THE MULTI-LOCATION STUDY OF SIX-ROWED BARLEY LINES FOR MALT QUALITY

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ABSTRACT: In Ethiopia, both two- and six-rowed barleys can grow in the highlands. However, the country is not self-sufficient in malt barley production to satisfy the growing demands of malt factories, and it depends on imports from other countries. Little effort has been made to study the potential of Ethiopian six-rowed barley genotypes for malt quality traits. Hence, a two-year (2017/18-2018/19) experiment with 12 six-rowed type barley genotypes including one two-rowed malt barley standard check (IBON174/03) was conducted in Bekoji, Holata and Kofale research plots to assess the potential of six-rowed barley genotypes for malt quality. Randomized complete block design with three replications was used. Malt quality data were collected and the data was analyzed using R statistical software, R version 4.1.3 (2022-03-10), agricolae package. Tukey HSD means comparison showed that the 2.8-mm slot sieve test (42.57%) and the dry matter-based crude protein of barley line 17148-16 (11.8%) are significantly greater than the check but the fine grind hot water extract of the line (79.8%) is slightly greater than for the check (78.25%). Therefore, the findings from the two-year experiment in the three locations indicated that the six-rowed barley line 17148-16 fulfilled the malt quality requirements and can be used in the future malt quality improvement of six-rowed barleys in Ethiopia.

Keywords: Line 17148-16, malt quality, six-rowed barleys, Tukey HSD.

INTRODUCTION

Barley is a major crop in the highlands of Ethiopia, where it is grown by more than four million smallholder farmers in an area of about one million hectares of land (CSA, 2022). Ethiopia has a growing malt beverage sector and beer production has grown nearly 20% annually, from 1 million hectoliters in 2003 to roughly 4 million hectoliters in 2012 (Abu and Teddy, 2014). Nevertheless, the favorable environment and market opportunity and the share of malt barley production is relatively low (about 15%) compared to food barley (Lakew and Fekadu, 2015). Generally, barley productivity in Ethiopia remained significantly lower than global and regional averages (FAO, 2013). Stress factors like poor distribution of rainfall, low soil fertility (Mulatu and Stenfania, 2011), low productivity of landraces and unavailability of improved barley

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technologies to farmers (Lakew and Fekadu, 2015), diseases (scald, net blotch, spot blotch and rusts) and insect pests (aphids and barley shoot fly) (Yirga et al., 1998) have been reported as major causes of significant yield reduction.

In Ethiopia, barley is cultivated in either *meher* (the main rainy season) or *belg* (the short rainy season) mainly for food, though the country has a huge potential for malt barley production. Both two- and six-rowed types can be used for malt intended for beer production. It has been reported that national production meets only 35% of the domestic demand (Molla et al., 2018). Breweries like Heineken Ethiopia import 67% of raw barley and malt (Gerrit van Loo, personal communication). A four-year (2017-2020) data obtained from the Ministry of Trade and Industry showed that Ethiopia imported 57,588,420.83 kg of barley malt from abroad (Woolfrey et al., 2021) which is worth 30,287,369.60 USD. The domestic demand for malt barley is likely to increase.

Malt barley research in Ethiopia has been engaged in evaluating the local barely collections (farmers' varieties) and screening introduced malt barely from Europe, the USA, and ICARDA for their suitability for malting purposes (Lakew and Fekadu, 2015). The introduction and/or development of new high-yielding malt barley varieties would greatly contribute to satisfying the growing domestic demand, boost export earnings, and substantially generate income for farmers. Recognizing the little effort made in two-rowed malt barley improvement, absence of any work done in six-rowed barley for malting, and the low barley malt supply to domestic breweries in Ethiopia, research in six-rowed barley for malting contributes to better supply of barley malt to breweries in Ethiopia. The need to do research on six-rowed barley malt quality improvement arose from low malt supply and poor quality in two-rowed barley (Aychew Bekele, personal communication). Research in the area of quality improvement is very young as compared to malt barley producing countries of the world. The lack of six-rowed barley varieties with good malting quality is considered as a gap in malt barley research in Ethiopia. Malting barley must meet specific quality requirements which are affected by several biotic and abiotic factors. Therefore, this study was conducted to investigate the malting quality of six-rowed barley genotypes in three locations and to identify six-rowed barley lines fulfilling malting quality.

MATERIALS AND METHODS

Site description

The experiment was carried out in three locations (Holata, Bekoji and Kofale) for two consecutive years (2017/18-2018/19). The Holata Agricultural Research Center (HARC) is located 09°03'N and 38°30'E at an altitude of 2400 m.a.s.l. Its mean annual rainfall is 1044 mm, mean maximum and minimum temperature of the area is 22^{O}C, and 6.1^{O}C respectively and has a mean relative humidity of 60.6% (HARC, 2005). Bekoji is located at latitude of 7° 34'N and longitude of 39° 09' E with an elevation of 2810 m.a.s.l. Kofale is located at 7°04' N latitude, 38°78' E longitude and 2515 m.a.s.l. These locations are potential areas for barley production.

Plant material

Forty-eight six-rowed barley genotypes, the mother accessions of which were obtained from the Ethiopian Biodiversity Institute, were developed from the 2014/15 and 2015/16 cropping seasons. The selection was based on scald ratings and yield performances. These were multiplied ear-to-row in HARC's experimental plots during the main cropping season of 2016/17. Twelve lines were selected from the 48 genotypes. The grains of barley lines were sorted as mealy or glassy as described in the Reynolds (1909) Method 935.28. Before planting the lines, grains were cut cross-sectionally using a cutter. The cut surface of each grain from the lines was grouped as mealy or glassy depending on the amount of flour present. The 12 six-rowed barley lines and one two-rowed standard check (IBON174/03) were sown in a randomized complete block design (RCBD) with three replications. Each plot area was divided into four rows with a spacing of 20 cm between rows and a row length of 2.5 m.

Data collection

Grain quality analysis

Sieve test

Hundred grams of dockage-free barley grains from each line was measured and taken to a sieve. For five minutes, the grains were shaken on 2.8-mm, 2.5-mm, and 2.2-mm diameter slots. The grains retained on 2.8-mm, 2.5-mm, and 2.2-mm and those passing through the 2.2-mm slots were separately measured and recorded as percentages (Mastanjevic et al., 2017).

Moisture content and test weight

The moisture content and the test weight of dockage-free six-rowed barley grains from each line were measured using a grain analysis computer (GAC 2100)-DIKEY-john corporation, USA.

Crude protein content and fine grind hot water extract

Crude protein content and fine grind hot water extract data of the barley grains of each line were generated using Opus 7.5 software. The crude protein and fine grind hot water extract analyses instrument was tango Bruker optics (calibrated FT-IR near-infrared spectroscopy). The working principle is the interaction of electromagnetic radiation with protein and carbohydrates. The interaction produced spectra of a specific organic compound from which the models for crude protein and fine grind hot water extract were developed by Opus 7.5 software.

Data analysis

R version 4.1.3 (2022-03-10), agricolae package, (R Core Team, 2022) was used to examine the grain quality data obtained from the barley lines. For the quality-related measures, Tukey HSD was used to compare the means of the barley lines.

RESULTS

The analysis of variance (ANOVA) for sieve test (2.8-mm, 2.5-mm and 2.2-mm slot sieves) (Table 1 and 2), dry matter-based test weight, moisture content (Table 3), dry matter-based crude protein, and dry matter-based fine grind hot water extract (Table 4) showed very highly significant difference (100% confidence) among the barley lines, line-location, line-year, and line-location-year interactions. Therefore, the mean comparison for the lines was possible.

Table 1. Analysis of variance for sieve test (> 2.8-mm and > 2.5-mm slot sieves).

> 2.8 mm					
	Df	Sum Sq	Mean Sq	F value	Pr. (>F)
Trt	12	24486.3	2040.5	91.6731	< 2.2e-16***
Loc	2	12513.6	6256.8	281.0941	< 2.2e-16***
Year	1	12.3	12.3	0.5547	0.4576058
Trt:loc.	24	7972.2	332.2	14.9235	< 2.2e-16***
Trt:year	12	764.3	63.7	2.8614	0.0014736**
Loc:year	2	401.2	200.6	9.0126	0.0002059***
Trt:loc:year	24	2391.6	99.6	4.4768	6.735e-09***
Loc:year:rep	12	811.2	67.6	3.0369	0.0007891***
Residuals	143	3183.0	22.3		

> 2.5 mm					
	Df	Sum Sq	Mean Sq	F value	Pr. (>F)
Trt	12	4483.1	373.6	10.2843	<2.114e-14***
Loc	2	22991.9	11495.9	316.4630	< 2.2e-16***
Year	1	3755.1	3755.1	103.3715	< 2.2e-16***
Trt:loc.	24	16145.3	672.7	18.5188	< 2.2e-16***
Trt:year	12	2077.1	173.1	4.7650	1.563e-06***
Loc:year	2	1420.3	710.1	19.5487	3.125e-08***
Trt:loc:year	24	4365.2	181.9	5.0069	3.773e-10***
Loc:year:rep	12	4035.9	336.3	9.2584	4.709e-13***
Residuals	143	5194.7	36.3		

Trt – barley line; Loc – location; rep-replication

Sign. codes: 0 '*** '0.001 '**'0.01 '*'0.05

MS error=22.2587; DF=143; Mean=11.39996; CV=41.38537

Sign. codes: 0 '*** '0.001 '**'0.01 '*'0.05

MS error=36.32633; DF=143; Mean=40.94755; CV=14.71915

Table 2. Analysis of variance for sieve test (> 2.2-mm and < 2.2-mm slot sieves).

> 2.2 mm					
	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Trt	12	12136.6	1011.4	49.2310	< 2.2e-16***
Loc	2	12387.5	6193.7	301.4912	< 2.2e-16***
Year	1	36.7	36.7	1.7847	0.1837
Trt:loc.	24	3437.3	143.2	6.9715	1.691e-14***
Trt:year	12	1920.1	160.0	7.7888	4.954e-11***
Loc:year	2	416.1	208.0	10.1263	7.709e-05***
Trt:loc:year	24	1390.8	57.9	2.8208	7.535e-05***
Loc:year:rep	12	1018.0	84.8	4.1296	1.535e-05***
Residuals	143	2937.7	20.5		

< 2.2 mm					
	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Trt	12	9033.2	752.8	20.9274	< 2.e-16***
Loc	2	28236.4	14118.2	392.4938	< 2.e-16***
Year	1	4833.0	4833.0	134.3593	< 2.e-16***
Trt:loc.	24	7365.8	306.9	8.5322	< 2.e-16***
Trt:year	12	1635.2	136.3	3.7883	< 5.269e-05***
Loc:year	2	3030.6	1515.3	42.1262	4.132e-15***
Trt:loc:year	24	4374.6	182.3	5.0674	2.729e-10***
Loc:year:rep	12	4541.9	378.5	10.5224	1.046e-14***
Residuals	143	5143.8	36.0		

Trt – barley line; Loc – location; rep-replication

Sign. codes: 0 '*** '0.001 '**'0.01 '*'0.05

MS error=20.54369; DF=143; Mean= 30.060736; CV=15.07786

Sign. codes: 0 '*** '0.001 '**'0.01 '*'0.05

MS error= 35.97046; DF=143; Mean=17.52124; CV=34.23009

Table 3. Analysis of variance for dry matter-based grain test weight and moisture content.

Test weight (kg/hl)						Moisture content (%)					
	Df	Sum	Mean Sq	F value	Pr (>F)		Df	Sum Sq	Mean Sq	F value	Pr (>F)
Trt	12	6574	547.8	15.0444	< 2.e-16***	Trt	12	10.8474	0.90395	9.9868	5.137e-14***
Loc	2	55018	27508.9	755.4418	< 2.e-16***	Loc	2	3.5738	1.78689	19.7416	2.686e-08***
Year	1	7239	7239.4	198.8063	< 2.e-16***	Year	1	0.2912	0.29121	3.2173	0.0749753
Trt:loc.	24	7241	301.7	8.2853	< 2.e-16***	Trt:loc.	24	6.1318	0.25549	2.8227	7.455e-05***
Trt:year	12	2866	238.9	6.5598	< 2.957e-09***	Trt:year	12	3.9624	0.33020	3.6481	8.748e-05***
Loc:year	2	9725	4862.7	1333.5386	< 2.e-16***	Loc:year	2	1.1753	0.58763	6.4921	0.0020010**
Trt:loc:year	24	4040	168.3	4.6227	< 3.026e-09***	Trt:loc:year	24	5.9492	0.24788	2.7386	0.0001197***
Loc:year:rep	12	808	67.3	1.8492	0.04568*	Loc:year:rep	12	0.8542	0.07119	0.7865	0.6636944
Residuals	143	5207	36.4			Residuals	143	12.9435	0.09051		

Trt – barley line; Loc – location; rep-replication

Sign. codes: 0 '*** '0.001 '**'0.01 '*'0.05

MS error=36.41429; DF =143; Mean=43.21897; CV=13.96245

Sign. codes: 0 '*** '0.001 '**'0.01 '*'0.05

MS error =0.0905; DF=143; Mean=11.66687; CV=2.578717

Table 4. Analysis of variance for dry matter-based crude protein content and fine grind hot water extract.

Crude protein (%)						Fine grind hot water extract (%)					
	Df	Sum Sq	Mean Sq	F value	Pr (>F)		Df	Sum Sq	Mean Sq	F value	Pr (>F)
Trt	12	2181.70	181.808	79.4845	< 2.2e-16***	Trt	12	6074.2	506.19	34.2396	< 2.2e-16***
Loc	2	109.10	54.552	23.8494	1.153e-09	Loc	2	774.2	387.09	26.1836	2.045e-10***
Year	1	13.41	13.409	5.8624	0.01672*	Year	1	171.6	171.59	11.6068	0.0008535***
Trt:loc.	24	210.78	8.783	3.8397	2.342e-07***	Trt:loc.	24	1282.4	53.43	3.6144	8.356e-07***
Trt:year	12	270.38	22.531	9.8505	7.742e-14***	Trt:year	12	778.2	64.85	4.3868	6.073e-06***
Loc:year	2	93.27	46.637	20.3891	1.620e-08***	Loc:year	2	955.0	477.49	32.2987	2.662e-12***
Trt:loc:year	24	295.72	12.322	5.3869	5.004e-11***	Trt:loc:year	24	1406.6	58.61	3.9645	1.162e-07***
Loc:year:rep	12	53.73	4.477	1.9574	0.03236*	Loc:year:rep	12	247.9	20.66	1.3972	01736210
Residuals	143	327.09	2.287			Residuals	143	2114.1	14.78		

Trt – barley line; Loc – location; rep-replication

Sign. codes: 0 '*** '0.001 '**'0.01 '*'0.05

MS error=2.28734; DF=143Mean= 17.38021; CV= 8.701823

Sign. codes: 0 '*** '0.001 '**'0.01 '*'0.05

MS error=14.78366; DF=143; Mean= 71.07996; CV=5.409334

Mean Comparisons

Sieve test

On 2.8-mm diameter slots, the barley line 17148-16 was significantly different from all lines, including the check. The percentage of barley grain retained on the 2.8-mm sieve was 42.57, but the check gave 23.98, followed by line 3257-16, resulting in 12.62 (Table 5). Line 17204-5 grain plumpness on 2.8-mm slot sieve is the least (3.865) of all lines. The malt barley standard specifies that 35-40% of the grain be retained on 2.8-mm slot sieve, 40-50% on 2.5-mm, 5-10% on 2.2-mm and the amount passing through 2.2-mm slot sieve be 1%.

Table 5. Mean comparison for sieve test.

Sieve Test (%)											
> 2.8 mm			> 2.5 mm			> 2.2 mm			< 2.2 mm		
17148-16	**42.568333**	**a**	CHECK	51.76882	a	CHECK	51.76882	a	17204-5	27.233333	a
CHECK	23.979412	b	16820-16	43.90056	b	16820-16	43.90056	b	16863-2	24.002222	ab
3257-16	12.621111	c	16822-12	42.98444	b	16822-12	42.98444	b	3462-12	22.581667	abc
3436-9	10.772222	cd	3257-16	42.23056	bc	3257-16	42.23056	bc	3436-9	21.711667	abc
16910-19	9.963333	cde	16734-6	42.10833	bc	16734-6	42.10833	bc	3257-16	19.793333	bcd
16863-2	7.715556	cdef	**17148-16**	**41.72000**	**bc**	**17148-16**	**41.72000**	**bc**	16812-4	18.496111	bcd
16734-6	7.575000	cdef	16814-7	41.67222	bc	16814-7	41.67222	bc	16734-6	17.826111	bcd
16814-7	6.808333	def	3436-9	41.64556	bc	3436-9	41.64556	bc	16910-19	17.053889	cd
16822-12	6.787222	def	16910-19	40.36389	bcd	16910-19	40.36389	bcd	16814-7	16.857222	cd
16812-4	5.846667	def	16812-4	40.36389	bcd	16812-4	40.36389	bcd	16822-12	16.508333	cd
16820-16	5.631111	def	3462-12	36.08167	cde	3462-12	36.08167	cde	16820-16	14.928333	d
3462-12	4.765000	ef	16863-2	34.81444	de	16863-2	34.81444	de	CHECK	6.710588	e
17204-5	3.865000	f	17204-5	33.26500	e	17204-5	33.26500	e	**17148-16**	**3.472778**	e

Means with different letters are significantly different according to Tukey HSD test.

Test weight

Line 17148-16, which is the best in plumpness on 2.8-mm slot sieve, showed no difference in test weight compared to the check (Table 6). Line 17148-16 exhibited a test weight of 50.5 kg/hl and the check gave a test weight of 54.2 kg/hl.

Moisture content

For moisture content, there was no significant difference among the lines and the check except lines 17204-5, 3257-16, 16863-2, 16820-16, 16814-7 showing difference when compared to line 16910-19 (Table 6).

Table 6. Mean comparison for dry matter-based test weight, moisture content, dry matter-based crude protein and dry matter-based fine grind hot water extract.

Parameters											
Test weight (kg/hl)			Moisture content (%)			Crude protein (%)			Fine grind hot water extract (%)		
CHECK	54.19765	a	16910-19	11.98333	a	16910-10	20.44444	a	**17148-16**	**79.81111**	a
17148-16	**50.48778**	**ab**	16822-12	11.86667	ab	16812-4	20.31667	a	CHECK	78.25294	ab
16820-16	45.94889	bc	3436-9	11.81611	ab	16822-12	20.23889	a	3462-12	75.57111	abc
16910-19	44.48611	bcd	16734-6	11.79444	abc	3436-9	20.11667	a	3257-16	75.41611	bc
3436-9	44.19167	bcd	CHECK	11.79412	abc	16734-6	19.85000	a	17204-5	75.33333	bc
3462-12	44.19056	bcd	3462-12	11.77278	abc	16863-2	18.97222	a	16910-19	73.07222	cd
16812-4	44.01944	bcd	16812-4	11.72778	abc	16814-7	18.85000	a	16820-16	69.35000	de
16814-7	43.33944	cd	**17148-16**	**11.70000**	**abc**	16820-16	18.82778	a	16734-6	67.47778	ef
16734-6	43.31833	cd	16814-7	11.63333	bc	3462-12	14.79611	b	16822-12	67.28333	ef
16822-12	41.53000	cd	16820-16	11.62222	bcd	CHECK	13.95294	b	16863-2	67.22222	ef
3257-16	38.03500	de	16863-2	11.46111	cde	3257-16	13.82000	b	16812-4	66.38333	ef
16863-2	34.57944	e	3257-16	11.29333	de	17204-5	13.76667	b	16814-7	65.38333	ef
17204	34.13222	e	17204-5	11.21111	e	**17148-16**	**11.80000**	**c**	3436-9	63.88111	f

Means with different letters are significantly different according to Tukey HSD test.

Crude protein

The mean comparison among the lines for crude protein exhibited a difference when assessed using Tukey HSD. Barley line 17148-16 excelled all other lines, including the check. This line was found to have 11.8% crude protein, whereas the check variety's protein content was 13.95% which is beyond the malt barley protein limit of 13% for six-rowed barley and 12.5% for two-rowed barley (Table 6).

Fine grind hot water extract

The mean comparison among the lines, including the check, showed that line 17148-16 fulfilled crude protein requirement and gave a fine-grind hot water extract value slightly greater than the check even if the difference was statistically insignificant (Table 6). However, the result showed a statistically significant difference between line 17148-16 and lines 3257-16, 17204-5, 16910-19, 16820-16, 16734-6, 16822-12, 16863-2, 16812-4, 16814-7 and 3436-9.

DISCUSSION

Grain plumpness indicates the amount of starch contained and more plump malt barley grain is preferred to thinner ones. The sum of the percentages of grains from the best performing line 17148-16 on the exact sieve slot sizes was found to be 96.43%. Plump grains have more starch directly related to the amount of fine grind hot water extract. Line 17148-16 is beyond the EBC (European Brewery Convention) standard for the 2.8-mm slot sieve test. Two-rowed malt barley varieties released in Ethiopia, Singitan (IBON-MRA P# 26) (Tamene et al., 2016) and HB 1454 (Lakew and Fekadu, 2015) gave 98.3% and 93%, respectively when the percentage of grains retained on 2.8-mm, 2.5-mm and 2.2-mm slot sieves are summed.

Malt barley grain has to be uniform in plumpness, crude protein content, grain size, moisture content, test weight, thousand kernel weight and color for the malting process. Malt barley grains of different plumpness must not be malted together because grains of different plumpness imbibe water differently (Henry and Kettlewell, 1996). This leads to uneven germination, which results in different rates of enzymatic action and, therefore, different grain modification in the malting process and the occurrence of problems in the brewing process afterward. Therefore, sieve test results for 2.8-mm, 2.5-mm and 2.2-mm slot sieves are separately provided to decide whether a malt barley variety fulfills the plumpness specifications in the malt barley standard or not.

Test weight and thousand grain weight have a highly significant positive correlation with fine grind hot water extract (Sarkar et al., 2008). The test weight result obtained from the six-rowed barley lines evaluated in the present study (50.5 kg/hl) is comparable to a study conducted in India. A test weight in the range of 50.5-71 kg/hl in a study on 131 genotypes of two-rowed and six-rowed barley of Indian and exotic origin was reported by Sarkar et al. (2008). The EBC specifies malt barley test weight in 48-75 kg/hl. Therefore, line 17148-16 fulfilled the standard for the parameter test weight despite the absence of significant difference when compared to the check.

Moisture content is critical from harvest and storage to the final sale of malt barley. If the moisture content is beyond the set standard (11-13%), there is a risk of quality reduction or even grain loss in-store by molding and heating. Moisture level needs to be low to prevent heat damage and the growth of disease-causing microorganisms. The moisture content of malt barley should be less than 13% when stored (Henery, 2004). Cardoso et al. (2010) have found that malt barley samples with moisture content 11-11.5% after harvest and kept in plastic bags for five months resulted in the lowest germination percentage from higher moisture content. The bag with a higher moisture content range had a maximum CO_2 value of 13%, indicating higher respiration which is not suitable for safe storage. The moisture content obtained from the barley line 17148-16 (11.7%) and the check (11.8%) are not significantly different. These moisture content values are within the range required for this parameter.

There is a strong relation between grain crude protein content and the resulting malt and beer quality (Robinson et al., 2007). In this study, lines 3462-12, 3257-16, 17204-5 and the check did not show a significant difference in crude protein. All have about 14% crude protein content. The mean crude protein content of the rest of the lines ranged from 18.8% (line 16820-16) to 20.4% (line 16910-19). Excess crude protein in malt barley grain means the proportion of barley starch is less than the minimum requirement. Less starch content leads to less fine-grind hot water extract from the corresponding malt. Reduced amount of extract results in less volume of beer at the end of the brewing process. Crude protein content above the brewery standard causes haze which reduces beer quality (Robinson et al., 2007). The development of beer haze is greater when higher protein malt is used (Paynter, 2015).

The present study is in agreement with the previous results reported by Galano et al. (2008) which reported crude protein content that ranged from 8.4% to 9.5% for two-rowed barley varieties Beka, HB 120, HB 52 and Holker. The result also conformed to the crude protein standard set by the EBC (10.5-12.5% for two-rowed malt barley and 10.5%-13% for six-rowed barley). The crude protein exhibited by the promising line 17148-16 was also comparable to the experimental result obtained from different malt barley varieties (Liben et al., 2011; Tazebchew et al., 2018; Deme et al., 2019; Bekele et al., 2020).

Crude protein content is affected by several factors. Studies by different researchers show that grain crude protein content is affected by the rate of nitrogen fertilizer applied, the variety used, seed rate and the location where the crop is grown (Liben et al., 2011; Cai et al., 2013; Kassie and Tesfaye, 2019; Bekele et al., 2020; Ojha et al., 2020). Cai et al. (2013) revealed that grain protein content is significantly and positively correlated with soluble protein in malt and diastatic power and negatively correlated with fine malt grind hot water extract. According to Paynter (1996), high protein barley grains contain higher levels of gel proteins that can limit the separation of the fine grind hot water extract from the husk by blocking filter pores. This increases fine grind hot water extract filtration time and reduces the throughput of beer through the brewery. The gel proteins also limit the amount of starch that can be broken down into malt fine grind hot water extract during modification. Another consequence of excess protein barley intended to be malted for brewing is the change of flavor profiles of packaged beer with time. Bitterness decreases with time, while sweetness increases with time after packaging (Paynter, 1996).

Malt barley protein content must not be shallow to ensure that fermentation is not limited. Yeast requires soluble proteins which are obtained from the degradation of protein in the grain during malting. For stable foam, there should be sufficient protein in beer. Beer made from low protein malts may have foam stability problems that the foam disappears rapidly (Paynter, 1996). Lacing (adhesion of foam to the side of the glass) is also limited by a lack of protein in the grain. Since the crude protein content of the promising barley line in this study (17148-16) is neither too much nor too low, the beer from the corresponding malt is expected to be free from the protein-related problems mentioned.

The barley line 17148-16 have shown comparable fine grind hot water extract value with research findings in Ethiopia and other countries. In Ethiopia, Lakew and Fekadu, (2015) registered two-rowed malt barley variety HB 14541 developed at Holata to have an acceptable grind hot water extract value of 76%. Tamene et al., (2016) reported that the registered two-rowed malt barley Singtan (IBON-MAR p# 26) produced a fine grind hot water extract value of 78% in an experiment conducted for two consecutive years at Sinana, Gobba, Dinsho and Dodola areas. Galano et al. (2011) has also shown a fine grind hot water extract of 76.8-79.2% from two-rowed malt barley varieties Beka, HB 120, HB 52 and Holker grown at Holata. In Croatia, Mastanjevic et al. (2017) have obtained fine grind hot water extract of > 80% from malt barley varieties Tifanny and Vanessa. In a study done in India, Sarkar et al. (2008) reported a mean fine grind hot water extract of 77.93% and found a significant positive correlation with test weight, thousand-grain weight, bold grains (%), malt friability and homogeneity. In an assessment on spring malt barley in Poland, Gorzelany et al. (2019) found a mean fine grind hot water extract of 81.15%. Fine grind hot water extract requirements of the Asella Malt Factory in Ethiopia and the EBC is 77-79%. Therefore, the 79.8% fine grind hot water extract value exhibited by line 17148-16 fulfilled brewery requirement, making this line a potential material for six-rowed malt barley quality improvement endeavors in Ethiopia.

CONCLUSION AND RECOMMENDATION

Based on this study, six-rowed barley line 17148-16 fulfilled sieve test, test weight, moisture content, dry matter-based crude protein and dry matter-based fine grind hot water extract requirements. This line can be a potential source of genes responsible for grain plumpness, test weight, dry matter-based crude protein and dry matter-based fine grind hot water extract. Therefore, malt barley breeders, malt barley agronomists, malt factories and breweries in Ethiopia are advised to exploit this line. Similar work must also be carried out in the future to exploit the barley genetic resources in Ethiopia.

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