grain yield and yield related traits of bread wheat genotypes for the combined analysis of variance (ANOVA) over years and locations (eight environments)

Source of variation	DF	Mean square					
		Days to heading	Days to maturity	Plant height (cm)	Biomass yield ($Kgha^{-1}$)	Grain yield ($Kgha^{-1}$)	1000 kernels weight (g)
Genotype(G)	15	167.6^{**}	146.9^{**}	877.3^{**}	53770^{ns}	13400^{**}	141.1^{**}
Location (L)	3	5569.1^{**}	27001.3^{**}	2154.8^{**}	361350^{**}	829649^{***}	1012.1^{***}
Year (Y)	1	41.2^{***}	2957.3^{**}	3607.6^{**}	385900^{**}	109120^{***}	8.7^{ns}
GL	45	15.9^{**}	47.5^{**}	62.8^{**}	54830^{**}	7396^{**}	8.0^{ns}
GY	15	4.9^{**}	9.4^{ns}	31.03^{ns}	35490^{ns}	6512^{*}	4.9^{ns}
LY	3	40.3^{***}	68.3^{**}	1005.7^{**}	1861000^{**}	45263^{***}	22.9^{*}
GLY	45	8.6^{*}	8.5^{ns}	34.8^{ns}	30600^{ns}	6031^{*}	6.7^{ns}
Error	256	2.2	6.6	36.4	32230	4047	6.2

***, **,* significant difference at 0.1%, 1% and 5 % probability levels, respectively, ns = non

since they have the longest distance from the biplot origin (Yan & Rajcan, 2002). This indicates that vertex cultivars were not the best in any of the test environments suggesting that this cultivar were the poorest in some or all of the environments. To generalize, vertex cultivars are the most responsive cultivars; they are the best or else the poorest cultivars in some or all of the test environments

Since we have tested the genotypes over eight environments, the analysis clustered them in to four mega-environments. Therefore, locations are divided into four groups (mega-environments) based on the winner genotypes. The environment cluster indicated there was a huge variability of season at Dahana and Lalibela, while consistency of season at Geregera and Kon. The two principal components of GGE biplot explained (71.5% of the interaction) was lower than the finding of Zhang et al. (2006) on grain yield of soybean cultivar evaluation (80%). However, the report of Khazratkulova et al. (2015) (61.3%) on winter wheat genotypes for grain yield trait was less than this value.

The AMMI analyses (Zobel et al., 1988) partition the total variation into environmental effect (75.2%), genotype by environment interaction effect (19.3%) and genotypic effect (5.5%). Environment was the predominant source of variation which had big effect on the grain yield performances of bread wheat genotypes. Based on the AMMI model (Gauch & Zobel, 1996) explained, additive effects (both genotype and environments) and non-additive effects (GE interaction) explained 80.7%, and 19.3 % of the total treatment variations (G+E+GE), respectively. Similarly, Tarakanovas & Ruzgas (2006) reported that environment, genotype and genotype by environment were attributed 77.1%, 7.1%, and 15.8 % of the total variation on winter wheat grain yield respectively. Gauch and Zobel (1996) reported that IPCA score of a genotype in the AMMI analysis can be indicator of the stability of a genotype across environments. The closer the IPCA scores are to zero, the more stable the genotypes are across their testing environments.

Vorobeycmss96y02555-040Y-020m exhibited high mean grain yield and well adapted to most of the tested environments by which released with the name "Sorra" . Parus/pastorcmss96y…..48m won in Dahana in 2010 but it was late maturing genotype. Rubei/PRINIACMSS96Y026825-040-Y won in Lalibela2010 and Dinknesh (standard check) won in Dahana 2011.

Sorra has beetr yield advantage of 36.6% and 18.4% over farmers' variety and standard check respectively. Tamene et al. (2018) did research on bread wheat varietal development reported a grain yield advantage of 20.58% over standard check Madawalabu and 41.32% over local check Hollandi respectively which has nearly the same result with this experiment.

The responsiveness of tested genotypes to yellow rust disease was varied from zero (not affected) to 80% susceptible reaction. Most of the rest bread wheat genotypes showed susceptible response with medium to very high percentage of severity. Genotype Vorobeycmss96y02555-040Y-020m has moderately resistant response to yellow rust disease with low present of severity (10%) and Croc-/aesquarrosa has moderately resistant and some moderately susceptible types of reaction with high percentage of severity (30%). The current result is in agreement with Tamene et al. (2018) which reported the reaction bread wheat genotypes to wheat rust diseases.

In conclusion, among the sixteen bread wheat genotypes tested across four locations in two cropping seasons, genotype Vorobeycmss96y 02555-040Y-020m was selected as early maturing, high yielding, resistant to yellow rust and fitting for moisture deficit wheat growing areas. Besides, this bread wheat variety has a yield advantage of 18.4% and 36.6 % over the standard Dinknesh and the local checks, respectively. So, this variety was officially released in 2012 by the name Sorra and recommended for Geregera, Kon, Lalibela and other similar agro-ecological zones. In addition to this, Dinknesh was good for such environments like Dahana2011, the variety already released by Sirinka Agricultural Research Center for moisture stress areas, so that, multiplication and dissemination of this variety will be done for Dahana and similar environments.

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