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Agronomic Performance of Food Barley (*Hordeum vulgare* L.) Varieties and their Response to Plant Density at West, Arsi Zone, Oromia Regional State of Ethiopia

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Abstract

Food barley grain is used to make different traditional food stuffs and drinks. The straw is also used for feed other purposes. National area coverage of barley in Ethiopia was around 959,273.4 ha. Food barley production share was estimated to be 90% while that of malt barley having a share of 10% in Ethiopia. The primary zones in Ethiopia for producing food and malt barley are in Oromia region, among which West Arsi zone, in particular, has great potential for cultivating both food and malting barley. Optimum plant population is an important yield determinant of food barley, but there is no information on the optimum barley plant density at west Arsi. Therefore, the field experiment was executed with the objective of evaluating the response of yield, yield components and related quality traits of food barley to plant population densities. Three food barley varieties and six levels of plant density were evaluated during growing season of 2018 and 2019 G.C. The design was split plot design with varieties assigned to main plot factor and plant density to sub-plot factor with three replications. The analysis result indicates the main effects of variety and fertilizer rate had significant effect on plant height, grain yield, biomass yield, number of grain per spike and harvest index. Plant population of 300 plants/ m2 (142 kg ha-1) gives higher (6311.1 kg ha-1) grain yield while the lowest grain yield (4268.8 kg ha-1) was scored at the lowest plant density (100 plants / m2). Plant density significantly affected above ground biomass and harvest index. The highest (16899 kg ha ha-1) and smallest (12026 kg ha-1) mean value of above ground biomass were recorded at 300 plants/ m2 and 200 plants/ m2, respectively. The highest harvest index was obtained at 130 kg ha-1 which is 42.2% while lowest harvest index was 33.4% recorded at 300plants/m2. Besides to this, the study was conducted that based on grain yield and yield components of food barley. Therefore the production of food barley with higher yield, optimal kernel protein concentration and higher economic benefit was obtained when plant population density of 300 plants/ m2 (142 kg ha-1) is used for the production of food barley varieties around West Arsi area and similar agro-ecology.

Keywords: Plant Density; Variety; Food Barley; Grain Yield

Introduction

Food barley (*Hordeum vulgare*) is estimated to be originated in Southwest Asia [1,2]. Barley cultivation was started 5000 BCE in Egypt, 2350 BCE in Mesopotamia, 3000 BC in northwestern Europe, and 1500 BCE in China [3].

"Barley serves as a source of nutrition for both humans and animals. About 75% of the barley produced is used for human consumption and 25% is used for livestock feed. Food barley (six-row barley) typically holds more protein and enzyme content and two-row barley (malt barley) has more carbohydrate content and a different taste. Barley can be consumed as bread, beverages, stews, and other dishes" [4]. It is a rich in fiber, molybdenum, manganese, selenium, copper, vitamin B1, chromium, phosphorus, magnesium and niacin [5].

Barley grain is used for the preparation of different traditional foods, such as Injera, Kita, bread, Kolo, Genfo (Porridge**)**, Beso , "Chuko", "Shameta (fermented porridge)", "Kinche (from cracked barley grain,", and Shorba, Tella (traditional beer) in Ethiopia [6,7].

Most of barley production (87%) in Africa was accounts to Algeria, Ethiopia and Morocco [8] from which Ethiopia represents almost a quarter of the entire output across the African continent [9]. Among malt barley and food barley, Ethiopia produces mostly food barley, with its share estimated to be 90% [10].

Food and Malt barley are largely produced in Oromia (Arsi, Bale, North Shewa) and Amara (North Gondar and West Gojjam) regions of Ethiopia [11]. "Kofele district in West Arsi is a favorable area for both food and malting barley production. Optimum plant density is an important yield determinant for food barley. Higher plant density results in higher plant competition which will enhance yield reduction and higher production cost. Similarly, lower seed rates may lower the grain yield. The variety also determines the target plant density rate for optimum grain yield of cops" [12]. West Arsi areas are potential for food barley production in Ethiopia however there is lack of information concerning barley plant density in this area. So, the experiment was designed to determine the optimum plant population for higher yield at West Arsi and similar agro ecologies.

Materials and Methods

Study Site Description

"This Experiment was executed for two consecutive years in the 2018 and 2019 during main cropping seasons at Oromia regional state, Kofele district in the Kulumsa Agricultural Research Center (KARC) substation. This site is located at $07^0 04' 27''$N latitude and $38^0 46' 45''$E longitude. The altitude of the site is 2660 meters above sea level. The distance from the capital city of Ethiopia (Addis Ababa) is 274 kilometers. The average annual minimum and maximum temperatures of the area are 7.9 and 16.6 °C, respectively. The region has a bimodal rainfall distribution and receives an annual rain fall of 1211mm". The soil type of the area is pellic vertisol (IUSS Working Group WRB, 2014).

Experimental Design and Treatment Arrangement

The field experiment was designed in a split-plot design with three replications. Food barley varieties were assigned to the main plot and plant density to sub-plot. The main plot factor had three food barley varieties (HB-42, EH1493 and HB1307) and the sub-plot factor had six levels of plant density (100 plants/m^2, 200 plants /m^2, 300 plants/m^2 , 400 plants /m^2, 500 plants /m^2 and 130kg/ha of seed as a control). Treatments and treatment combinations were assigned randomly to the experimental unit within each block.

Experimental Procedures

The experimental field was ploughed using a disc plough and harrowed by a tractor before planting. The field layout was done and each treatment was assigned randomly to experimental plots within each blocks in accordance to the design. Spacing of 1.5 m wide between blocks and 0.5 m between plots within a block were used. The growth plot area of 10.4 (2.6 m × 4 m) was used. The seeds were planted in rows by using a manual row marker at the beginning of July. Triple supper phosphate fertilizer of 100 kg ha^{-1} was applied across all treatments at the time of sowing and Split application of urea (46% N) fertilizer was used (half at planting and half at the tillering stage after weeding and during the presence of light rainfall to avoid the potential loss of nitrogen into the atmosphere). All other recommended agronomic practices were properly followed throughout the crop growth stage. The net plot area of 6 m^2 (2m × 3m) was harvested excluding the border rows within the range of middle of December to early January, depending on the maturity date of each variety.

Seed rate was calculated by using the following formula:

$$Sr\left(\frac{kg}{ha}\right) = \left[\frac{ttp.\left(\frac{\#}{m2}\right) * TKW(g)}{le}\right] \div 100$$

where:
Sr is the seed rate, tp is target plants (density?), thousand seed weight, is likely establishment
The average germination percentage of seed used for the experiment was 97%.

Data Collection

Data on yield, yield attributes and quality of food barley such as plant height, number of spikes per 50 cm, number of seeds per spike, grain and aboveground total biomass yields, harvest index, thousand kernel weights, and hectoliter weight were recorded. The plant height (from the soil surface to the tip of the spike excluding awns) was measured at physiological maturity and taken from ten randomly chosen plants in each plot. Harvesting for yield determination was done manually from the net plot area of 2m X 3m. The harvested samples were air-dried to constant weight to measure above ground biomass and finally trashed to separate straw and grain yield. The trashed samples of grain was cleaned and weighed to record grain yields. The weighed samples were adjusted to a standard moisture content of 12.5% and converted into kg ha^{-1} for the purpose of statistical analysis. In the physiology lab at KARC, the number of seeds per spike was randomly taken from each plot, and the corresponding kernel and hectoliter weights were calculated using seed counters and hectoliter weighing instruments. In the KARC plant nutrition laboratory, the Kjeldahl method was used to calculate the kernel N concentration.

Grain yield (kg ha^{-1}): grain yield was recorded and adjusted to 12.5% moisture content. Grain Yield (kgha^{-1}) at 12.5% moisture base = yield obtained (kg ha^{-1}) x (100−%mc)/(100−%MC), where, mc=Measured grain moisture content (%) and MC=the standard moisture content (12.5%) [13].

Harvest index: was calculated, as the ratio of dried grain weight adjusted to 12.5% moisture content to the dried total above-ground biomass weight and multiplied by100. Seed moisture content was determined using a seed moisture tester instrument.

Data Analysis

The recorded data were subjected to analysis variance using the general linear model (PROC GLM) procedure of SAS version 9.4. Plant density and food barley varieties were regarded as fixed effects, whereas year and replicates were regarded as random variables. Every experiment underwent a distinct analysis of variance, and then the homogeneity of the experimental errors was tested. Combined study across several years was carried out once the homogeneity of error variances was demonstrated. Significant differences between and/or among treatment means were compared using the least significant differences (LSD) test at $P \leq 0.05$.

Results and Discussion

Growth Parameters

Plant height: The analysis of variance revealed that plant height was significantly ($P < 0.05$) influenced by the main effect of plant population. But, this parameter was not significantly ($P > 0.05$) affected by varieties and the interaction effect of variety and plant population (Table 1).The plant height mean value increased with increasing plant population from 100 plants m^2-500 plants m^{-2}. The plant height value varies from 100.8 cm to 112.2 cm. The higher (112.2 cm) plant height was recorded from 500 plants m^{-2} plant population; which was statically comparable with the plant height obtained from 300-400 plant m^{-2}. The shortest (100.8 cm and 100.9 cm) plant height was recorded from 100 and 200 plant m^{-2}. The result of this experiment was in agreement with Soomro, et al. [14] which declared that high seeding rate produced greater plant height compared to low seeding rate. Similar finding was reported by Rahman [15,16] who elaborated that the higher density of plants increases umber competition for access to sunlight and it will also stimulate vegetative growth which results in increased plant height.

Spike length: The data of this study indicates the main effect of plant density, variety and interaction effect of the plant density and varieties didn't show significant effect on spike length (Table 1). The longer (5.4 cm) and the shortest (4.9 cm) spike length were recorded from EH1493 and HB-42 food barley variety. Even though the main effect of plant density do not significantly affect spike length the longest (5.5 cm) and the shortest (4.8 cm) spike length were obtained from (100 and 500) plants/ m^2 respectively. In contradict with this finding food barley varieties have different genetic potential regarding to spike length.

Yield and Yield Components

Number of grains per spike: The analysis of variance indicates that the main effects of food barley plant density was significant($P < 0.05$) for number of grains per spike, while the main effects of varieties and interaction effects of plant density and variety were not significant for number of grains per spike. The highest (54.0 and 53.7) and statically equal value of grains per spike was obtained from 300 plants m^{-2} and 200 plants /m^2 respectively. The lowest grain per spike (47.0) was obtained from the highest (500 plants/m2) food barley plant density. The same finding was reported by Soleymani, et al. [17] who elaborated that the increase of plant density (Seeding rate) could increase the number of spikes per unit area, but the number of seeds per spike was decreased. Likewise, Dereje, et al. [18] reported that kernels per spike of food barley showed significant difference for plant density.

Grain yield: The analysis of variance revealed that plant density showed highly significant difference ($p < 0.01$) in grain yield of food barley whereas variety and interaction effect of plant density and varieties did not show a significant difference in grain yield. The maximum grain yield (6311.1 kg ha^{-1}) of food barley was obtained at 300 plants/m^2 (142 kg ha^{-1}) seeding rate. Statically equivalent value with 300 plant/m^2 was also obtained from 500 plant/ m^2 and from control treatment with grain yield value of (5753.5 and 5665.1) kg ha^{-1} respectively (Table 2). On the other hand the lowest grain yield (4268.8kg/ha) was recorded at the lowest plant density (100 plants/m^2). This result agrees with the findings of Mehrpooyan M, et al. [19] and Nejad RD, et al. [20], who elaborated that the grain yield of barley was significantly affected by cultivars and planting densities per unit area. Moreover Dobocha D, et al. [18] who reported that the grain yield of food barley was significantly affected by plant density.

Dry biomass yield: The dry biomass yield was significantly ($P \leq 0.05$) affected by the main effects of plant density of food barley, However, this variable was not significantly (P> 0.05) influenced by the man effect of varieties and the interaction effect of varieties and plant density. The highest (16899 kg ha^{-1}) biomass yield of food barley was attended from 300 plants/m^2, followed

Variety	PH(cm)	SL(cm)
HB-42	103.4	5.1
EH1493	109.1	5.4
HB1307	104.7	4.9
LSD (0.05%)	NS	NS
plant density		
100 plants/m^2**(48 kg/ha)**	100.9b	5.5
200 plants/m^2 **(97 kg/ha)**	100.8b	5.1
300 plants/m^2 **(142 kg/ha)**	110a	5.4
400 plants/m^2**(187 kg/ha)**	110.7a	4.9
500 plants/m^2 **(229 kg/ha)**	112.2a	4.8
Control 130kg/ha	**110.8a**	5
LSD (0.05%)	4.1	NS
CV	10.6	12.4

Where: LSD = list significant difference, CV= coefficient of variance, PH= plant height and SL=spike length

Table 1: The main effects of plant density and varieties on growth parameters of food barley averaged over years.

Variety	GPS	GY(kg ha^{-1})	BY(kg ha^{-1})	HI (%)
HB-42	48.6	5274	13564	38.9
EH1493	55.4	5585	14291	39.9
HB1307	49.3	5082	13050	40.1
LSD (0.05%)	NS	NS	NS	NS
plant density				
100 plants/m^2**(48 kg/ha)**	51.4ab	4268.8d	13815ab	33.4b
200 plants/m^2 **(97 kg/ha)**	53.7a	4789.7cd	12026b	37.5ab
300 plants/m^2 **(142 kg/ha)**	54.0aa	6311.1a	16899ab	41.1a
400 plants/m^2**(187 kg/ha)**	48.7bc	5096.9bcd	12277bb	42.0a
500 plants/m^2 **(229 kg/ha)**	47.0cc	5753.5ab	13403bb	41.9a
Control 130kg/ha	51.7ab	5665.1abc	13390b	42.2aa
LSD (0.05%)	**3.5**	**893.97**	**3099.7**	**5.97**
CV	**7.2**	**17.47**	**23.61**	**15.63**

Where: LSD = list significant difference, CV= coefficient of variance, GPS= grain per spikes, GY= grain yield, BY= Biomass yield and HI= harvest index

Table 2: The effects of plant density and varieties on yield and yield components of food barley averaged over year.

(13815 kg ha^{-1}) biomass yield was obtained from 100 plants/ m^2.The lowest (12026 kg ha^{-1}) biomass yield was obtained from 200 plants / m^2 (Table 2). The present result is in agreement with the finding of Zewdie Bishaw, et al. [21] who reported "a positive association between biomass yield and plant height, thus taller plants resulted higher biomass yield". In contradiction with the present finding, Jemal Abdulkerim, et al. [22] also reported that "higher biomass yield was recorded on increased seeding rates of 200 and 175 kg ha^{-1}". Similarly, Iqbal, et al. [23] also found that biological yield increased as seeding rate increased from 125 kg ha-1 to 150 and 175 kg ha^{-1}. Moreover, Seleiman, et al. [24] confirmed that increasing seeding rates up to 350 or 400 grains m-2 increased grain, straw and biomass yields.

Harvest index: "The statistical analysis indicates that the harvest index was significantly ($P < 0.05$) affected by the main effects of plant density. Moreover, this parameter was not influenced by food barley varieties and the interaction effects of plant density and varieties. The harvest index reflects the ability of the genotypes to partition their dry matter into seed and straw, and the ability to maintain the right balance between seed and straw yield" [25]. The highest (42.2%) harvest index was obtained from control (130 kg ha^{-1}) plant density, followed by a statically equivalent mean value of harvest index was recorded from 200-500 plants/ m^2. The lowest (33.4 %) harvest index was recorded from the lowest (100 plants/ m^2) plant density (Table 3). Zeng and Shannon [26] also reported that at high density carbohydrate supply was limited, and thus resulted in the reduction of harvest index. Similarly, previous results of Zaheer, et al. [27] showed a reduction of harvest index due to high seed rate per unit area.

Grain Quality Parameters

Hectoliter weight: The analysis of variance indicates that HLW was significantly ($P<0.01$) affected by both the main effects of varieties and plant density, while the interaction of the two factors was the non-significant effect on this parameter (Table 3).The highest (68.2 kg hL^{-1}) was recorded from HB 42 variety followed by statically similar value obtained from EH1493 and HB1307 with its value of (64.0 and 65.1) kg hL^{-1} respectively. Hectoliter Variation among varieties might be due to the genetic makeup of food barley varieties. In agreement with this finding Tayyar S [28], who elaborated that hectoliter weight, was significantly influenced by genotype. The present result was also aligning with Biruk G, et al. [29] who stated that at favorable environmental condition, hectoliter weight is slightly increased with nitrogen level. Rick G, et al. [30] reported that the acceptable hectoliter weight for barley were in the range 66.1- 72.8 kg. Thus the current results exhibited acceptable hectoliter weight in all varieties.

Thousand kernel weight: The present results also revealed the presence of variation in thousand kernel weight among the tested varieties. The highest (57.5 g) and lowest (49.7 g) mean thousand kernel weights were obtained from HB42 and EH1493 food barley varieties, respectively (Table 3). This could be a result of the genetic behavior of cultivars that are favored by environmental variables; this could cause a rise in the process of photosynthesis and the build-up of carbohydrates in the grain, resulting in heavy seed, which could be linked to their innate potential. The highest (50.8 g) thousand kernel weight was recorded at the plant density of 300 plants/ m^2. A statically similar value of thousand kernel weight was also recorded from 200 plants/m^2 and 400 plants /m^2 (Table 3). The lowest (49.4 g) hectoliter weight was obtained from 100 plants/ m^2 .The decrease of thousand kernel weight in high densities could be related to lower carbohydrate supplies before pollination in stems containing spikes and higher breathing of crop in such densities which could decrease the continuity of leaf area and consequently limit grain filling. In line with this, Baloch, et al. [31] reported that thousand kernel weights decreased with an increase in seeding rate. Moreover Nejad, et al. [20] elaborated that as "the planting density increased, fewer photosynthetic materials were devoted to filling the grains due to the increase of interplant and intra-plant competitions and ultimately the thousand kernel weight decreased" [32-36].

Variety	TKW (g)	HLW(kg hL^{-1})
HB-42	57.5a	68.2a
EH1493	49.7c	64.0b
HB1307	43.1b	65.1b
LSD (0.05%)	2.6	1.5
plant density		
100 plants/m^2**(48 kg/ha)**	49.4c	65.0b
200 plants/m^2 **(97 kg/ha)**	50.4ab	66.4a
300 plants/m^2 **(142 kg/ha)**	50.8a	65.8a
400 plants/m^2**(187 kg/ha)**	50.5ab	65.9a
500 plants/m^2 **(229 kg/ha)**	50.2b	65.9a
Control 130kg/ha	50.0b	66.2a
LSD (0.05%)	**2.7**	**0.9**
CV	3.4	2.9

Where: LSD = list significant difference, CV= coefficient of variance, HLW= hectoliter weight and TKW= thousand kernel weight

Table 3: The effects of plant density and varieties on hectoliter weight and thousand kernel weight, of food barley averaged over year.

Conclusion

The field experiment was conducted during the main cropping season of 2017/18 and 2018/19 at Kofele sub-station of KARC, with the objective of evaluating the effects of plant population densities on the yield and yield components and related quality traits of barley varieties. Data on growth parameter, yield and yield components as well as quality parameters of food barley varieties were also collected and analyzed. Based on the present finding, among the six levels of plant density the use of 300 plants /m^2 was superior in most of agronomic traits and economic benefits. Therefore 300 plants/ m^2 plant density is recommended for all three in the study area and other similar agro-ecologies for optimal grain yield, and economic profit.

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