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EVALUATION OF ETHIOPIAN BARLEYS GENETIC VARIATION FOR AGRONOMIC AND NUTRITIONAL QUALITY TRAITS IN NORTHERN ETHIOPIA

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Barley is an important crop mainly used for human food in Ethiopia, but little is known on variation in nutritional quality. The objective of this paper was to evaluate the nutritional quality among different Ethiopian barley lines. Of 144 Ethiopian barley genotypes tested, a subset of 39 genotypes was selected using Near Infrared Reflectance (NIR), grown in field trials at three locations and evaluated for quality and agronomic traits. There were significant variations in chemical contents with significant environmental effects. The mean values (range) over the three sites were: starch (52.5–61.5%), protein (9.7–15.0%), β-glucan (3.4–5.4%), thousand kernel weight (TKW) (36.7–62.1 g), Fe (27.8–48 mg kg^{-1}), and Zn (23.7–50.2 mg kg^{-1}). Most hulless lines had significantly higher β-glucan and protein contents, but lower TKW and grain yield than the hulled lines. Protein, β-glucan, Fe and Zn contents were negatively correlated with starch and grain yield, whereas TKW was positively correlated with grain yield. Most of the barley lines showed consistent performance in quality traits across environments, and the genetic factor contributed up to 65% of the total variation. The results revealed that nine hulled (BCC19, BCC21, BCC126, BCC158, BCC161, BCC46, BCC132, BCC136 and *Himblil*) and three hulless lines (BCC180, BCC182 and BCC184) had higher than average starch, β-glucan, protein, Fe and Zn contents with medium to high TKW and grain yield. These barley genotypes seem suitable for food uses and are promising in barley breeding.

Key words: Starch, β-glucan, Protein, Hulled, Hulless, Grain yield, Genetic variation

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INTRODUCTION

Barley *(Hordeum vulgare* L.) is the fourth most important cereal crop in the world after maize, wheat and rice in total production (FAOSTAT, 2014). It is mostly cultivated for malt and animal feed, and has limited use as human food in the western countries (Newman and Newman, 2008). However, barley is mainly used for food in different forms in countries such as Morocco, Ethiopia and Tibet (Newman and Newman, 2006). In Ethiopia, barley is a staple food crop for subsistence farmers in low input and low rainfall marginal environments, and the straw is used for animal feed (Abay et al., 2008; Asfaw, 2000; Bekele et al., 2005). It covers about 1.0 million ha of land with average grain yield productivity of 2.1 t ha^{-1} (CSA, 2016), and different barley varieties are being cultivated from 1400 to 4000 meters above sea level in the northern and central regions of Ethiopia (Asfaw, 2000; Demissie and Bjørnstad, 1996)). Barley contributes significant share (among cereals) in the food consumption of the highlands and out of the total barley production (2 million tons) in 2016, about 63% has been used for household food consumption, 19.9% for seed, 13.4% for sale, 2.4% for malt, and only 0.6% for animal feed (CSA, 2016). It is considered as the most important crop due to its multipurpose uses in different traditional dishes and homemade alcohol drinks (Abay et al., 2008; Mulatu and Grando, 2011).

Research has shown that barley has good nutritional value and contains high levels of starch (49–67%), dietary fiber (13–27%) and protein (8–18%) (Åman and Newman, 1986; Andersson et al., 1999; Oscarsson et al., 1996). It provides essential amino acids which humans must get from their diet, with lysine, threonine and methionine being limited, and it is a good source of vitamin B-complex and vitamin E or tocols (McIntosh et al., 1995; Newman and Newman, 2008). Barley also provides essential elements such as iron (Fe) and zinc (Zn) (Newman and Newman, 2008). Recently, barley is regarded as a healthy food due to its high dietary fiber content, partially soluble fiber *β*-glucan and this soluble β-glucan is beneficial for

human health because it regulates glycemic response, lowers blood cholesterol level and minimizes the risk of heart disease (Behall et al., 2004; McIntosh et al., 1995; Tiwari and Cummins, 2011; Ullrich et al., 2008)). As a result, research on food barley nutritional value is getting more focus mainly considering the beneficial effect of barley food in human health (Baik and Ullrich, 2008; McIntosh et al., 1995). However, the important quality traits such as *β*-glucan, protein, starch as well as grain yield and its components are affected by both genotypes, environments and their interactions (Åman and Newman, 1986; Andersson et al., 1999; Griffey et al., 2010; Oscarsson et al., 1998; Paynter and Harasymow, 2010; Zhang, 2001).

The existence of wide variability for quantitative and qualitative morphological characters in Ethiopian barley genotypes are well documented (Asfaw, 2000; Bjørnstad and Abay, 2010). Most of the previous studies gave less attention to the nutritional quality and less is known on barley nutritional aspects. Thus, the objectives of this study were to: (1) investigate the genetic variation of the Ethiopian barley genotypes for ß-glucan, starch, protein, iron and zinc contents; and (2) assess environmental effects on quality and agronomic traits among selected barley lines in northern Ethiopia; (3) identify varieties or lines combining optimal quality with good yield and other agronomic traits.

MATERIALS AND METHODS

Barley genotypes

One hundred and forty four representative barley genotypes (including two row, six row types and irregular spikes, with varied glume colours, and of hulled and hulless types) were grown in the 2008 summer season at Mekelle University (MU), in Northern Ethiopia. These barley genotypes represent all main barley growing regions of Ethiopia with altitude range from 1650-3750 meters, including four nationally released varieties (*Misrach*, *Demtu*, *Shege* and *HB*42); seven common barley landraces from Tigray (*Atsa*, *Burguda*, *Demhay*, *Haftusene*, *Himblil*, *Rie*, *Saesa* and *Sihumay*), and nine known important genetic stocks (CI0668, CI2266, CI2222, CI9819, Jet (CI0967), CI9654, *Hiproly*, HOR2937 and CI4364) were included in the screening test. They were planted in the field on a sandy loam soil using a plot size of 1 m x 1.5 m in 5 rows. Recommended seed rate of 100 kg ha^{-1} and fertilizer rate of 50 kg ha^{-1} Urea and 100 kg ha^{-1} diammonium phosphate were applied. The grains were harvested and out of the 144 barley lines, 39 were selected and grown again in 2009 summer season in a randomized complete block design (RCBD) with alpha lattice arrangement in two replications with plot size of 1.2 m x 2m (2.4 m^2) at Korem and Hagereselam sites. Korem site has an of altitude 2500 m, rainfall 651 mm, average temperature max 23.4 ^oC, min 7.4 ^oC, soil clay loam, and Hagereselam has altitude 2576 m, rainfall 441 mm, average temperature max 21.8 ^oC, min 12.3 ^oC, and with silt loam soil type.

Kernel Weight and Milling

Thousand kernel weight (TKW, grams) was measured by counting samples of 1000 kernels from each genotype using a numerical seed counter and expressed as weight in grams. All grain samples were milled using cyclone laboratory mill model Falling Number 3100 (Perten Instruments AB, Sweden) using a 0.8 mm sieve. Dry weight of the flour samples was determined by oven-drying duplicate samples of 800 mg at 105 ^0C for overnight.

Selection of Barley Lines by Near Infrared Reflectance Spectroscopy (NIRS)

Flour samples of 144 barley lines were analyzed using XDS Rapid content^{TM} Analyzer DK-3400 Hillerød, Denmark. Reflectance spectra were obtained from 144 barley flour samples taking duplicate analyses of each line. After taking the average of replicates, the region of 1100 to 2450 nm was used for principal component analysis (PCA) using Unscrambler X version 10.1 Software CAMO AS, Norway. A calibration using 23 Ethiopian barley lines that were analyzed for β-glucan content was used to estimate β-glucan contents of the barley samples and a few with similar estimates were removed to reduce the sample size to 39 barley lines for further study.

Chemical Analysis of Barley Flour Samples

Flour samples of the selected 39 barley lines grown at Mekelle University, Korem and Hagereselam were analyzed for starch, protein and β-glucan contents at the Norwegian University of Life Sciences, laboratory. The samples were analyzed for total starch using the Megazyme total starch assay procedure (Amyloglucosidase/α-amylase method) AOAC (method 996.11) and AACC (method 76.13) as described by McCleary et al. (1994). Total *β*-glucan content was analyzed using Megazyme assay mixed linkage kit (Megazyme International Ireland Ltd., Wicklow, Ireland) based on McCleary method (McCleary and Codd, 1991). Total Nitrogen content was determined by Bremmer and Mulvaney (1982) combustion method using Elemental analyzer model CHN–1000 (Leco, USA). The protein content was calculated by multiplying % N x 6.25 and presented as percent dry weight. Zinc (Zn) and iron (Fe) contents were determined by dry ashing flame atomic absorption spectroscopy at the International Centre for Agricultural Research in the Dry Areas (ICARDA, Aleppo, Syria) laboratory.

Statistical Analysis

Analysis of variance and correlation analysis were done using GenStat software 16th edition (VSN International, 2013). Duncan's multiple range test was used to detect differences among treatment means ($P < 0.05$ level of significance). The data were analyzed using a general linear model (GLM). The mean data of nutritional and agronomic performance of each genotype was subjected to principal components analysis (PCA) using the Unscrambler X version 10.1 Software to study the relationships in chemical and physical components.

RESULTS

NIR Screening Results

The NIR spectra 1100-2450 nm results showed five clusters (Fig. 1) with high variation in beta-glucan, starch and protein contents. Representative barley lines 39 (32 hulled and 7 hulless) were selected from the five clusters of total 144 barley lines: seven lines from cluster one (1 hulless and 6 hulled), twelve hulled lines from cluster two, most with white glume colour, nine lines (2 hulless and 7 hulled) from cluster three most with white glume colour, one grey black and one bright grey; four hulled lines (2 brown grey and 2 black grey colour) from cluster four, seven lines from cluster five (4 hulless and 3 hulled) all with black glume colour in the right of the bi-plot. The NIR spectra confound variation in colour and chemical contents, as seen by the characterization of the lines from the 5 clusters (Fig. 1).

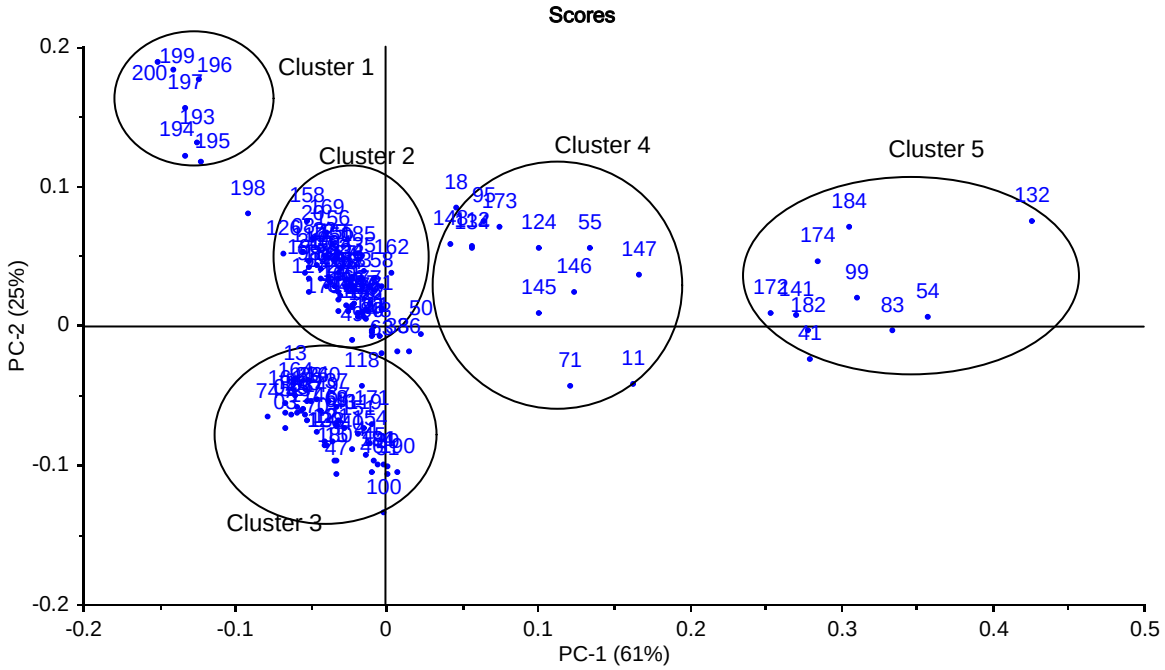

Figure 1. Principal Components Analysis (PCA) score plot of 144 barley genotypes used for NIR screening.

Starch, Protein and β–glucan Contents

The barley lines varied significantly ($P< 0.01$) and accounted for 32.6% of the total variation, while environmental effects and genotype by environmental interaction (GEI) have explained 25.2% and 24.4% of the variation, respectively. Some lines showed non-consistent ranking due to significant G x E interaction effects, but most genotypes had consistent starch content across locations. The average total starch of the lines over three locations ranged from 50.6 to 64.6% on dry weight basis. Comparing the three locations for starch showed that the highest starch content was obtained from Hagereselam (52.6–64.6%) followed by Korem (50.9–62.9%) and MU (50.6–61.7%). Starch content was higher in the hulless than in the hulled lines and the variation within and between hulled and hulless was significant (Tables 1 & 2).

Protein content varied significantly among lines ($P < 0.01$) at all the three sites. The G x E interaction and environmental effects were also significant ($P < 0.01$). Most of the variation in protein content was due to the genotypes factor (65.0%) while environmental effects and GxE explained 20.1% and 9.4%, respectively (Table 2). Most lines showed consistent performance in protein content across locations, except few that had variable performance due to G x E interaction effects. The mean protein content of the lines across three locations varied from 9.3 to 15.0%.

Table 1. Analysis of mean squares (a), and means of locations (b) for different physical and chemical components of hulled and hulless barley genotypes as well as agronomic performance.

a. Mean squares

Source of Variation	DF	Total starch (% w/w)	Beta glucan (% w/w)	Kernel weight (g)	Protein (%)	Maturity days	Grain yield (kg ha^{-1})	Zinc mg kg^{-1}	Iron mg kg^{-1}
Environment (E)	2	325.1**	8.2**	1689.1**	65.2**	3401**	3262432**	28.4^{ns}	700.8**
Genotype (G)	38	22.2**	1.3**	234.5**	11.1**	318**	123476**	123.5**	87.0**
G x E	76	8.3**	0.20**	65.7**	0.79**	27**	40416**	36.0**	34.5**
Residual	116	3.5	0.06	5.4	0.31	8.2	3129	7.5	6.3
Hulled (H)	31	18.3**	0.74**	215.5**	8.4**	349.2**	82541**	113.4**	88.7**
Hulless (HL)	6	28.3**	0.34**	107.6**	0.29^{ns}	11.9**	37835**	13.7**	20.1**
Hulled vs. Hulless	1	84.2**	7.28**	2102.6**	65.7**	525**	1850827**	25.2^{ns}	33.5^{ns}
b. Location means									
Korem		56.3b	4.2b	53.2a	11.9b	114.0a	1541.6a	35.5a	37.2a
Hagereselam		58.9a	3.83c	45.5b	10.5c	112.4b	1233.9b	34.7a	33.0b
MU		54.8c	4.4a	44.7c	12.3a	102.0c	1154.4c	–	–
LSD (5%)		0.59	0.07	0.74	0.176	0.91	17.74	0.87	0.80
P-value		<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.05	<0.01

*, ** significant at $P<0.05$, $P<0.01$ level of probability, respectively and ^{ns} = non-significant

The highest mean protein content was recorded from the hulless 2-rowed genotype BCC182 and few hulled 6-rowed and 2-rowed barley lines (Table 2). Evaluation of the lines at each location indicated that average protein content ranged from 9.9 to 16.1% at MU, 9.4 to 15.6% at Korem, and 8.7 to 13.7% at Hagereselam (Table 2). The hulless had higher protein content than the hulled lines at MU (Table 2). At Korem, there was high variation within and between hulled and hulless. At Hagereselam, most lines had low protein content and variation within the hulled was higher than within the hulless (Table 2).

Table 2. Total starch, protein and beta-glucan contents of different barley genotypes tested at three locations in Tigray, northern Ethiopia.

	Barley	Total starch (% w/w)				Protein (%)				Beta glucan (% w/w)			
	Lines	Korem	H/selam	MU	**Mean**	Korem	H/selam	MU	**Mean**	Korem	H/selam	MU	**Mean**
Hulled	BCC 19	51.4	58.0	54.1	54.5	13.3	9.9	13.5	12.2	4.8	4.2	4.9	4.6
	BCC 21	54.6	58.6	57.2	56.8	12.0	9.7	12.3	11.4	4.3	4.1	4.8	4.4
	BCC 46	55.3	52.6	52.3	53.4	12.5	13.7	12.5	12.9	4.1	4.4	4.7	4.4
	BCC 54	56.1	58.0	55.8	56.6	11.2	9.8	11.2	10.8	3.7	3.2	3.8	3.6
	BCC 57	53.1	59.1	54.8	55.7	12.2	10.6	11.9	11.6	4.1	3.4	4.1	3.9
	BCC 74	56.8	61.9	56.5	58.4	9.9	8.7	10.4	9.7	3.6	3.6	3.6	3.6
	BCC 78	57.1	60.5	54.8	57.5	10.9	9.9	11.1	10.6	3.7	3.4	4.3	3.8
	BCC 99	57.3	60.9	53.3	57.2	10.0	9.1	10.2	9.8	4.1	3.6	4.4	4.0
	BCC 100	55.6	55.6	50.6	54.0	12.9	13.0	12.8	12.9	4.2	4.3	4.6	4.3
	BCC 118	60.7	60.3	52.6	57.9	10.0	9.1	10.1	9.7	3.8	3.2	3.5	3.5
	BCC 126	56.7	57.8	52.1	55.5	12.1	10.3	12.1	11.5	4.4	4.0	4.5	4.3
	BCC 127	55.5	59.2	59.9	58.2	11.6	9.2	12.2	11.0	4.1	3.9	4.6	4.2
	BCC 129	57.1	59.7	57.0	57.9	13.0	9.9	13.4	12.1	4.0	3.7	3.9	3.9
	BCC 132	50.9	53.4	53.3	52.5	14.3	12.2	14.9	13.8	4.2	4.2	5.0	4.5
	BCC 136	52.4	57.8	50.9	53.7	14.7	11.5	14.8	13.7	4.5	4.2	5.3	4.7
	BCC 145	58.7	63.4	55.7	59.3	10.6	10.1	10.7	10.4	3.4	2.9	3.9	3.4
	BCC 147	58.5	61.0	58.9	59.4	10.9	10.3	11.3	10.8	3.5	3.1	4.3	3.6
	BCC 148	57.1	58.2	52.6	56.0	11.2	12.5	11.6	11.8	3.9	3.9	4.3	4.0
	BCC 150	56.0	61.1	52.0	56.3	11.3	9.7	11.9	11.0	4.0	3.4	4.6	4.0
	BCC 151	57.0	58.8	52.4	56.1	9.7	9.3	10.4	9.8	4.3	3.5	4.9	4.2
	BCC 158	54.6	55.6	55.8	55.3	13.8	11.7	13.6	13.0	4.5	4.2	4.7	4.5
	BCC 160	56.8	60.0	57.0	57.9	10.0	8.8	10.4	9.7	4.2	3.5	4.7	4.1
	BCC 161	53.6	57.1	58.1	56.3	11.8	10.1	12.6	11.5	4.3	3.9	4.8	4.3
	BCC 173	54.9	58.9	56.7	56.8	12.6	11.5	12.5	12.2	4.0	3.9	4.7	4.2
	Misrach	57.7	59.1	51.8	56.2	11.5	9.4	11.7	10.9	3.9	3.5	4.4	3.9
	Demtu	59.5	58.4	54.3	57.4	10.6	11.1	11.6	11.1	3.7	3.6	4.0	3.8
	Atsa	52.9	55.7	53.1	53.9	12.8	10.2	13.3	12.1	4.5	4.3	3.8	4.2
	Burguda	54.2	56.8	56.4	55.8	11.9	9.7	12.3	11.3	4.2	3.7	4.1	4.0
	Haftusene	59.2	59.5	53.2	57.3	9.4	8.7	9.9	9.3	4.0	3.3	3.4	3.6
	Himblil	56.1	58.5	54.0	56.2	10.4	8.9	10.9	10.1	5.1	3.8	4.2	4.4
	Saesa	53.9	58.5	53.3	55.2	12.3	10.1	13.1	11.8	4.2	3.8	3.9	4.0
	Sihumay	57.6	58.3	61.7	59.2	11.5	10.6	12.1	11.4	4.0	3.3	3.1	3.5
	Mean	55.89	58.51	54.75	56.38	11.65	10.28	11.97	11.30	4.10	3.72	4.30	4.04
	LSD (5%)	3.12	3.47	3.67	2.16	1.18	1.29	0.72	0.65	0.48	0.60	0.43	0.28
	P-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hulless	BCC 138	60.0	62.3	52.6	58.3	12.8	11.5	13.5	12.6	4.9	3.8	4.5	4.4
	BCC 172	62.9	64.6	57.0	61.5	11.8	10.0	12.2	11.3	4.0	3.2	4.2	3.8
	BCC 174	56.7	61.4	56.7	58.3	13.2	12.8	13.9	13.3	3.7	3.5	4.6	4.0
	BCC 180	60.0	60.6	57.1	59.3	12.7	11.6	13.1	12.5	5.0	4.6	5.1	4.9
	BCC 182	54.9	56.8	52.9	54.9	15.6	13.2	16.0	15.0	5.1	5.2	5.9	5.4
	BCC 184	53.3	58.6	56.0	56.0	14.9	12.8	15.2	14.3	4.8	4.7	6.7	5.4
	Demhay	59.4	60.9	55.8	58.7	12.9	11.7	13.3	12.6	4.5	4.3	4.6	4.5
	Mean	58.17	60.73	55.46	58.12	13.39	11.94	13.87	13.07	4.58	4.19	5.10	4.62
	LSD (5%)	3.44	3.57	2.15	2.29	0.67	1.38	0.86	0.58	0.307	0.60	0.37	0.23
	P-value	0.005	0.024	0.008	<0.01	<0.01	0.013	<0.01	0.01	<0.01	0.002	<0.01	<0.01

Note: H/selam = Hagereselam, MU = Mekelle University

The variation in β-glucan content due to genotypes, test locations and the interaction between genotypes and locations was very significant ($P < 0.01$). The genetic factor contributed 56% of the total variation while the location effect and G x E interactions explained 18.6% and 17.6% of the variation, respectively. The hulled genotypes (BCC19, BCC21, BCC126, BCC158, BCC46, BCC132, BCC136 and *Himblil*) and hulless (BCC180, BCC182 and BCC184) showed consistent performance in β-glucan across locations, while other genotypes showed non-constant ranking due to G x E interactions (Table 2). The difference in β-glucan content between hulled and hulless was more consistent than within each class (mean across the three sites 4.0 and 4.6%, respectively). The genotypes BCC19, BCC21, BCC136, BCC180, BCC182 and BCC184 are some of the promising lines that had consistently high β-glucan contents. Most hulless lines had significantly higher β-glucan than the hulled lines almost in all locations. Within each location mean β-glucan varied from 3.1 to 6.7% at MU, 3.4 to 5.1% at Korem and 2.9 to 5.2% at Hagereselam. At Korem, the variation within and between hulled and hulless in β-glucan was significant, but the range showed less variation. Interestingly, the hulled 6-row *Himblil* had the highest β-glucan content among the hulled lines at Korem, almost similar with the highest value in the hulless. Relatively low β-glucan contents were recorded from Hagereselam both in the hulled and hulless lines (Table 2).

Iron and Zinc Contents

Barley lines varied significantly ($P < 0.01$) both for Fe and Zn contents in the two locations. Locations differed significantly for Fe, but not in Zn content. Fe content varied from 27.1 to 52.3 mg kg^{-1} at Korem and 23.2 to 55.8 mg kg^{-1} at Hagereselam, with significant variation in the hulled lines, but not in the hulless. The difference for Zn content within hulled and hulless was significant but the variation between hulled and hulless was not significant. Zn content ranged 27.6 to 49.5 mg kg^{-1} at Korem and 20.4 to 57.8 mg kg^{-1} at Hagereselam. Mean Zn content at Korem was 35.3 mg kg^{-1} in the hulled and 36.8 mg kg^{-1} in the hulless. At Hagereselam, variation in Zn content was much higher among the hulled (20.4–57.8 mg kg^{-1}) than among the hulless (22.0–41.1 mg kg^{-1}). The hulled genotypes (BCC46, BCC136, BCC158, BCC173 and Saesa), hulless (BCC174, BCC180, BCC182 and BCC184) had relatively higher Fe and Zn contents in the two locations..

Agronomic Traits

Barley lines also differed significantly ($P < 0.01$) in days to maturity and TKW in all the three locations. The G x E interactions and location effects were evident ($P < 0.01$) for these parameters. The genetic factor contributed 55.2 and 49.7%, environmental factors 31.1 and 18.8%, and G x E interaction 27.8 and 9.36%, respectively of the total variation for days to maturity and TKW. All the barley genotypes required longer maturity days at Korem than at Hagereselam and MU. The range in days to maturity was 102 to 128 days at Korem, 101 to 124 days at Hagereselam and 81 to 121 days at MU. Most 2-row lines matured earlier than the 6-row types in all the three sites (Table 3). This is because the 6-row barley lines are adapted to the high altitude areas and are late maturing than 2-row lines in Ethiopia.

Grain yield also varied significantly ($P < 0.01$), and the environmental factors accounted for 44.5% of the total variation than the genetic and G x E interaction effects, 31.9% and 20.9%, respectively. Higher TKW and grain yield were observed at Korem where there was relatively higher rainfall. The mean grain yield of the lines was 1542 kg ha^{-1} at Korem, 1234 kg ha^{-1} at Hagereselam and 1154 kg ha^{-1} at MU (Table 3). Some hulled and hulless lines showed better performance across locations and had a greater average TKW and grain yield.

Associations of Quality and Agronomic Traits

Results of PCA of different grain chemical and physical components and yield are shown in the bi-plot (Fig. 2). The PC1 and PC2 explained 35% and 24% of the variation, respectively. The PCA bi-plot indicated that protein, β-glucan, Fe and Zn, located to the left quadrant, were positively correlated to each other but negatively correlated with starch and grain yield, located in the right quadrant (Fig. 2). TKW was positively correlated with grain yield but negatively with starch. Most of the hulless lines are displayed on the lower bottom axis of PC2, corresponding to higher β-glucan, protein and starch content while the majority of hulled lines on the top right of the bi-plot corresponds to higher grain yield and higher TKW contents (Fig. 2). Thus, PC2 seem to explain relationships linked to hull (hulled- hulless), and hulled lines had higher TKW content. The hulled 2-rowed lines BCC19, BCC21, BCC126, BCC158, BCC161, and hulled 6-rowed BCC46, BCC132, BCC136, *Himblil*; and hulless 2-rowed BCC180, BCC182 and BCC184 (Tables 2 & 3) were the best lines identified. They had relatively high mean β-glucan, protein, medium to high, Fe, Zn, TKW, starch, grain yield, and have both desirable nutritional quality and agronomic traits that could be used for food production and in the barley breeding programmes.

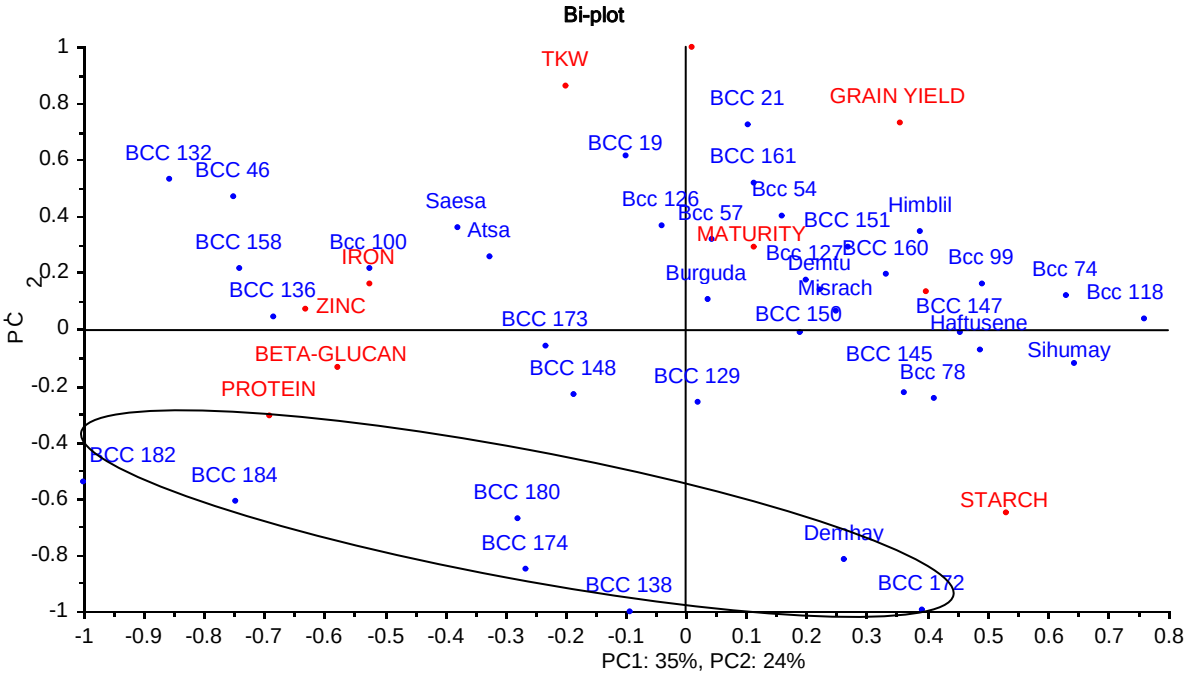

Figure 2. Bi-plot of PC1 and PC2 of different barley genotypes and measured chemical and physical traits

DISCUSSION

Starch, Protein and β-glucan Contents

Significant G x E interaction and environmental effects on total starch indicates that the performances of some genotypes were influenced by variation in environmental conditions. However, most genotypes had consistent performance for this trait across locations. Twelve out of 32 or (37%) of the hulled genotypes had higher starch content than the mean starch for the hulless at MU that might be due to poor performance of the hulless genotypes under moisture stressed conditions. The average starch content over locations was higher for hulless than for hulled lines but the difference was relatively narrow, and similar results were reported by Andersson et al. (1999) and Griffey et al. (2010).

The results demonstrated that there were higher genotypic variations in protein (65%) and β-glucan contents (56%) than the environmental and G x E interaction effects. Relatively high protein and β-glucan contents were recorded from the low rainfall (348 mm) and drought stressed environment of MU. This might be explained by the fast maturation and reduced grain filling period that resulted in reduced starch and yield, but increased protein and β-glucan contents. This is in agreement with Åman and Newman (1986) who found that increased protein but lower starch content in barleys grown in Montana short dry growing season. Similarly, the relatively increased β-glucan content at drier and low rainfall of MU is in agreement with the report of Perez-Vendrell et al. (1996) and MacGregor and Fincher (1993) who indicated that barley varieties grown in dry conditions during grain filling have high grain β-glucan content. However, Paynter and Harasymow (2010) argue that cultivars grown in areas having similar rainfall had different β-glucan content, suggesting differences in grain β-glucan could not be justified by variation in the amount of rainfall only, but also due to genetic and environmental effects. In general, results in the current study are in agreement with the findings of other studies (Andersson et al., 1999; Griffey et al., 2010; Hang et al., 2007; Holtekjolen et al., 2006; Oscarsson et al., 1998; Paynter and Harasymow, 2010; Zhang et al., 2002). Most of these studies indicated that both the barley genotypes and environmental conditions had an influence on the grain protein and β-glucan contents, with the former having greater effect than the later. The grain β-glucan content in the Ethiopian landrace lines (n = 39, 3.4–5.4%) had a range similar to those reported by Nair et al. (2010) (n = 10, 3.3–5.8%), but lower than that reported by Zhang et al (2002). Barley grain protein and β-glucan contents are controlled by many QTLs (Emebiri et al., 2005),(Han et al., 1995; Kling et al., 2004).

Iron and Zinc Contents

Micronutrient deficiency of Fe and Zn from the food is common problem in the world and enhancing nutrient content of crops for human food is a priority agendum. Micronutrient deficiency is not only due to scarcity of the micronutrients, but

also due to poor bioavailability, and this is prevalent in cereals due to the binding effect of phytate (Frossard et al., 2000; House, 1999). Nutrient malnutrition can be improved by plant breeding either by increasing the grain nutrients or by improving their bioavailability in the edible plant products (Frossard et al., 2000; House, 1999). Barley lines with high average Fe and Zn contents might have a heritable genetic factor for efficient uptake of micronutrients and translocation to the grains. In the present study, the significant positive correlations between Fe and Zn content and protein with both Fe and Zn content suggests selection of promising genotypes for increased levels of both micronutrients would be effective. But these traits are negatively correlated with grain yield which is a challenge for plant breeders. Significant positive correlation of Fe and Zn with protein is important because sulphur containing amino acids like methionine has been reported to have positive association for the bioavailability of these elements (House, 1999). In a similar study, Zhao et al. (2009) found a significant variation in grain Fe and Zn among 175 wheat lines and a positive correlation of Fe and Zn with grain protein content was reported.

Associations among Quality and Agronomic Traits

Results of the different grain chemical and physical components are presented in the PCA bi-plot (Fig. 2). The negative correlations of protein, β-glucan, Zn and Fe contents with grain yield and starch implies that selection of barley lines with higher content of former traits is at the expense of the latter. This is a main challenge to plant breeders to develop a crop variety simultaneously containing all desirable agronomic and nutritional quality traits. In the present study twelve (9 hulled and 3 hulless) lines were identified which had relatively high β-glucan, protein, starch, Fe, Zn, grain yield and TKW contents (Tables 1 & 3). Early maturity is also an important trait to escape the drought; however, in semi-arid areas like Tigray, the quality of grain components grown under moisture stress environment could be affected. Moreover, most of the quality traits such as high β-glucan, protein, starch, Fe and Zn contents, and the agronomic traits (higher grain yield and TKW) are quantitatively inherited and controlled by many QTLs.

Table 3. Days to maturity, TKW and grain yield of different barley genotypes tested in Tigray, northern Ethiopia.

	Barley Lines	Days to maturity				1000 kernel wt (g)				Grain yield (kg ha^{-1})			
		Korem	H/selam	MU	**Mean**	Korem	H/selam	MU	**Mean**	Korem	H/selam	MU	**Mean**
Hulled	BCC 19	118.0	115.5	95.0	116.3	64.9	61.3	59.2	61.8	1605	1525	1178	1436
	BCC 21	113.0	111.0	94.5	111.7	65.4	60.6	60.3	62.1	1851	1501	1244	1532
	BCC 46	127.0	123.0	115.0	124.3	52.8	50.4	48.2	50.4	1710	1122	802	1211
	BCC 54	122.0	119.0	112.0	120.0	53.7	47.6	46.3	49.2	1481	1261	1272	1338
	BCC 57	118.5	117.0	114.5	117.5	59.9	48.4	50.2	52.8	1649	1249	952	1283
	BCC 74	110.0	109.0	95.0	109.3	43.8	43.9	43.0	43.6	1690	1556	1300	1515
	BCC 78	111.5	112.5	114.5	112.2	50.0	41.3	41.2	44.2	1706	1387	903	1332
	BCC 99	119.5	117.0	98.0	117.8	51.8	46.8	42.9	47.2	1835	1415	1029	1426
	BCC 100	125.5	123.0	110.0	123.8	53.8	50.5	52.8	52.4	1440	1059	816	1105
	BCC 118	113.5	111.5	96.0	112.2	48.1	40.6	39.8	42.8	1689	1483	1237	1470
	BCC 126	110.0	107.5	106.0	108.3	62.1	57.7	54.9	58.2	1609	1141	1425	1391
	BCC 127	110.0	108.0	105.0	108.7	61.9	52.3	52.7	55.6	1608	1247	1379	1412
	BCC 129	109.0	107.0	95.0	107.7	41.2	35.0	34.0	36.7	1547	1092	1385	1341
	BCC 132	125.5	121.5	103.0	122.8	61.0	56.5	51.8	56.4	1417	1088	798	1101
	BCC 136	111.0	108.5	97.5	109.3	47.4	41.9	41.5	43.6	1396	1199	1304	1299
	BCC 145	114.5	112.5	109.0	113.2	48.7	38.6	41.9	43.1	1504	1155	1026	1228
	BCC 147	114.0	112.5	105.0	113.0	52.0	40.8	47.7	46.8	1527	1240	1176	1314
	BCC 148	102.0	102.0	81.0	102.0	52.4	46.4	38.1	45.6	1305	1086	899	1097
	BCC 150	106.5	106.0	90.0	106.2	42.5	39.2	40.4	40.7	1522	1221	1381	1374
	BCC 151	113.0	111.0	98.0	111.7	53.4	42.7	54.8	50.3	1586	1368	1400	1451
	BCC 158	109.5	108.0	89.0	108.5	59.4	55.6	39.0	51.4	1464	1215	1477	1385
	BCC 160	115.5	113.5	109.0	114.2	53.0	41.1	52.4	48.8	1732	1122	1484	1446
	BCC 161	110.5	108.5	97.0	109.2	61.1	52.8	52.7	55.5	1687	1383	1512	1527
	BCC 173	102.5	101.0	87.0	101.5	55.5	52.4	50.1	52.7	1682	1116	1224	1341
	Misrach	117.5	116.0	113.0	116.5	52.3	38.0	49.0	46.4	1565	1405	1045	1338
	Demtu	128.0	123.5	121.0	125.0	61.6	51.1	39.5	50.7	1479	1224	1235	1312
	Atsa	107.0	105.0	94.0	105.7	61.3	54.9	28.9	48.4	1541	1224	1362	1376
	Burguda	109.5	111.0	95.0	110.5	65.6	57.1	30.2	51.0	1568	1350	1040	1319
	Haftusene	119.5	121.5	115.5	120.8	51.7	40.7	34.7	42.4	1463	1233	1136	1277
	Himblil	119.0	122.0	114.0	121.0	53.7	41.7	46.2	47.2	1700	1431	1435	1522
	Saesa	107.5	105.0	84.0	105.8	58.5	52.1	41.7	50.8	1577	1341	1436	1451
	Sihumay	125.5	124.0	114.0	124.5	50.3	36.9	39.7	42.3	1423	1195	1267	1295
	Mean	114.5	112.9	102.1	109.8	54.71	47.41	45.17	49.10	1580.0	1269	1205	1352.0
	LSD (5%)	8.50	7.17	0.92	3.58	3.03	3.68	5.52	2.54	86.2	43.9	192.0	69.3
	P-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hulless	BCC 138	112.5	110.0	103.0	110.8	42.9	30.8	39.8	37.8	1170	1036	729	978
	BCC 172	107.5	105.5	89.0	106.2	41.4	33.4	41.0	38.6	1427	1042	1319	1263
	BCC 174	109.5	106.0	97.0	107.2	36.6	31.1	53.0	40.2	1406	1045	763	1071
	BCC 180	117.5	115.0	111.0	115.8	43.4	38.5	52.1	44.6	1552	1069	886	1169
	BCC 182	108.5	106.5	99.0	107.2	54.3	47.4	40.9	47.5	1285	1131	1012	1143
	BCC 184	111.0	109.5	98.0	110.0	54.5	38.5	42.4	45.1	1313	1063	1012	1129
	Demhay	117.5	118.0	111.0	117.8	50.0	41.4	29.0	40.1	1412	1103	741	1085
	Mean	112.0	110.07	101.2	107.7	46.15	37.28	42.58	42.0	1366	1070	923	1120
	LSD (5%)	1.64	3.16	3.90	1.03	4.25	5.96	9.17	3.40	67.27	51.83	52.32	32.80
	P-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.008	<0.01	<0.01	0.028	<0.01	<0.01

The current barley production in Ethiopia mainly focused on grain yield quantity and there are some well adapted varieties being cultivated for their higher grain yield and end use qualities. Abraha et al.(2013) reported that *Haftusene* in the southern, *Burguda* in the eastern and the released variety *Felamit*, *Fetina* and *Hiryti* are being cultivated for their better *Tihlo* and *injera* (flat bread) () making quality uses. Although the hulless varieties are expected to have higher β-glucan and protein contents required for food uses, but they have lower grain yield, smaller grain size and requires more management. As a result, the hulless lines are not grown in large areas in Ethiopia. Those hulled as well as hulless lines identified in this study that have better nutritional quality and agronomic traits could be the best for food barley production in Tigray.

CONCLUSION

High genetic diversity provides an opportunity to select barley lines suitable for food end use qualities. The study has shown significant variation among Ethiopian barley lines in grain chemical and physical components. In most analyzed traits, the genetic factor was the most important contributing greater to the total variation in quality and agronomic traits. The use of NIR screening is a rapid method to select and develop improved barley lines for food utilization. Considering the significant role of barley multipurpose uses in food and local drinks, this study identified nine hulled and three hulless barley lines that had better quality traits that could be used in barley breeding and production for food uses. Moreover, the findings would contribute useful information to plant breeders, food science research, and barley growers. Further research on multi-location trial and end product quality evaluation might be needed.

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