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Determination of Optimum Plant Densities for Malt Barley (*Hordeum vulgare L.*) Varieties in Lemu-Bilbilo District, Highlands of Arsi Zone

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Abstract

Detecting optimum plant density is one of the important agronomic practices to improve the production and productivity of malt barley varieties. Therefore, this study was initiated to determine the right plant densities to advance the production and productivity of malt barley varieties in Lemu-Bilbilo district, highlands of Arsi zone, Southeastern Ethiopia on two farmers' fields during 2017 main cropping season. The treatments studied include three malt barley varieties (Bekoji1, EH1847 and Travler) assigned to main plot and six plant densities (D1 = 100 plants m^{-2}, D2 = 200 plants m^{-2}, D3 = 300 plants m^{-2}, D4 = 400 plants m^{-2} and D5 = 500 plants m^{-2} and D6= Recommended seed rate of 100 kg ha^{-1} (as a control) assigned to sub-plot. The experiments were carried out in randomized complete block design in split plot arrangement with three replications. The results revealed most of the studied agronomic parameters significantly affected by the main as well as the interaction effect of varieties and plant densities at both experimental fields. Travler was the dwarf variety when compared with Bekoji1 and EH1847 varieties. Increasing plant densities resulted in decreased spike length even though the increment was inconsistent for Travler variety. The promising yield was gained from the combination of Travler with control, Bekoji1 and EH1847 with D3, but the yields of two varieties statistically at par with control seed rate at field 1 whereas from EH1847 and Travler at D4, Bekoji1 at D2, but didn't show significant with the yield obtained from control at field 2. The highest value of harvest indexes were noted from Travler and EH1847 sown with D1 while statisticaly at par with control whereas for Bekoji1 at control. The heavier and lighter 1000-kernels weight (51.15 g, 44.92 g) were gained at D1 and D5, respectively. Moreover, the above ground dry biological yield difference of EH1847 at D4, Travler at D5 and control showed non-significant at field 1 whereas between Bekoji1 at D4, EH1847 at D5 and control at field 2. Thus, in view of the present study findings seed rate of 100 kg ha^{-1} can be suggested for the production and productivity of EH1847 and Travler malt barley varieties at the experimental fields and similar agro ecologies.

Keywords

Malt Barley, Plant Densities, Varieties, Yield and Yield Components

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1. Introduction

Malt barley (*Hordeum vulgare L.*) is mainly a cost-effective crop produced for industrial malt grain production, cottage and for local beer as well as alcohol production [1]. It is considered as one of the cash crops and its demand by malt factory has increased due to its better capability of processing and the growth of breweries and beer intake levels in Ethiopia [2]. However, only about 35–40% of the industrial demands supplied from internal production and the remaining quantity

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is imported from abroad by foreign currency [3]. Regardless of the importance of barley as a food and malting crop, the efforts made so far to generate improved production technologies and its productivity has remained low. For example, its average national yield is about 1.97 t ha^{-1}, which is low compared to the world average of 3.1 t ha^{-1} [4].

The low yield of barley is partly recognized to cultivation of unimproved low yielding varieties, low level of soil nutrient contents particularly nitrogen and phosphorus, lack of appropriate seeding rate, the influence of several biotic and a biotic stress and the minimal promotion of improved barley production technologies [5]. As a result of these, using optimum seeding rate is one of the most important factors to maximize productivity and improve the qualities required for malting purpose. If more seed rate is used, plant population might be more and there might be competition among plants for water, nutrients and sunlight resulting in low quality and low yield. On the other hands, when low seed rate is used yield might be lower due to lesser number of plants per unit area [6]. Therefore, to alleviate these constraints and exploit the genetic yield potential of barley more effort is needed among others, assessing them under different agronomic practices. In line with this, the researches investigation to date showed that the crop plants should cover the soil as early as possible to intercept maximum sunlight to produce higher dry matter as the intercepted solar radiation and dry matter production are directly related to each other [7]. Optimum seeding rate resulted in more uniformity of barley kernels, which improves the modification process and produces higher quality malt whereas kernels weight declines with increasing seeding rate and which in turn reduce malt acceptability [8].

The level of quality of barley for malting is determined to a large extent by the agronomic practices carried out by the farmer, particularly the level of nitrogen fertilization, seeding rates and dates [9], by the choice of variety [10], former crop remains [11] and cultivation systems [12]. The effects of seeding rate on barley yield and malting quality have been variable, but most studies have indicated little or no improvement in yield at rates above optimal seeding rate [13]. In general, increasing barley seeding rates tended to reduce protein concentration, but kernel plumpness and weight were also reduced (8). This presents a problem because maltsters require relatively plump seed, which also has relatively low protein concentration. In a study so far, it was found that seeding malting barley at 400 compared with 200 seeds m^{-2} reduced kernel plumpness, but also resulted in earlier maturity, lower protein concentration and more uniform kernels [14]. This is important because lower protein results in more uniform kernels, thus ultimately yielding more homogenous malt [15]. Yield related parameters such as: productive tillers per plant, number of grains per spike and 1000- kernels weight are more useful criteria for selecting evolving high yield varieties due to their high heritability values and direct effect on grain yield [16]. The same seeding rate recommendations are generally made for all malt barley varieties in Ethiopia including the study area regardless of their seed size and tillering capacity. Nevertheless, such recommendation on seeding rate is not addressing the required optimum yield and quality of the malting barley varieties and hence need to be custom made. Therefore, this study was conducted with the objective of determining the optimum plant densities to improve the production and productivity of malt barley varieties in Lemu-Bilbilo district, highlands of Arsi zone.

2. Materials and Methods

2.1. Description of the Study Areas

On-farm field experiments were conducted in 2017 growing season at Lemu-Bilbilo district, Oromia region. The study area is one of the major wheat growing areas in the region. The trial was conducted in two farmers' fields located at 39° 15’ 39” E and 07° 32’ 80” N, altitude of 2805 meter above sea level for field 1 and at 39° 13’ 87” E and 07° 36’ 88” N, altitude of 2606 meter above sea level for field 2. Lemu Bilbilo district is located 235 km away from Addis Ababa to Southeast direction. The average mean minimum and maximum temperature are 7.9 and 18.6°C, respectively. It receives mean annual rainfall of 1020 mm with pseudo bi-modal distribution and maximum (202 mm) occurs in August (KARC, unpublished). Wheat, malt and food barley, faba bean and field pea are the most common crops cultivated in study site. Nitosols dominated the soil of the experimental areas [17] and silty clay in texture [18].

2.2. Experimental Design and Procedure

The experiments were conducted during the 2017 main cropping season under rain fed conditions at Lemu-Bilbilo district of Arsi Zone of Oromia Regional State at two farmers’ fields. The experiment comprised of 18 treatments with three malt barley varieties and six levels of plant densities m^{-2}, laid out in randomized complete block design in split plot arrangement with three replications. The main plots consisted of varieties (Bekoji1, EH1847 and Travler) and sub-plot with plant densities (D1 = 100 plants m^{-2}, D2 = 200 plants m^{-2}, D3 = 300 plants m^{-2}, D4 = 400 plants m^{-2} and D5 = 500 plants m^{-2} and D6= Recommended seed rate of 100 kg ha^{-1} (as a control). The net plot size was 2.6 m * 2.4 m (6.24 m^{2}), and the spacing between main plots and sub plots was 1 m and 0.5 m, respectively. The distance between blocks was 1.5 m. Urea (46% N) 50 kg ha^{-1} was used as source of N in split form of application (2/3 at planting and 1/3 at tillering) as top dress. Basal application of NPS was used at the rate of 100 kg ha^{-1} at time of planting to all experimental units. Other agronomic practices were properly carried out as per the recommendations of the areas. Finally, the seed rate kg ha^{-1} for densities of plants m^{-2} are calculated by using the following formula: Seed rate (kg ha^{-1}) = number of plants m^{-2} ∗ 1000-kernels weight (g) / field establishment (%).

2.3. Data Collected

Data on growth, grain yield and yield components such as plant height, spike length, number of grains per spike, thousand kernel weight (TKW), Harvest index, grain, and above ground biological yields were collected and measured at the recommended time. Harvesting was done by hand using sickles. Hundred-culm weight (100 cw) were collected from four points within a net plot and slashed from close to the ground surface and the dry matter yield of aboveground biomass was determined. The harvest index (HI) was calculated as the ratio of grain yield from hundred-culm to above ground biomass yield of hundred-culm weight expressed as a percentage. Grain yield was determined from 6.24 m ^{2} net plot by hand threshing of the harvested samples. Yield adjustments were made based on 12.5% moisture content. After threshing, grain samples were randomly taken and TKW was determined using seed counter then determined by weighing 1000 grains. The number of grains per spike was determined by hand counting of the grains from five spike samples and averaging them.

2.4. Statistical Analysis

All growth, yield and yield components data collected were subjected to analysis of variance using the General Linear Model procedure of R computer software version 3.6.1 [19]. Data were analyzed for each two trials individually across tested sites. Whenever treatment effects were significant, the mean differences were separated using the Least Significant Difference (LSD) test at 5% level of significance.

3. Results and Discussion

Plant height

The response of varieties on plant height was highly significant ($P<0.01$) at both field 1 and 2 while the response of plant densities and the interaction of varieties versus plant densities were showed non-significant. Bekoji1 was found to be the tallest variety, with 112.17 and 95.83 cm high at field 1 and 2, respectively but, the difference in plant height between Bekoji1 and EH1847 was significantly at par at field 2. Travler was the shortest malt barley variety, with recorded plant height of 60.00 and 57.22 cm at field 1 and 2, respectively. This result was agreed with findings of Kefale and Hawassa [20] who stated varietal difference in plant height might be due to genetic behaviour in combination with locations, but not due to spacing. Likewise, Shahzad *et al.* [21], Jemal *et al.* [22] and Abebe [23] found that the height of the crop is mainly controlled by the genetic makeup of varieties.

Spike length

The main effect of varieties and plant densities didn't show significant ($p<0.05$) on average spike length at both field 1 and 2, but the interaction effect of varieties versus plant densities were showed significant ($p<0.05$) at field 1 and showed non-significant at field 2. From visual observation of figure 1, the results indicated that the highest spike length of all three varieties were gained at the lowest plant density of 100 plant m^{-2} and the spike length difference of Travler and EH1847 as well as EH1847 and Bekoji1 varieties were significantly the same. The result of this study revealed that increasing plant densities resulted in decreased spike length even though the increment was inconsistent for Travler variety. This might be due to the lower competition for growth resource between plants at low plant densities per unit area of land. The result was conformity with that of Lake [24] who reported that longer spike length was recorded at lower seed rate. On the other hand, Shahzad *et al.* [21] identified that the varietal difference in spike length is controlled by genetic makeup of the genotype and the environmental magnitude.

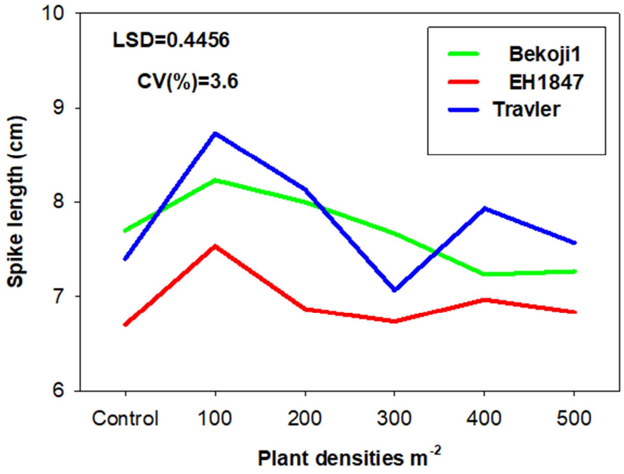

Figure 1. Interaction effect of varieties and plant densities on spike length of bread wheat at field 1 (a).

Number of grains spike^{-1}

The analysis of variance indicated that the main effect of varieties and plant densities were highly significantly ($p<0.001$) affected number of grains spike^{-1} and the interaction of varieties versus plant densities didn't show significant with respect to number of grains spike^{-1} of malt barley at field 1, but neither the main effects of varieties and plant densities nor their interactions showed significant ($p<0.05$) on number of grain spike^{-1} at field 2. Bekoji1 variety was found to have the maximum number of grains spike^{-1} (29.26) and showed significant difference with both EH1847 and Travler varieties, but the number of grains spike^{-1} of EH1847 was showed non-significant with that of Travler variety at field 1 (Table 1). The result was in line with the work of Bogale *et al.* [1] who reported that genetic characteristics of different malt barley varieties were contribute different number of grains per spike. Likewise, Abdoli and Saeidi [25] testified that significant differences were found among varieties in terms of the number of grains per spike. On the other hand, the peak number of grains spike^{-1} (28.44) was recorded at the lowest plant density of 100 plants m^{-2} and showed significant with 500 plants m^{-2}, but didn't show significant with the rest plant densities including control (Table 1). That could be due to the fact that, at the lowest plant density, there is enough spacing that permits appropriate distribution of light, water, nutrients and other growth resources to have better number of grains per spike at a given area of land. Conversely, the lower number of grains spike^{-1} at the upper plant density might be as a result of higher competition between plants for growth resources. The result obtained was in line with that of Whaley *et al.* [26] who found that number of grains spike^{-1} increased by 50% in wheat plants when crop density decreased. Furthermore, Kiliç and Gürsoy [27] stated that a consistent decrease in number of grains spike^{-1} with increasing seed rate.

Table 1. Effect of varieties and plant densities on some agronomic parameters of bread wheat in two farmers' fields in Lemu-Bilbilo District of Oromia, Ethiopia in 2017.

Treatments	Field 1				Field 2		
	PLH (cm)	GPS	HI (%)	TKW (g)	PLH (cm)	SL (cm)	GPS
Varieties							
Bekoji1	112.17a	29.26a	35.56c	50.63	95.83a	6.89	27.29
EH1847	92.39b	26.66b	41.24b	48.79	82.78a	7.43	24.87
Travler	60.00c	26.48b	52.23a	45.29	57.22b	7.70	24.83
LSD (5%)	5.41	2.53	5.27	NS	17.50	NS	NS
CV (%)	4.6	7.00	9.3	10.00	16.90	11.60	9.30
Plant density m^{-2}							
100	85.22	28.44a	42.51ab	51.15a	75.56	7.19	25.56
200	88.56	28.02ab	43.39ab	50.35ab	78.33	7.59	26.47
300	90.00	27.22ab	42.81ab	48.16bc	78.33	7.57	25.18
400	88.56	27.80ab	38.70b	46.02cd	77.78	7.00	25.62
500	87.22	26.07b	45.05a	44.92d	81.11	7.13	24.89
Control (100 kg ha^{-1})	89.56	27.23ab	45.57a	48.82b	80.56	7.58	26.24
LSD (5%)	NS	2.11	5.07	2.23	NS	NS	NS
CV (%)	4.70	5.10	7.80	3.10	9.00	6.40	7.70

CV= Coefficient of variance; PLH=Plant heights; SL = Spike length; GPS=Grains per spike; HI= Harvest index, TKW=Thousand kernels weight. Means followed by the same letter(s) within a column are not significantly different from each other at 5% level of significance, NS: Not significant.

Grain yield

The analysis of variance results showed that there were a significant difference among plant densities and the varieties as well as their interactions for grain yield at both field 1 and 2. In these experiments, the results revealed that Travler variety gave promising yield under field 1 condition whereas EH1847 variety under field 2 condition (Figures 2 and 3). The results were in line with the work of Muhammad *et al.* [28] who reported the the grain yield differences among barley genotypes associated with the relatively high heritability. Incase of plant densities, grain yield increased to its maximum at control (100 kg ha^{-1}) at field 1 and at D4 at field 2 (Figures 4 and 5). The statistics suggested there were no significant differences between the yield of control, D3 and D5 at field 1 whereas at D4 and D5 at field 2. Rhizosphere misuse and photosphere disturb the plants particularly when the plants dense together [29]. However, in the closely populated plants, the competition of air, nutrients, and light is very high and this reduces the yield and yield related traits [30]. As a result, optimum plant density ensures that the plants grow properly with their aerial and underground parts by utilizing more sunlight and soil nutrients, respectively [31]. On the other hand, the results of interaction between varieties and planting densities on the grain yield showed that the combination of Travler with control, Bekoji1 and EH1847 with D3 were the best at field 1, but the combination of Bekoji1 and EH1847 with D3 were statistically at par with that of the combination of two varieties with control seed rate at field 1 (Figure 6). The results also showed that EH1847 and Travler varieties gave high yield at D4 whereas at D2 for Bekoji1 variety eventhough they didn't show significant with respect to the corresponding yield obtained from the combination of control seed rate with all tested three malt barley varieties at field 2 (Figure 7). These differences might be due to the genetic characteristics of the varieties that gave different amounts of grain yield with different plant densities per unit area and difference in the tested sites. This result is consistent with the fingings of Fox *et al.* [32] who testified that the yield and quality specifications of a given malting barley variety are determined by its genetic makeup and the physical conditions during growth and harvesting time. Furthermore, Jairus *et al.* [33] found that the differences in grain yield of malt barley was as a function of varieties and experimental sites. In addition, this result is also in line with that of Aynewa *et al.* [34] who stated that barley varieties showed different capacities to acclimate different tested environments.

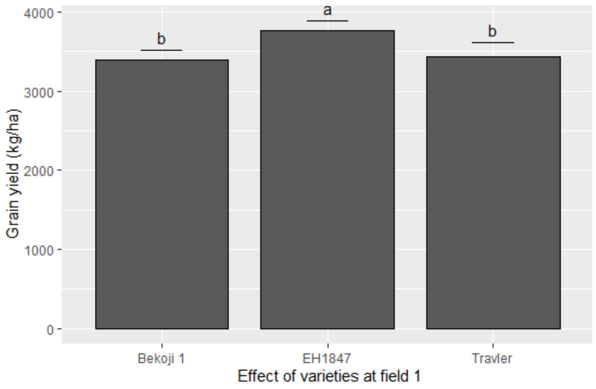

Figure 2. Effect of varieties on grain yield of malt barley at field 1 (b).

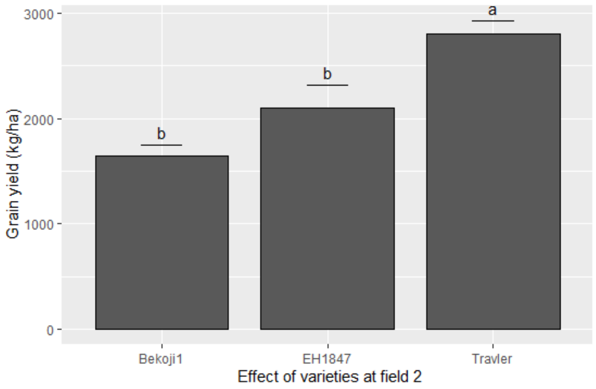

Figure 3. Effect of varieties on grain yield of malt barley at field 2 (c).

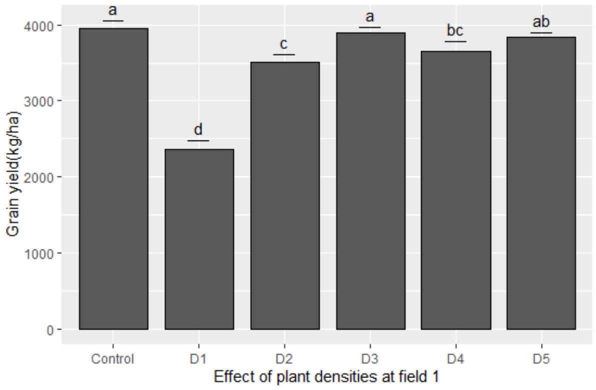

Figure 4. Effect of plant densities on grain yield of malt barley at field 1 (d).

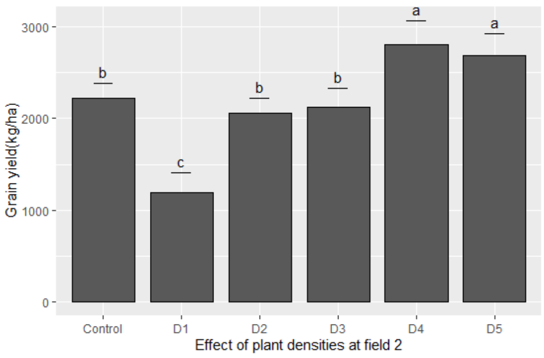

Figure 5. Effect of plant densities on grain yield of malt barley at field 2 (e).

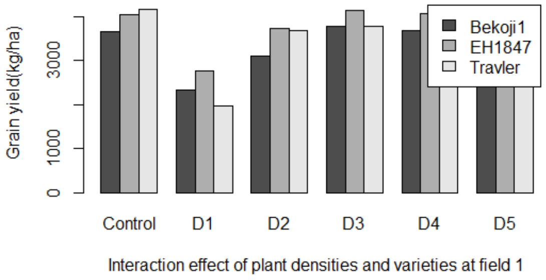

Figure 6. Interaction effect of plant densities and varieties on grain yield of malt barley at field 1. D1: 100 plants m^{-2}, D2: 200 plants m^{-2}, D3: 300 plants m^{-2}, D4: 400 plants m^{-2}, D5: 500 plants m^{-2} (f).

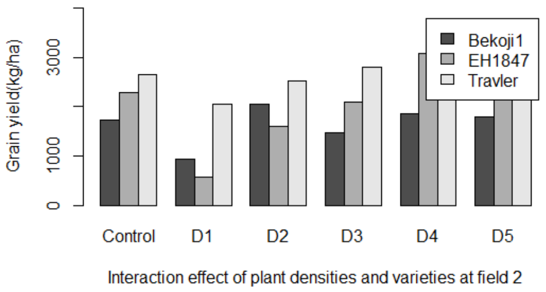

Figure 7. Interaction effect of plant densities and varieties on grain yield of malt barley at field 2. D1: 100 plants m^{-2}, D2: 200 plants m^{-2}, D3: 300 plants m^{-2}, D4: 400 plants m^{-2}, D5: 500 plants m^{-2} (g).

Above ground dry biological yield

Results of the study revealed that above ground dry biological yield showed variations between the varieties, plant densities as well as the interaction between varieties and plant densities at both experimental sites. The results presented in Figure 8 and 9 showed that the above ground dry biological yield for Bekoji1 variety was higher than the rest two malt barley varieties at field 1 while for Travler at field 2, but statistically no above ground dry biological yield difference among Bekoji1 and Travler at field 1. The greater above ground dry biomass of Bekoji1 variety at field 1 and Travler at field 2 might be attributed due to the tallest plant height and spike length of the varieties, respectively. These results were in line with Bishaw *et al.* [35] who described that the affirmative relationship between biomass yield and plant height, in which the taller plants resulted higher biomass yield. With respect to plant densities, the highest above ground dry biological yield was recorded at D4 at both field 1 and 2, but didn't show significant difference with D3 and D5 at field 1 and 2, respectively (Figures 10 and 11). The results of varieties × plant densities interaction effects on above ground dry biological yield were presented in Figure 12 and 13. The differential effect of varieties on the plant densities for the maximum above ground dry biological yield can be observed from the combination of Bekoji1 and EH1847 at D4 whereas at D5 for Travler, but the above ground dry biological yield difference among EH1847 at D4 and control as well as Travler at D5 and control showed non-significantly at field 1. In contrary, at field 2 the peak biological yields were recorded from Travler, EH1847 and Bekoji1 at plant densities of D5 and D4, correspondingly which revealed non-significant with control seed rate with respect to Bekoji1 at plant density of D4 and EH1847 variety at D5, in that order. These above ground dry biological yield variances might be due to the genetic characteristics of the varieties that are responsive for different plant densities per unit area at different tested sites. These results consistent with the results obtained by Abebe *et al.* [36] who revealed the interaction of plant populations and varieties of wheat had significant effect on biological yield.

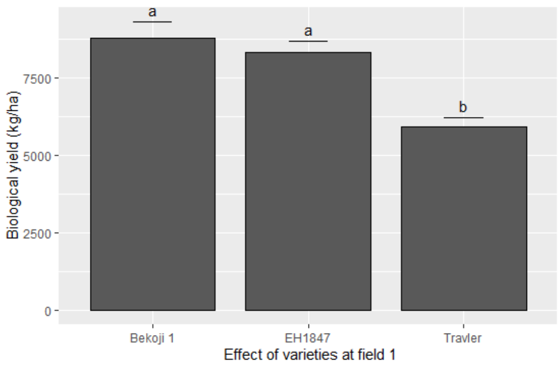

Figure 8. Effect of varieties on above ground dry biological yield of malt barley at field 1 (h).

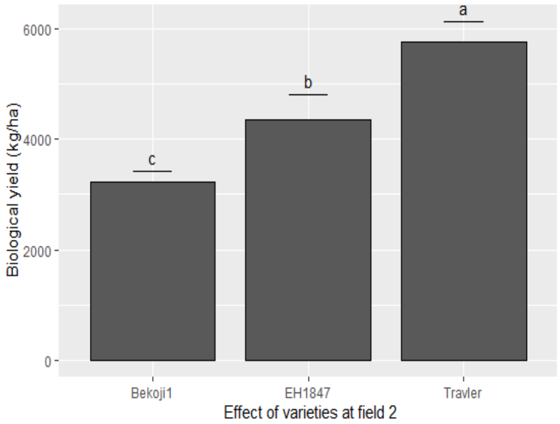

Figure 9. Effect of varieties on above ground dry biological yield of malt barley at field 2 (i).

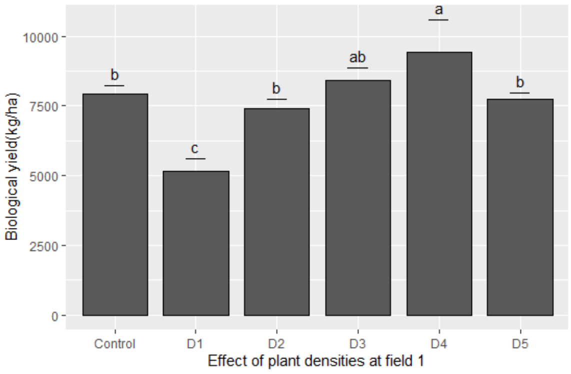

Figure 10. Effect of varieties on above ground dry biological yield of malt barley at field 1 (j).

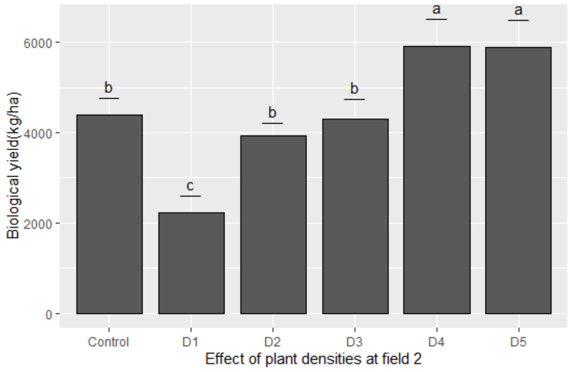

Figure 11. Effect of varieties on above ground dry biological yield of malt barley at field 2 (k).

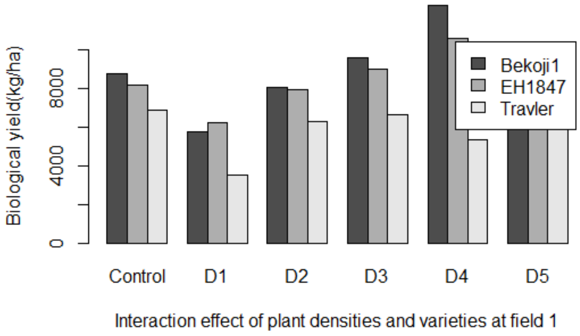

Figure 12. Interaction effect of plant densities and varieties on above ground dry biological yieldof malt barley at field 1. D1: 100 plants m^{-2}, D2: 200 plants m^{-2}, D3: 300 plants m^{-2}, D4: 400 plants m^{-2}, D5: 500 plants m^{-2} (l).

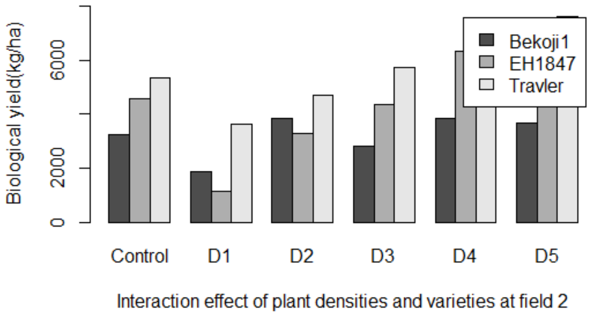

Figure 13. Interaction effect of plant densities and varieties on above ground dry biological yield of malt barley at field 2. D1: 100 plants m^{-2}, D2: 200 plants m^{-2}, D3: plants m^{-2}, D4: plants m^{-2}, D5: 500 plants m^{-2} (m).

Harvest index

The harvest index results indicated those of only varieties and plant densities showed significant difference at field 1 however only the interaction between varieties and plant densities exhibited significant on field 2. The average value of the data indicated that peak harvest index of 52.23% was gained from Travler as compared with Bekoji1 (35.56%) and EH1847 (41.24%) varieties which showed significant among each other at field 1. Likewise, among the plant densities the supreme harvest index (45.57%) was obtained from control (100 kg ha^{-1}) while the lowest harvest index (38.70%) was recorded from plots sown with plant density of D4 (400 plants m^{-2}) (Table 1). The interaction outcomes accessible in Figure 14 displayed that the highest harvest indexes were noted from Travler and EH1847 sown with D1 whereas for Bekoji1 variety at control but, the mean difference of highest harvest indexes among Travler and EH1847 sown with D1 were statisticaly similar with that of harvest index recorded from control. The lowest hervest indexes were recorded from Travler and EH1847 sown with maximum plant density D5 (500 plants m^{-2}) while at D4 for Bekoji1 variety. In line with these findings, Donald and Hamblin [37] reported that harvest index is proportional to grain yield and factors that influence grain yield indirectly an impact on harvest index.

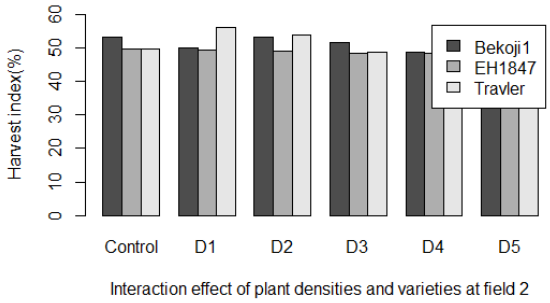

Figure 14. Interaction effect of plant densities and varieties on harvest index of malt barley at field 2. D1: 100 plants m^{-2}, D2: 200 plants m^{-2}, D3: 300 plants m^{-2}, D4: 400 plants m^{-2}, D5: plants m^{-2} (n).

Furthermore, Jemal *et al.* [22] found that the decrement of harvest index with increasing seeding rates designates the adverse effect of translocation of photosynthetic towards the sink and their accumulation in other fragments.

Thousand kernels weight

Statistical analysis of the data revealed that only plant densities had a significant ($p<0.05$) effect on 1000-kernels weight at field 1, while only the interaction effects of varieties and plant densities did show significant ($p<0.05$) on 1000-kernels weight at field 2 (Table 1 and Figure 15). The mean value of the data designated that among the plant densities the top 1000-kernels weight (51.15 g) was found from the lowest plant density (D1) while the lowest 1000-kernels weight (44.92 g) was recorded from plots sown with top plant density of D5 (Table 1). In case of interaction, the highest harvest indexes were recorded from Travler at D1 whereas for Bekoji1 and EH1847 varieties tested with control but, the mean difference of highest harvest index of Travler variety sown with D1 was statisticaly similar with that of harvest index recorded from control.

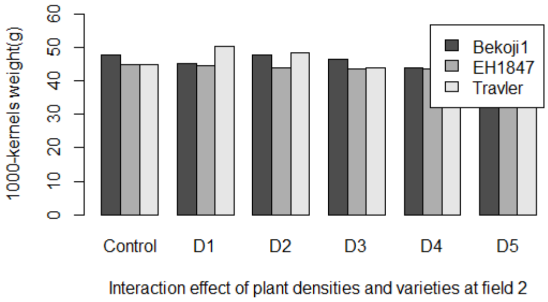

Figure 15. Interaction effect of plant densities and varieties on thousand kernels weight of malt barley at field 2. D1: 100 plants m^{-2}, D2: 200 plants m^{-2}, D3: 300 plants m^{-2}, D4: 400 plants m^{-2}, D5: 500 plants m^{-2} (o).

The lowest hervest indexes were recorded from Travler and EH1847 sown with maximum plant density (D5) while at D4 for Bekoji1 variety (Figure 15). This result is in line with the work of [24] who stated that thousand kernels weight decreased with increasing seeding rate.

4. Conclusion

The results of this study indicated that grain and aboveground dry biomass yields were significantly affected by the interaction effect of varieties and plant densities at both experimental fields whereas the interaction effect of varieties and plant densities did show significant for harvest index and 1000-grains weight at field 2 and spike length at field 1. Furthermore, the main effect of varieties and plant densities also affected grain and aboveground dry biomass yields at field 1 and 2 while number of grains spike^{-1} and harvest index affected at only field 1. Plant height was affected only by the main effect of varieties at both study fields. Bekoji1 and EH1847 were the tallest varieties when compared with Travler variety. The longest spike lengths of all three tested varieties were recorded from the lowest plant density of 100 plants m^{-2}. On average control (100 kg ha^{-1}) seed rate combination with EH1847 and Travler gave the better grain yield at both study fields. the above ground dry biological yield difference among EH1847 at D4 (400 plants m^{-2}) and control as well as Travler at D5 (500 plants m^{-2}) and control showed non-significant at field 1 whereas revealed non-significant with control seed rate with respect to Bekoji1 at plant density of D4 and EH1847 variety at D5 at field 2. Therefore, based on the findings of the present study seed rate of 100 kg ha^{-1} would be recommended for the production and productivity of EH1847 and Travler malt barley varieties at the study fields and similar agro ecologies.

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