Journal of

Plant Sciences

ISSN 1816-4951

Academic
Journals Inc.

www.academicjournals.com

OPEN ACCESS Journal of Plant Sciences
ISSN 1816-4951
DOI: 10.3923/jps.2020.22.27

Research Article
Evaluation of Food Barley (*Hordeum vugarae* L.) Varieties by Varied Plant Population Densities in the Highlands of Arsi Zone, Southeastern Ethiopia

Dereje Dobocha, Wogayehu Worku, Fasil Shimeles, Almaz Admasu, Zenebe Mulatu and Debela Bekele

Ethiopian Institute of Agricultural Research, Kulumsa Agricultural Research Center, Wheat Regional Center of Excellence, Department of Agronomy and Crop physiology, P.O. Box 489, Asella, Ethiopia

Abstract
Background and Objective: Barley (*Hordeum vulgare* L.) is one of the major cereal crops grown in Ethiopia and for millennia it has been supplying the basic necessities of life for many in the Ethiopian highlands. This study was aimed to evaluate barley varieties as affected by various plant population densities in the highlands of Southeastern Ethiopia. **Materials and Methods:** In order to evaluate the effects of plant population densities on the yield and yield components and related quality traits of barley varieties, a split plot experiment in the form of randomized complete block design with 3 replications was carried out. The main factor consisted of three barley varieties and the sub factor consisted of 6 levels of planting density. **Results:** The results showed that EH1493 and HB1307 varieties was higher yielder than HB42 variety. The highest grain yield of EH1493 and HB1307 varieties were recorded at 261 plants m^{-2} or control whereas the highest yield of HB42 was obtained at 500 plants m^{-2}. The maximum values of 1000 grain weights of almost all three varieties were gained from 261 plants m^{-2}. The highest values of hectoliter weight was gained from 300, 200 and 400 plants m^{-2} for EH1493, HB1307 and HB42 varieties, respectively. **Conclusion:** In short, it was concluded that based on grain yield and related yield components 261 plant m^{-2} was economically feasible for the production of EH1493 and HB1307 food barley varieties around Lemu-Bilbilo areas and similar agro-ecologies.

Key words: *Hordeum vulgare* L., varieties, population density, grain yield, harvest index, grain weight, hectoliter weight

Citation: Dereje Dobocha, Wogayehu Worku, Fasil Shimeles, Almaz Admasu, Zenebe Mulatu and Debela Bekele, 2020. Evaluation of food barley (*Hordeum vugarae* L.) varieties by varied plant population densities in the highlands of Arsi zone, Southeastern Ethiopia. J. Plant Sci., 15: 22-27.

Corresponding Author: Dereje Dobocha, Ethiopian Institute of Agricultural Research, Kulumsa Agricultural Research Center, Wheat Regional Center of Excellence, Department of Agronomy and Crop physiology, P.O. Box 489, Asella, Ethiopia

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Barley (*Hordeum vulgare* L.) is one of the major cereal crops grown in Ethiopia. For millennia it has been supplying the basic necessities of life (food, feed, beverages and roof thatching) for many in the Ethiopian highlands[1]. Barley is a cool-season crop that is adapted to high altitudes. It is grown in a wide range of agro climatic regions under several production systems at altitudes of about 3000 m.a.s.l or above, it may be the only crop grown that provides food, beverages and other necessities to millions of people. Barley grows best on well-drained soils and can tolerate higher levels of soil salinity than most of other crops[2].

Barley has a long history of cultivation in Ethiopia as one of the major cereal crops and it is reported to have coincided with the beginning of plow culture[1]. Barley types are predominantly categorized as food and malting barley based on their uses, while in Ethiopia the highest proportion of barley production area is allocated for food barley. Food barley is principally cultivated in the highland areas of Ethiopia where the highest consumption is in the form of various traditional foods and local beverages from different barley types[3]. It is commonly cultivated in stressed areas where soil erosion, occasional drought or frost limits the ability to grow other crops[2].

Although Ethiopia is a centre of diversity for barley, most of the farmers in the country still obtain very low yields due to a combination of genetic, environmental and socioeconomic constraints[4]. Barley is the most dependable and desirable crop for the resource-poor highland farmers where poor soil fertility, frost, water logging, soil acidity and soil degradation are the major yield limiting factors and where other cereals fail to grow. In such areas, barley is the major source of food, home-made drinks, animal feed and cash[5].

Agronomic practice that includes seed and fertilizer rate determines the production and productivity of crops. Row spacing and seed rate in barley is an important agronomic practice to maximize the yield and quality of barley crop[6]. Proper row spacing is important for maximizing light interception, penetration, distribution in crop canopy and average light utilization efficiency of the leaves in the canopy and thus affect yield of a crop[7].

Plant density defines the number of plants m^{-2}, which in turn determines the area available to each plant[8]. This determines the yield and productivity of a particular crop. Like many other researchers, Ahmadi and Hossein[9] have reported that in order to achieve greater production per area unit, in addition to having good cultivars which are compatible with the environment plants reaction and their side requirements such as the number of plants per area unit are highly significant. Recently, Holeta Agricultural Research Center has released food barley varieties EH-1493, HB-42 and HB-1307 for the potential areas of the country with no specified plant populations per unit area and with seed rate of 125 kg ha^{-1} which is approximately 261 plants m^{-2} estimated from average test weight and seed rate of 3 varieties. Plant populations per meter square vary with varieties in a given period. Since plant population per meter square has a direct effect on the cost of seed and final yield, information on this line is highly vital when a new variety is released and growing environments are changed. Optimum plant density of a crop variety at one location may not apply at other locations because of variation in soil type and other environmental conditions. thus, there is a need to develop site-specific recommendations. Therefore, the recommendation suggested at one time could be used for some time based on maturity groups and growth habit and other associated management factors. Hence, the objective of this study was to determine the optimum plant population's unit per area on yield and yield components of different food barley varieties.

MATERIALS AND METHODS

Description of experimental site: The experiments were conducted at Lemuna Bilbilo district of Oromia Regional state, Southeastern Ethiopia under on-farm conditions (3 farmer's fields) during the 2016-2017 main cropping seasons. The experimental sites are located at 07°31'72''-07°32'79'' North latitude and 39°13'54''-39°17'31'' East longitude, altitude ranges of 2631-2817 m.a.s.l. Nitosols dominated the soil of the area[10]. Rainfall data recorded at experimental sites weather stations indicated that the rainfall was nearly normally distributed during the experimental years. The areas received an annual rainfall of 996-957 mm during the 2016-2017 cropping seasons, respectively (Fig. 1). The mean maximum and minimum temperatures of the areas during the 2016-2017 growing seasons were ranges 20-20.3 and 3.7-4.2°C, respectively. It was indicated that the highest mean maximum amount of rainfall was received in August-July, respectively (Fig. 1).

Experimental design and procedure: The experiments were conducted at Lemu Bilbilo Districts on three farmer's fields for 2 years (2016-2017) in main cropping seasons. The experiments were laid out in a randomized complete block design in split plot arrangement consisting of 3 food barley varieties (V1 = EH1493, V2 = HB42 and V3 = HB1307) as main plot and 6 plant population densities (P1 = 100 plants m^{-2}, P2 = 200 plants m^{-2}, P3 = 300 plants m^{-2}, P4 = 400 plants m^{-2} and P5 = 500 plants m^{-2}. Recommended seed rate of 125 kg ha^{-1} (261 plants m^{-2} as a control) as a subplot with 3 replications. Urea (46% N) 50 kg ha^{-1} was used as source of N in split form of application (1/3 at planting and 2/3 at tillering) as top dress as per the treatments. Basal application of NPS was used at the rate of 121 kg ha^{-1} at time of planting to all experimental units. The size of the subplot was 4×2.6 m and the distance between subplot and blocks (rep) were 1 and 1.5 m, respectively. Other agronomic practices were properly carried out as per the recommendations of the areas.

Data collected: Agronomic parameters collected included plant height, spike length, seeds $spike^{-1}$, grain yield ha^{-1}, Thousand Grain Weight (TGW), Hectoliter Weight (HLW) and Harvest Index (HI) which is calculated by the ratio of grain yield to biological yield. To estimate grain yield of food barley, the net plot sizes of 2×3 m (6 m^2) were harvested from each plot in December. After threshing, the harvested materials

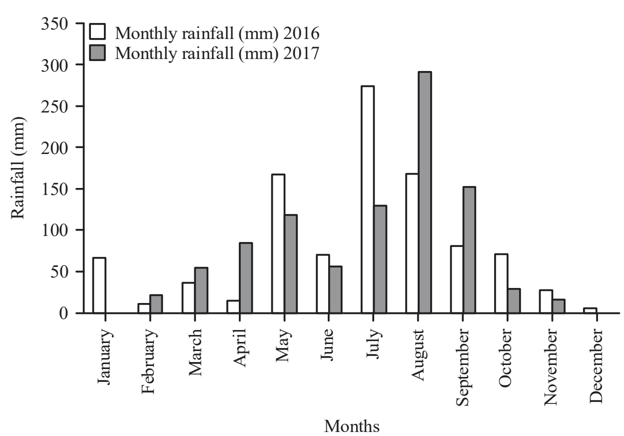

Fig. 1: Monthly rainfall (mm) during the experimental years (2016-2017) at Lemu Bilbilo Districts

(grains) were cleaned, weighed and adjusted to 12.5% moisture level. The total seed yields recorded on a plot basis were converted to kg ha^{-1} for statistical analysis.

Statistical analysis: The crop data were subjected to analysis of variance using the General Linear Model procedure of R computer[11] software version 3.5. Data were not combined over the year due to heterogeneity. Whenever treatment effects were significant, the mean differences were separated using the Least Significant Difference (LSD) test at 5% level of significance.

RESULTS AND DISCUSSION

The results from the analysis of variance indicated significant effects of food barley varieties and population densities on most of the variables studied (Table 1). The interaction effects of varieties by population densities were less important.

Impact of variety: All parameters tested in this experiment; spike length, number of seeds per spike, grain yield, harvest index, 1000-grain weight and hectoliter weight were highly significantly (p<0.01) affected by varieties except plant height which showed non-significant among varieties (Table 1). The EH1493 had higher spike length, number of seeds per spike, grain yield, harvest index and hectoliter weight than HB1307 and HB42 varieties whereas HB42 was higher in 1000-grain weight than the rest two varieties (Table 2). The highest spike length was obtained from EH1493 variety. High density development of inflorescence per plant (potential seed number) will compete in the situation and the smaller size of the spike[12]. Similar to this, it was reported that production of grains per spike reduced photosynthesis and carbohydrate production materials produced by the spike[13]. These results are confirmed by other investigators[14]. The relative advantage in grain yield of EH1493 variety might be largely attributed to

Table 1: Mean squares of plant height, spike length, number of seeds $spike^{-1}$, grain yield, harvest index, 1000-grain weight and hectoliter weight, as affected by main and interaction effects of varieties and population densities

Mean squares								
Sources of variation	DF	PLH (cm)	SL (cm)	SPS	GY (kg ha^{-1})	HI (%)	TGW (g)	HLW (kg hL^{-1})
Replication	2	69.0^{ns}	0.4^{ns}	15.1^{ns}	712390.0^{ns}	4.3^{ns}	2.2*	5.2^{ns}
Variety (V)	2	79.0^{ns}	4.9**	223.2**	30844631.0**	170.4**	277.0**	89.0**
Error (a)	4	91.4	0.2	8.7	936027.0	7.6	0.3**	1.2
Plant population (P)	5	187.0**	0.3*	36.6*	6493460.0**	54.0^{ns}	2.1**	1.9*
V×P	10	20.0^{ns}	0.2^{ns}	20.8^{ns}	718065.0*	14.1^{ns}	3.2**	2.3**
Error (b)	30	17.3	0.1	14.2	293750.0	30.6	0.3	0.6

DF: Degree of freedom, PLH: Plant height, SL: Spike length, GY: Grain yield, HI: Harvest index, SPS: No. of seeds/spike, TGW: 1000-grain weight, HLW: Hectoliter weight, SPS: Seeds per spike, *Significant, **Highly significant, ^{ns}Non-significant at 5% probability level

Table 2: Mean values of plant height, spike length, number of seed spike^{-1}, grain yield, harvest index, 1000-seed weight and hectoliter weight, as affected by variety and plant populations

Varieties	PLH (cm)	SL (cm)	SPS	GY (kg ha^{-1})	HI (%)	TSW (g)	HLW (kg hL^{-1})
EH1493	111.3	8.6^{a}	56.2^{a}	5620.9^{a}	45.8^{a}	44.9^{c}	70.6^{a}
HB1307	107.9	7.8^{b}	51.2^{b}	5492.7^{a}	39.7^{b}	48.3^{a}	69.5^{b}
HB42	107.6	7.6^{b}	49.3^{b}	3292.3^{b}	43.6^{a}	52.7^{b}	66.4^{c}
LSD 0.05	NS	0.4	2.7	895.4	2.5	2.5	1.0
Plant populations							
100 plants m^{-2}	103.1^{b}	8.3^{a}	54.0^{b}	3195.4^{c}	54.1	47.8^{c}	68.0^{b}
200 plants m^{-2}	103.1^{b}	8.1^{ab}	54.4^{a}	4534.6^{b}	54.4	48.8^{ab}	69.4^{a}
Control (261 plants m^{-2})	110.8^{a}	7.8^{bc}	50.0^{e}	5229.8^{a}	50.0	49.2^{a}	68.8^{a}
300 plants m^{-2}	112.2^{a}	8.0^{abc}	52.4^{d}	5061.0^{a}	52.4	48.9^{ab}	68.9^{a}
400 plants m^{-2}	111.4^{a}	8.1^{ab}	52.8^{c}	5393.4^{a}	52.8	48.6^{b}	68.9^{a}
500 plants m^{-2}	112.9^{a}	7.7^{c}	49.6^{f}	5397.6^{a}	49.6	48.4^{b}	69.2^{a}
LSD 0.05	3.9	0.3	0.3	521.8	NS	0.5	0.7

PLH: Plant height, SL: Spike length, SPS: No. of seed per spike, GY: Grain yield, HI: Harvest index, TSW: Thousand seed weight, HLW: Hectoliter weight, means followed by the same letter(s) within a column are not significantly different from each other at 5% level of significance, ^{ns}Non-significant

its higher spike length, number of seeds/spike and genotypic makeup of the variety. This result was in agreement with Abtew *et al*.[15] who reported a notably superior performance of grain yield between food barley varieties. On the other hand, cultivars with high harvest index are able mobilize more carbohydrates from green plants organs and thus increase the yield[16]. In another study, Ghorbani *et al*.[17] reported that even though the harvest index increased as the grain yield increased, the proportion of such increase for biological yield was more than the increase of harvest index.

Impact of plant population densities/unit area: Plant height, spike length, number of seeds per spike, grain yield, 1000-grain weight and hectoliter weight were highly significantly (p<0.01) affected by plant population densities/unit area except harvest index which showed non-significant among plant population densities (Table 1). Plant height was increased from 100-300 plants m^{-2} and the increments was inconsistent after 300 plants m^{-2} (Table 2). The result was in line with that of Rahman[18] who reported that increasing the density of plants increased umber competition for access to sunlight and it will also stimulate excessive vegetative growth and increased the plant height. The same finding was reported by Farnia *et al*.[13]. The highest spike length was obtained from the lowest plant populations per unit area. The highest value of seeds per spike (54.4) was recorded from 200 plants m^{-2} whereas the lowest seeds per spike (49) were obtained from the lowest plant populations per unit area. In line with this result, Soleymani and Shahrajabian[19] who stated that the increase of applied seeds could increase the number of spikes per unit area, but the number of seeds/spike was decreased. Even if no significant difference among control, 300, 400 and 500 plants m^{-2}, The mean comparison of different density levels showed that the highest and the lowest grain yield belonged to the density of 100 seeds m^{-2} by the average of 5397.6 kg ha^{-1} and the density of 500 seeds m^{-2} by the average of 3195.4 kg ha^{-1} (Table 2). The reason could be due to the fact that as the density increased, the grain yield increased too which was due to higher biological yield, harvest index and the number of grains per spike in the highest grain yield in comparison to low densities. Moreover, the main reason of the highest grain yield in higher densities was the greater number of spikes in those densities[20]. Ahmadi and Hossein[9] stated that the main reason of the difference between grain yields in different densities was associated with the number of plants m^{-2}, so that as the plant density increased the recent component significantly increased and devoted the most changes to it in comparison to other two yield components. Actually, the higher number of grains/spike and also the heavier weight of 1000-grain in low densities of plant could not compensate for the yield reduction due to fewer number of spikes/area unit.

Interactions between treatments: The analysis of variance results showed that the interaction effect of the treatments on grain yield, 1000-grain weight and hectoliter weight were significant at 1 and 5% level, respectively (Table 1). Grain yield of EH1493 and HB1307 varieties were increased with increasing plant population densities up to 261 plants m^{-2} or control whereas the yield of HB42 increased with increasing plant populations m^{-2} unless no statistical difference among control, 300 and 400 as well as 400 and 500 plant population densities per unit area (Fig. 2a). The results were consistent with the findings of Mehrpooyan *et al*.[21] and Nejad *et al*.[20] reported that grain yield of barley was significantly affected by cultivars and planting densities per unit area. The 1000-grain

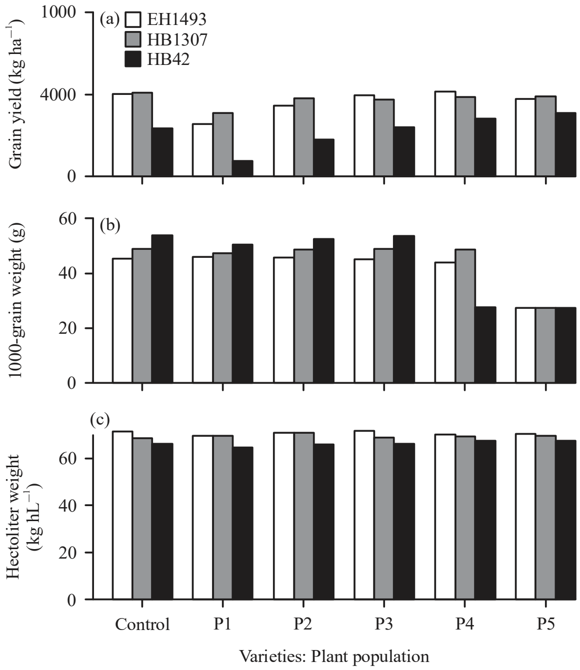

Fig. 2(a-c): Interaction effect of plant populations and varieties on (a) Grain yield, (b) Thousand grain weight and (c) Hectoliter weight of food barley combined over sites and years

P1: 100 plants m^{-2}, P2: 200 plants m^{-2}, P3: 300 plants m^{-2}, P4: 400 plants m^{-2}, P5: 500 plants m^{-2}

weights of almost all 3 varieties were showed increasing trends with plant population densities up to control (Fig. 2b). The decrease of 1000-grain 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, Nejad *et al.*[20] reported that as the planting density increased, less photosynthetic materials were devoted to filling the grains due to the increase of interplant and intra-plant competitions and ultimately the weight of 1000-grain decreased. In terms of hectoliter weight, it was increased with increasing plant population densities up to P3 for EH1493 variety whereas it was increased up to P2 for HB1307 variety and the increment was inconsistent for HB42 variety in which the highest value of its hectoliter weight was recorded at P4 and P5 unless non-significant difference among them and P2 (Fig. 2c). This might be due to the genetic makeup of food barley varieties. The present study was also in line with the report of Tayyar[22] who stated hectoliter weights of the varieties were significantly influenced by wheat varieties.

CONCLUSION

The two year study revealed that EH1493 and HB1307 varieties were higher yielder than HB42 variety. The highest grain yield of EH1493 and HB14307 varieties were recorded at 261 plants m^{-2} whereas at 500 plants m^{-2} for HB42 variety. The maximum values of 1000-grain weights of almost all three varieties were gained from 261 plants m^{-2}. The highest values of hectoliter weight (71.6, 70.8 and 67.5 kg hL^{-1}) was gained from 300, 200 and 400 plants m^{-2} for EH1493, HB1307 and HB42 varieties, respectively. In short, based on grain yield and yield related traits 261 plant m^{-2} was economically feasible for the production of EH1493 and HB1307 varieties around Lemu-Bilbilo areas and similar agro-ecologies.

SIGNIFICANCE STATEMENT

The present study discovered the evaluation of the beneficial effects of plant population densities for increased yield by enhanced yield components and related quality traits for productivity of food barley varieties. This study will help the researchers to uncover the critical areas of specified plant populations/unit area that many researchers were not able to explore. Thus, the significant finding of this study could add to the knowledge regarding plant populations per meter squares response to the yield and productivity of food barley varieties.

ACKNOWLEDGMENT

The author would like to thanks the Journal of Plant Sciences for publishing this article free of cost and to Karim Foundation for bearing the cost of article production, hosting as well as liaison with abstracting & indexing services, and customer services.

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