

Assessment of Malt Barley Genotypes for Grain Yield and Malting Quality Traits in the Central Highlands of Ethiopia

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Abstract

A multi-location variety trial was conducted with the objective to identify suitable malt barley varieties that satisfy the malt and brewing industry quality requirements and reduce the cost for importing malt barley. The trial was conducted to evaluate the performance of 28 promising malt barley varieties in seven environments (site-season combinations) during 2017 and 2018 cropping seasons. The phenological and agronomic data collected were subjected to analysis of variance (ANOVA) using 'R' software. All the traits analysis showed significant genotype, environment and genotype by environment interaction effects. Genotype, HB 52 X Bahati (G-5) exhibited high mean grain yield (5128 kg/ha) and significantly different for grain yield from one of the improved checks (Traveller). The other promising genotype, Bekoji-1 X Grace (G-8) showed acceptable malt quality results for extract (81.8 %), protein (10.0 %), friability (85 %) and lower values for beta -glucan (369 mg/l) with comparable grain yield to the improved checks (Traveller, HB1963). Similarly, genotype Sabin X Beka (G-7) showed acceptable malt quality results with lower level of beta-glucan (287mg/l). The "which-won-where" and "Mean vs. Stability" view of GGE biplot showed that, G-5 exhibited high mean grain yield and moderate grain yield stability and is the winner genotype in all test environments. Overall, G-8 is identified as potential malting barley candidate varieties to be tested for more industrial malt quality traits prior to variety verification trial and G-5 can be considered as potential parent in the malt barley crossing program for its good yield potential.

Keywords: ANOVA, GGE biplot, Malt barley, Grain yield, Malt quality and Stability

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INTRODUCTION

Barley is one of the most important cereal crops widely grown in the highlands of Ethiopia with annual production of about 2.0 million tons cultivated on an area of about 1 million hectares of land with an average national yield of 2.16 tons/ha (CSA, 2018). In the barley-based farming systems of the central highlands, smallholder farmers have very few alternative crops. One source of income could be growing malting barley, which has dependable local buyers in the country (Bayeh and Berhane, 2011). Both food and malt barley are grown side by side sharing similar agro-ecologies. However, the share of malt barley is roughly 15-20 % of the total barley production, which is the major input for beer production (Berhane *et al.*, 2016). Traditionally, both six-row and two row barley types are cultivated in the country, but the best malt quality for beer is produced from two row varieties.

Malt barley is a high-opportunity cash crop, with great room for profitable expansion, particularly when connected to growing breweries. However, there is a shortage of quality malt barley varieties to meet the demand of the local breweries that forced the malt factories to import large quantity of malt barley from abroad. The gap between domestic supply and demand indicates an opportunity to enhance local production and substitute import through huge untapped malt barley potential in the country. Malt imports has grown tremendously reaching over 75 thousand tons in 2017 covering about 70% of total annual demand and costing the country about 41.5 million USD (ERCA, 2017).

Malt barley production has not expanded as expected, despite the potential of the country to grow malting barley both in quality and quantity. There is a relatively huge domestic market for malt of reasonable quality, where large number of farmers in the highlands of Ethiopia can commit part of their barley area to malt barley production. Even though barley grows in many highland regions of the country, the adoption of the malt barley varieties is limited to the Arsi highlands and to a lesser extent in Bale where farmers can sale their produce to the Asela malt factory and to the emerging brewery companies such as Heniken, Diageo and Dashen. The lack of adoption of malt barley to other highland barley producing areas is due to limited extension activities by the ministry of agriculture and relevant organizations. Currently, there is an attempt to promote malt barley production in the central highlands of Oromia and Amhara region to provide malt to breweries through contractual production. Therefore, improving the knowledge and skill of farmers through demonstrating new malt barley varieties would be vital to increase production and productivity to fill the existing supply gap in the country. In addition the quality demand from the breweries and the malt factory is a bench mark for the malt barley breeding program. However, most of the nationally released malt barley varieties did not satisfy all the requirements that showed the importance of developing breeding activity to release the malt barley varieties that satisfy the quality parameter demand of the

breweries and the malt factories.

The National Agricultural Research system (NARS), has developed more than 15 malt barley varieties over the last three decades with the collaboration of national research system and international organizations. This paper presents the results of the malt barley multi-location variety trial conducted in seven environments. The target was to select high yielding, agronomically superior varieties with good malting quality traits, disease and pest resistance and promote best performing varieties for release or incorporate in the breeding pipeline development as recipients/donors of useful genes.

MATERIALS AND METHODS

Twenty eight malt barley genotypes were evaluated in two sets of experiment in 2017 and 2018 cropping seasons and from these genotypes twelve of them were evaluated repeatedly in both years. However, the remaining sixteen genotypes appeared once in each year (Table 1). Therefore, twenty materials were tested each year using RCBD design with three replications. The experiments were carried out at Holetta (9°00'N, 38°38'E, elevation 2400m), Bekoji (7° 15'N, 39°15'E, elevation 2830m), Kofele (7°00' N, 38°45' E , elevation 2700m) and Debreberhane (9°41'N, 39°32'E, elevation 2800m) experimental sites in a non-orthogonal set of six environments (site-season combinations). Twenty two of the experimental materials were selected from 2016 and 2017 malt barley preliminary variety trials and the other six genotypes were included as checks (Table 1).

Data were recorded on the following phenological and agronomic traits: days to 50% heading, days to 50% maturity, plant height (cm), hectoliter weigh (Kg hl⁻¹), thousand kernel weight (gm) and grain yield (Kg ha⁻¹) from four central rows. Plot yields were adjusted to 12.5% moisture content and converted to kilogram per hectare. Disease data were recorded on scald and net blotch on 0-9 scale and changed to percentage data, where 0=0%, 1=3%, 2=12%, 3=25%, 4=42%, 5=58%, 6=75%, 7=88%, 8=97%, 9=100% before transformed using angular transformation for statistical analysis. These traits were subjected to analysis of variance using R- software (R Core Team, 2017). In the analysis the environments were considered as random and genotypes as fixed effects, and a mixed effect model ANOVA was used for statistical analysis. The individual and combine environment analysis of variance of the experiment was conducted as the model suggested by Singh and Ceccarelli (1996).

$$Y_{ij} = \mu + G_i + B_j + e_{ij} \text{ and } Y_{ijk} = \mu + G_i + E_j + GE_{ij} + Bk_{(j)} + e_{ijk}.$$

Where, Y_{ij} = observed value of genotype i in block j , Y_{ijk} = observed value of genotype i in block k of environment j , μ = grand mean of the experiment, G_i = the effect of genotype i , B_j = the effect of block j , $Bk_{(j)}$ = the effect of block k in environment j , e_{ij} = error effect of genotype i in block j , E_j = environment effect, GE_{ij} = the interaction effect of genotype i with environment j , e_{ijk} = error (residual) effect of genotype i in block k of environment j . GGE bi-plots were performed on grain yield to determine stability of the genotypes using GGEBiplotGUI packages of R- software (R Core Team, 2017).

The malt quality traits, namely extract content [% DM], protein content [% DM], friability [%] and β -glucan content [mg/L] of selected genotypes were analyzed using the wet chemistry method in Germany malt quality laboratory “Versuchs- und Lehranstalt für Brauerei in Berlin” on malted grain following the appropriate procedure. Malt extract content was determined according to a small-scale version of the European Brewery Convention (EBC) Methods Manual, Section 4.9.1 (European Brewery Convention, 1998). Additionally, grain samples of all genotypes included in this study were analysed at Holetta quality laboratory following Near infrared spectroscopy (NIRs) technique using Bruker Tango instrument.

Table 1. Lists of malt barley genotypes and environments used for the trials

Trt	Genotype	Year	Trt	Genotype	Year	Loc	Year	Env
G1	Grace x HB 1307	17-18	G15	KWS_Grinada	2017	Holetta	2017	HO17
G2	Bekoji I x Bahati	17-18	G16	KWS-Hobbs	2017	Bekoji	2017	BK17
G3	HB 1307 x Su-Lilly	17-18	G17	KWS-Sassy	2017	Bekoji	2018	BK18
G4	Belgium 2	17-18	G18	KWS_Canton	2017	Kofele	2017	KF17
G5	HB 52 x Bahati	17-18	G19	KWS-Solicit	2017	Kofele	2018	KF18
G6	IBON 174/03 x Traveller	17-18	G20	IBON-HI13/14-41	2018	D/berhane	2018	DB18
G7	Sabini x Beka	17-18	G21	IBON-HI14/15-45	2018			
G8	Bekoji-1 x Grace	17-18	G22	IBON-HI14/15-56	2018			
G9	IBON 174/03 *	17-18	G23	IBON-HI14/15-96	2018			
G10	Holker	17-18	G24	IBON-HI14/15-102	2018			
G11	HB 1963 *	17-18	G25	IBON-HI14/15-147	2018			
G12	HB 1964	17-18	G26	MBHIBYT-23	2018			
G13	KWS-Dante	2017	G27	Explorer	2017			
G14	KWS-Eileen	2017	G28	Traveller **	2018			

*improved Check, locally developed; ** = Improved check, Introduced, G1-G12 evaluated for two years, G13-G28 evaluated for one year

RESULTS AND DISCUSSION

The combined analysis of variance, across seven environments showed highly significant variations among the malt barley genotypes tested for all quantitative traits considered. The differences among the environments were statistically significant for all traits. Similarly, genotype by environment interaction was significant for all traits (Table 2). It showed that all genotypes were not affected by environment equally. This G x E interaction effect made the selection process difficult and requires further stability analysis of the genotype to select the one relatively stable across environments and provide high yield.

Table 2. Mean squares of traits of 28 malt barley genotypes grown at six environments

	DF	DHE	DMA	PLH	SC(DF)§	NB(DF)§	TKW	HLW	GYLD
Gen	27	709**	461**	4370**	1719(27)**	572(27)**	295**	35**	11779569**
Env	5	2599**	4063**	4501**	9367(4)**	12017(4)**	1726**	826**	61902099**
Gen:env	87	26**	53**	131**	214(68)**	254(68)**	17**	7**	932567**
Env:rep	12	21**	16ns	107**	188(10)**	61(10)	9ns	1ns	2828458**
Residuals	228	9	16	40	74(190)	67(190)	8	4	441982
CV		3.56	2.78	6.61	16.35	39.31	5.82	2.94	16.92
Mean		84.6	143.4	96.0	52.5	20.9	47.5	67.6	3929.7

DF=degree of freedom, DHE=days to heading, DMA= days to maturity, PLH=plant height (cm), SC=scald (%), NB=net blotch (%), TKW= thousand kernel weight (g), HLW= hectoliter weight (Kghl⁻¹), GYLD= grain yield(kg ha⁻¹), **, * significant at 5% and 1% probability level, ns=non significant, §these traits were not recorded at DB18 and mean squares under those traits are angular transformed values

Among the tested genotypes even though not significantly different from some of the newly tested genotypes and check varieties (IBON 174/03, HB 1963, HB 1964), G5 (HB 52 x Bahati) showed highest mean grain yield. However, it had significantly highest mean grain yield than the registered European varieties (Explorer and Traveller). Then most genotypes (G21-G26) that were substituted during 2018 cropping season had higher mean grain yield comparable to G5, but it should be noticed that these genotypes were evaluated only at three environments (BK18, KF18 and DB18). Similarly, among the test genotypes evaluated at all environments, G6 (IBON 174/03 x Traveller) scored better mean grain yield. Whereas, the introduced malt barley (G13-G19) materials scored the lowest mean grain yield values. The maximum hectoliter weight (HLW) were recorded for the check variety G11 (HB1963), genotype G8 (Bekoji-1 x Grace) and G26 (MBHIBYT-23). Significantly higher mean TKW value was recorded on HB1964 (56.6g) and KWS-Eileen (52.6g). On the other hand, most introduced malt barley genotypes (viz. G13, G14, G15 G16, G17 and G19) had higher mean scald value of 67, 65, 69, 63, 67 and 72%, respectively. This is due to the fact that these materials evaluated under different environment condition than Ethiopia (Table 3). However, materials derived from crossing program had relatively better tolerance to scald. Accordingly, G1, G3, G4, G5, G6, G7 and G8 scored mean scald value of 53, 46, 45, 38, 51, 48 and 54%. Regarding net blotch most of tested materials showed moderate resistant. In contrast, these genotypes which had higher scald values showed lower net blotch scores. As an example G15, G22 and G27 scored 69, 80 and 74% for scald and 9, 23 and 10% for net blotch, respectively. This may be due to the confounding effect of scald on net blotch. Plant height showed consistently large variation among the malt barley varieties. Similarly, most foreign materials have short plant height, in contrast G7 revealed high mean plant height value of 116 cm followed by G8 (115 cm). G6 (IBON 174/03 x Traveller) and G9 (IBON 174/03) were relatively early whereas G-17 (KWS-Sassy), G14 (KWS-Eileen), G-18 (KWS-Canton) and other European introduced materials were late in days to maturity. Generally, among the malt barley genotypes tested in all environments, HB 52 x Bahati and IBON 174/03 x Traveller showed grain yield advantage as compared to the recently released check varieties (HB1963 and HB 1964) and better disease resistance (Table 3). Similarly, Bekoji-1 x Grace had comparable mean grain yield value as the standard checks (HB 1963, Traveller) and high values in mean grain physical quality parameters (TKW and HLW). In addition, the newly inserted genotypes (G21-G26) showed similar grain yield with recent check varieties and to confirm their performance over year, these genotypes genotypes will be evaluated again in 2019/20 cropping season.

Table 3. Over all mean for eight traits of 28 malt barley genotypes tested during the 2017 and 2018 main cropping season

Trt#	Genotype	DHE	DMA	PLH	SC§	NB§	TKW	HLW	GYLD
G1	Grace x HB 1307	84 ^{c-g}	143 ^{d-j}	114 ^{ab}	53 ^{d-i}	35 ^{abc}	49.5 ^{b-g}	69.8 ^{ab}	3995 ^{cd}
G2	Bekoji I x Bahati	79 ^{i-l}	137 ^{jk}	97 ^{fgh}	71 ^{abc}	25 ^{b-g}	44.1 ^{hi}	68.3 ^{a-e}	3972 ^{cd}
G3	HB 1307 x Su-Lilly	84 ^{c-g}	139 ^{h-k}	110 ^{a-d}	46 ^{g-j}	30 ^{b-e}	48.9 ^{b-g}	68.3 ^{a-e}	3920 ^{cde}
G4	Belgium 2	84 ^{d-h}	138 ^{ijk}	111 ^{abc}	45 ^{hij}	31 ^{bcd}	47.7 ^{d-g}	68.9 ^{a-d}	4049 ^{bcd}
G5	HB 52 x Bahati	81 ^{g-j}	141 ^{f-k}	106 ^{b-c}	38 ^{ij}	27 ^{b-f}	46.6 ^{ghi}	64.0 ^g	5128 ^a
G6	IBON 174/03 x Traveller	73 ^l	136 ^k	96 ^{gh}	51 ^{e-j}	23 ^{c-g}	51.2 ^{bc}	67.6 ^{b-e}	4470 ^{a-d}
G7	Sabini x Beka	82 ^{e-i}	140 ^{f-k}	116 ^a	48 ^{f-j}	31 ^{b-e}	50.7 ^{b-e}	68.6 ^{a-d}	3931 ^{cde}
G8	Bekoji-1 x Grace	81 ^{g-j}	140 ^{f-k}	115 ^{ab}	54 ^{e-i}	29 ^{b-e}	51.0 ^{b-d}	70.1 ^{ab}	4027 ^{bcd}
G9	IBON 174/03*	75 ^{kl}	135 ^k	88 ^h	54 ^{e-i}	28 ^{b-e}	48.8 ^{b-g}	67.0 ^{cde}	4487 ^{a-d}
G10	Holker	86 ^{cde}	141 ^{f-k}	106 ^{b-f}	48 ^{f-j}	41 ^{ab}	47.5 ^{e-h}	69.6 ^{abc}	4043 ^{bcd}
G11	HB 1963*	87 ^{cd}	145 ^{c-f}	104 ^{c-g}	57 ^{b-h}	28 ^{b-f}	50.4 ^{b-e}	70.5 ^a	4785 ^{ab}
G12	HB 1964	81 ^{g-j}	140 ^{f-k}	106 ^{b-c}	53 ^{d-i}	30 ^{b-e}	56.6 ^a	67.1 ^{cde}	4409 ^{a-d}
G13	KWS-Dante	96 ^b	149 ^{bcd}	55 ^{ij}	67 ^{a-f}	9 ^g	38.4 ^k	63.8 ^{fg}	1936 ^h
G14	KWS-Eileen	95 ^b	152 ^b	60 ^{ij}	65 ^{a-g}	17 ^{d-g}	52.6 ^{ab}	66.9 ^{b-g}	1905 ^h
G15	KWS_Grinada	94 ^b	146 ^{b-g}	52 ^j	69 ^{a-e}	9 ^g	39.0 ^{jk}	68.6 ^{a-e}	2193 ^{gh}
G16	KWS-Hobbs	97 ^{ab}	150 ^{bc}	60 ^{ij}	63 ^{a-h}	14 ^{efg}	38.5 ^k	65.5 ^{efg}	2870 ^{fgh}
G17	KWS-Sassy	102 ^a	164 ^a	63 ^{ij}	67 ^{a-f}	20 ^{c-g}	43.1 ^{ij}	66.0 ^{d-g}	2691 ^{gh}
G18	KWS_Canton	99 ^{ab}	152 ^b	66 ⁱ	49 ^{e-j}	21 ^{c-g}	43.1 ^{ij}	66.7 ^{c-g}	3050 ^{efg}
G19	KWS-Solicit	96 ^b	148 ^{b-c}	63 ^{ij}	72 ^{a-d}	14 ^{efg}	37.3 ^k	66.2 ^{d-g}	2430 ^{gh}
G20	IBON-HI13/14-41	77 ^{jkl}	140 ^{f-k}	88 ^h	66 ^{a-g}	21 ^{c-g}	46.8 ^{e-i}	68.1 ^{a-e}	3799 ^{def}
G21	IBON-HI14/15-45	77 ^{jkl}	137 ^{ijk}	100 ^{c-g}	53 ^{b-j}	23 ^{b-g}	50.6 ^{b-f}	69.4 ^{a-d}	4300 ^{a-d}
G22	IBON-HI14/15-56	82 ^{e-j}	136 ^{jk}	95 ^{gh}	80 ^a	23 ^{b-g}	48.3 ^{b-g}	66.1 ^{d-g}	4791 ^{abc}
G23	IBON-HI14/15-96	81 ^{f-j}	138 ^{f-k}	101 ^{c-g}	31 ^j	23 ^{b-g}	47.5 ^{c-i}	69.0 ^{a-e}	4392 ^{a-d}
G24	IBON-HI14/15-102	78 ^{i-l}	138 ^{g-k}	100 ^{d-g}	48 ^{e-j}	23 ^{b-g}	46.4 ^{f-i}	67.4 ^{a-f}	4700 ^{a-d}
G25	IBON-HI14/15-147	77 ^{i-l}	139 ^{f-k}	96 ^{e-h}	78 ^a	23 ^{b-g}	47.0 ^{e-i}	69.4 ^{a-d}	4370 ^{a-d}
G26	MBHIBYT-23	79 ^{h-k}	141 ^{e-k}	102 ^{c-g}	69 ^{a-e}	24 ^{b-g}	47.7 ^{c-i}	70.0 ^{abc}	4382 ^{a-d}
G27	Explorer	87 ^{c-f}	144 ^{c-i}	59 ^{ij}	74 ^{ab}	10 ^{fg}	39.5 ^{jk}	66.0 ^{d-g}	2775 ^{gh}
G28	Traveller*	89 ^c	145 ^{b-h}	88 ^h	48 ^{e-j}	51 ^a	46.0 ^{ghi}	66.9 ^{b-g}	4215 ^{bcd}

DHE=days to heading, DMA= days to maturity, PLH=plant height (cm), SC=scald (%), NB=net blotch (%), TKW= thousand kernel weight (g), HLW= hectoliter weight (hl g⁻¹), GYLD= grain yield (kg ha⁻¹), §these traits were not recorded at DB18, * = Improved checks

Individual environment mean grain yield and malt quality parameters value of tested malt barley genotype have been presented in Table 4. HB 52 x Bahati (G5) showed higher mean grain yield values across most environments, ranged from 3614 - 7026 kg ha⁻¹. Besides the grain yield the genotypes had better malt quality, it recorded 80.7, 8.3, 72, 699 values for extract, protein, friability and beta-glucan respectively. Similarly, the check variety (HB1963), exhibited the next high mean grain yield at most test environment and it also showed better values in malt quality traits. This confirmed that the variety is an alternative malting barley genotype for malting industry. Then IBON 174/03 x Traveller had higher mean grain yield values across test environments, but the genotype exhibited relatively poor malting quality. On the other hand, Bekoji-1 x Grace and Sabini x Beka showed premium malt qualities, they scored 81.8 and 81.5 for extract, 10.0 and 9.8 for protein, 85 and 78 for friability and 369 and 287 for beta glucan, respectively. These traits are the most important and relevant for the malt factories and breweries so that the breeders are working on improving it. Accordingly, the G8 and G7 scored mean grain yield value ranged 2915-5090 kg ha⁻¹ and 2804-6248 kg ha⁻¹ across the test environments with the high malt quality standard. (Table 4). Moreover G3 showed better values in all malt quality parameters. However, unlike other genotypes these values were recorded using NIRs techniques. So, the values should be further confirmed using wet chemistry method for solid conclusion. Consequently, even if HB 52 x Bahati and IBON 174/03 x Traveller were higher in grain yield performance, we can recommend genotype Bekoji-1 x Grace instead for its premium malt barley quality and acceptable grain yield potential.

Table 4. Individual location average grain yield and malt quality traits performances of the 12 malt barley genotypes

Trt#	Genotype	BK17	BK18	DB18	HO17	KF17	KF18	Mean	Extract %	Protein %	Friability %	Beta glucan (mg/l)
G1	Grace x HB 1307	3370	4820	3013	3611	4159	4872	3995	80.4	7.6	70	462
G2	Bekoji I x Bahati	3651	5813	2640	3101	3947	4822	3972	81.1*	13.5*	68*	333*
G3	HB 1307 x Su-Lilly	4236	6396	3634	2572	4015	2629	3920	84.0*	9.5*	86*	246*
G4	Belgium 2	3873	5926	2972	3325	3784	4426	4049	76.8	13.3	29	1000
G5	HB 52 x Bahati	5304	7026	3614	4293	4675	6046	5128	80.7	8.3	72	699
G6	IBON 174/03 x Traveller	3595	6265	3154	4019	4715	5075	4470	76.7	12.2	37	1000
G7	Sabini x Beka	4127	6248	2804	3441	3633	3287	3931	81.5	9.8	78	287
G8	Bekoji-1 x Grace	3880	5090	2915	4081	4000	3968	4027	81.8	10.0	85	369
G9	IBON 174/03	3874	6667	2348	4236	4855	5144	4487	79.4	10.6	50	1000
G10	Holker	3477	6373	3035	3658	3418	4179	4043	77.6	13	61	420
G11	HB 1963	4005	5818	3686	5355	5198	4252	4785	81.3	8.9	78	510
G12	HB 1964	3645	5350	2927	4277	4584	5625	4409	78.6	11.6	44	1000

*These data were recorded from Near infrared spectroscopy (NIRs) using Bruker Tango instrument
 NB= malt quality standards: Extract, >78 %, Friability, >77 %, Beta glucan, <400 mg/l, Protein, 9-11.5

GGE BIPLLOT

Significant mean squares for G X E indicated inconsistency of mean grain yield performance of genotypes in different environments. Studying the causes of G X E interaction helps to establish breeding objectives and identify areas of optimal cultivar adaptation (Yan and Hunt, 2001). The “which-won-where” view of the GGE biplot is important feature for mega environment identification. Therefore in this study based on the mean yield performance of malt genotypes, all environments fall into single sector. The six environments (KF17, KF18, BK17, BK18, DB18 and HO17) grouped as one mega environment and G5, G6, G9 and G11 performed well in all environments included in mega environments (Figure 1). In addition, G5 (HB 52 x Bahati) is the vertex genotype, which showed the superiority of the genotype in mean grain yield performance than the other genotypes included in the mega environment (Yan and Tinker, 2006). Moreover, no environments fell into sectors that contained the remaining genotypes, which indicates that they were the poorest genotypes in all test environments (Yan, 2001).

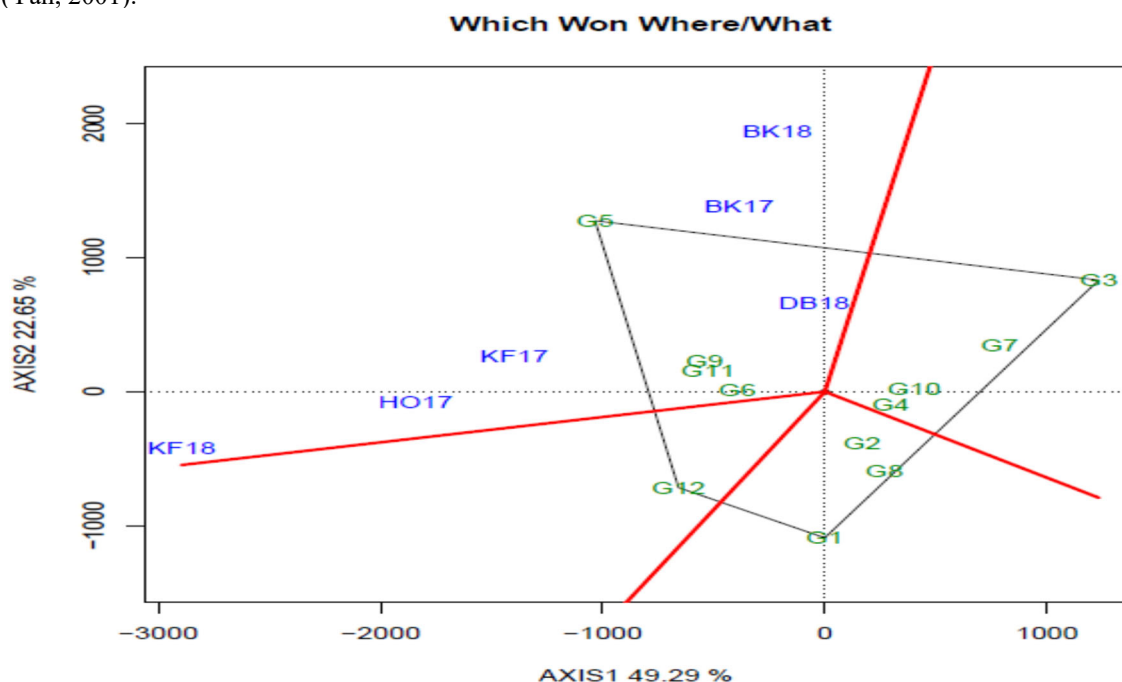


Figure 1. The which-won-where view of the GGE biplot of grain yield of Food barley genotypes based on the G x E data

The GGE biplot explained 72% of the grain yield variation due to GGE (Figure 2). “Mean vs. Stability” view of GGE biplot is efficient tool to compare genotype based on mean performance and stability across environments within a mega-environment (Yan *et al.*, 2007). Mean vs. stability view of GGE biplot presented in Figure 2. G-5 showed higher mean grain yield value than the other test genotypes and had moderate stability. The check varieties G-9 (IBON 174/03), G-11 (HB 1963) and the other test genotype G-6 (IBON 174/03 x Traveller) had the next highest mean grain values and these genotypes revealed good stability. On the other hand among high malt quality

yielding genotypes, G8 (Bekoji-1 x Grace) showed relatively better stability (Figure 2).

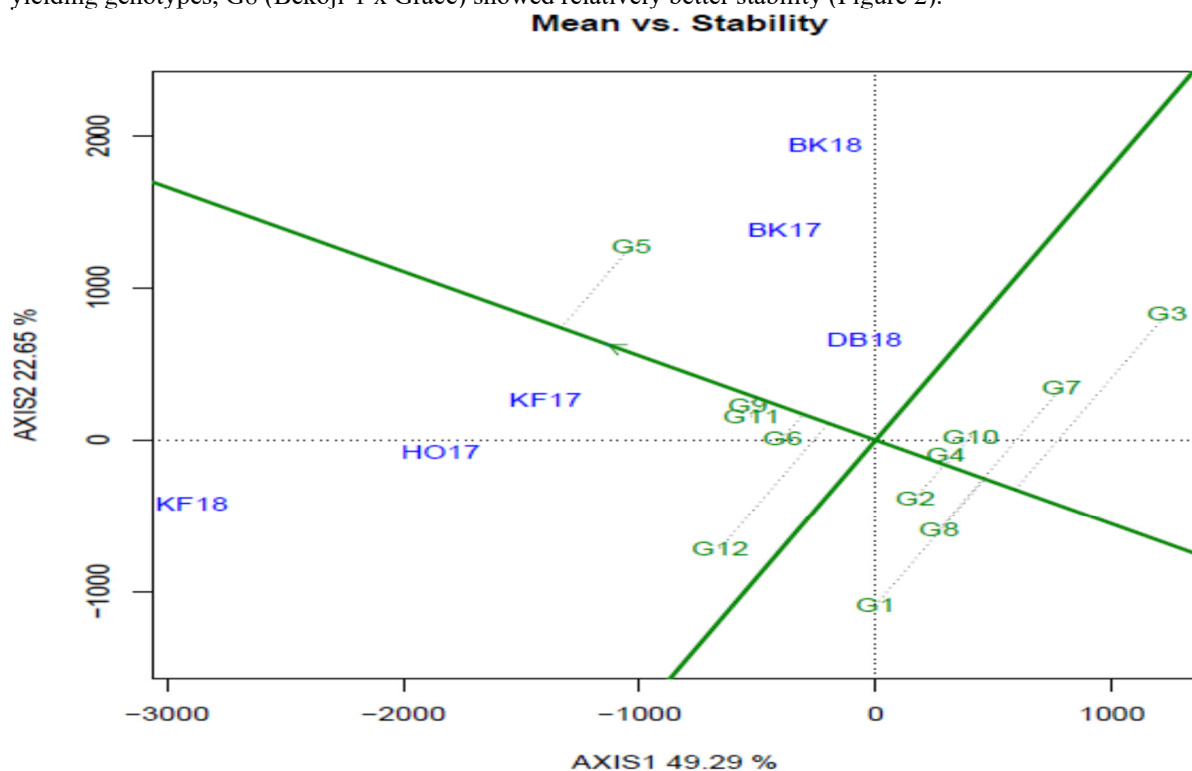


Figure 2. Mean grain yield performance and stability of genotypes based on the $G \times E$ data

CONCLUSIONS

The major finding from this study was that G-8 (Bekoji-1 x Grace) had shown a premium malt and physical grain quality result meeting the standard of the malt industry, which in most cases are missing in our elite varieties. The other genotype G-5 (HB 52 x Bahati) showed significantly higher mean grain yield and good malt quality traits, except for friability. The GGE biplot, G5 (HB 52 x Bahati) was the winning genotype in all test environments. Moreover, the “mean vs stability” view of GGE biplot indicated that G-5 recorded the highest mean grain yield. In terms of stability, the high yielding genotype (G-5) and the high quality genotype (G-8) showed moderate stability across test environments. Overall, genotypes G-8 is identified as potential malt barley candidate variety for further malt quality test prior to variety verification trial. Genotype G-5 is included in the crossing block as potential donor parent for its high yielding performance across the test environments. In addition, G-8 (Bekoji-1 x Grace) and G-7 (Sabini x Beka) are recommended for the malt barley crossing program as potential parent for their good malt quality traits (high malt extract and low beta-glucan).

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