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Study of heat units, growth and yield of barley (*Hordeum vulgare* L.) under different environments

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Abstract
The experiment was laid out in split plot design with 12 treatments, having different combinations of three Date of sowing i.e D_1= 20 October, D_2=5 November, D_3= 20 November and Row spacing i.e S_1=15cm, S_2=22.5cm, S_3= 30 cm and S_4=22.5cm bi-directional, replicated three times on sandy loam soil at Amritsar. From pooled data of *rabi* season 2022-23and 2023-24. It was observed that a significant increase in all growth characters, yield contributing characters, straw yield, grain yield was recorded with 5th November date of sowing of barley but remains at par with 20th October. On the other hand, it was found a significant increase in growth characters with S_1=15cm while yield contributing characters except tiller count, straw yield and grain yield was found to be significantly higher with Spacing of 22.5cm bi-directional. Further, it has been found that from farmer point of view, sowing of barley with bi-directional spacing gives better yield, which is evident from superior B:C ratio. D1 (20th Oct) treatment indicated more heat load than other treatment of date of sowing D2 (5th Nov) and D3 (20th Nov).

Keywords: *Hordeum vulgare* L., date of sowing, heat units

Introduction
Barley (*Hordeum vulgare* L.) is usually used as food for human beings and its grains have the largest use as animal feed all over the world. In addition, barley has some useful by-products, the most valuable being the straw which is used mainly for bedding purpose. It is also a valuable input to industries for extraction of malt to be utilized for brewing, baby foods, ayurvedic medicines and some liquor products. Barley contains 44.3 g carbohydrates, 0.7 g fat and 3.5 g proteins, and is a good source of magnesium, manganese, dietary fiber and selenium, copper, vitamin B_1, chromium, phosphorus and niacin. Barley having low water requirement as compared to wheat offers a good scope for diversification in *Rabi* season. Furthermore, there is a great demand for quality raw seed malt in international market and most of it is used for brewing beer. It is also used for livestock feed as well as human food.

Production trend of barley is declining due to lack of high yielding and superior quality varieties as well as management practices like appropriate sowing time, spacing, irrigation practices, fertilization application etc. Among these, sowing time has a great effect on growth and yield of barley. Varied climatic conditions may be responsible for the differences seen in the production of early and late sown crop. Early sown barley produces more tillers, heads and high yield than late sown crop. Very early planting of barley may expose the crop to higher temperature at tillering stage while late planting may result in low biomass production and poor grain development due to higher temperature conditions at the time of maturity, thus resulted in poor grain yield. It is reported that growth, yield attributes and protein content have different optimum sowing times (Singh *et al.,* 2013) [4].

Further, row spacing also has a significant effect on yield and yield components, water use efficiency, tillering and light interception. Narrow row spacing may results in more heads than wider rows, but it may be that the crop will face higher and quick soil moisture depletion and less interception of light in narrow rows. Closer row spacing had significantly higher yield of dry fodder, crude protein and ether extract as compared to wider row spacing. Soil moisture is generally conserved for more critical stages in later season in the case of wider rows. As both sowing time and spacing of rows influence the various growth and yield components of barley, so it is imperative to find out the best combination under local climatic conditions. So, keeping the above views in consideration, the present study was planned to study the effect of sowing time, row spacing and interaction on growth and yield of barley.

Materials and Methods

The field experiment was set up at Students' Global Group of Institutes, Amritsar during *Rabi* season of 2022-23 and 2023-24. Amritsar is situated at 31º 38′ North latitude, 72 º 52′ East longitudes and at an attitude of 236 meters above mean sea level. This track is characterized by semi-humid climate, where both winters and summers are extreme. The soil of the experimental field was categorized as sandy loam. The soil tested low in organic carbon and available nitrogen (N). However, available phosphorus (15 kg ha^{-1}) was found to be normal and potassium (150 kg ha^{-1}) status was high. The soil pH and electrical conductivity values were within the normal range. The experiment was laid down in split plot design having three different times of sowing as main plot treatments i.e. October 20 (D_1), November 5 (D_2), November 20 (D_3) and four different row spacings as sub plot treatments i.e. 15 cm (S_1), 22.5 cm (S_2), 30 cm (S_3), 22.5 cm- bidirectional sowing (S_4). The sowing of PL 807 variety of barley was done with recommended seed rate of 88 kg ha^{-1}. The crop was harvested manually with sickle after maturity. After drying, crop was weighed to record biological yield (q ha^{-1}). Then threshing was done manually. The grain yield of each plot was recorded (q ha^{-1}). The straw weight was recorded after deducting grain weight from the total bundle weight and expressed as straw yield in q ha^{-1}.

Daily growing degree days (GDDs) (°C days) were calculated as under: Daily GDD = [(Tmax + Tmin)/2] −Tb Where, Tmax and Tmin represent the maximum and minimum temperatures in °C and Tb denotes the base temperature (minimum temperature at which growth ceases) 5°C was used as base temperature for next phenophases. Accumulated GDDs for different phenophases were calculated by summation of daily GDD of each developmental stage. Accumulated GDDs for each phenophase were multiplied with day length to calculate PTU. Heat use efficiency (HUE) was computed by using the below given formulae: HUE (kg ha-1 °C days-1) = Grain yield (kg ha-1)/ Accumulated GDDs (°C days)

Results and Discussion

Growth Analysis

Maximum plant height was observed in crop sown on 5th November (D_2) but remained at par with D_1. The problem behind lower plant height of D_3 may be low temperature during vegetative growth. Maximum LAI was recorded with D_2 (4.34) followed by D_1 (3.73) and D_3 (3.28). Maximum growth parameters like plant height, LAI and dry matter accumulation was recorded with S_4 (95.34 cm) followed by S_2 (94.20cm), S_1 (92.57 cm) and S_3 (90.10 cm). LAI decreased with decrease in row spacing from S_4 (4.98) followed by S_2 (4.04), S_1 (3.17) and S_3 (3.04). These results are in accordance with those of Angiras and Sharma (1996). D_2 showed superiority in dry weight (22.82 g/plant) over D_1 (17.16 g/plant) and D_3 (19.35 g/plant) but remained at par with D_3. Row spacing significantly affected dry weight. Maximum dry weight was observed with S_4 (23.42 g/plant) followed by S_2 (21.39g/plant), S_1 (20.87 g/plant) and S_3 (17.10 g/plant). These results are in confirmation with Singh *et al.* (2013) [4] who also reported that dry matter accumulation was decreased as the sowing of crop was delayed from October 20 to November 10. The maximum pant height, dry matter accumulation and LAI produced by D_2 may be attributed due to favorable climatic conditions. Better growth of the crop was recorded with S_4 due to uniform distribution and maximum interception of light which led to better height, dry matter accumulation and LAI.

Yield Parameters

The crop sown on November 5 produced significantly more yield attributes such as number of tillers, number of grains, 1000-grain weight and ear length than October 20 which might be due to exposure to higher temperature under date of sowing of 20th October. However, sowing date November 20 remained at par with November 5 for yield attributes. More number of tillers under 20th November might be due to prevalence of congenial climatic conditions during tillering period. Superiority of November 5 over other Sowing times may be due to exposure of crop to the favorable weather conditions. Maximum tillers were recorded with S_4 followed by S_2, S_1 and S_3. Decrease in spike length with delayed sowing may be due to low temperature exposure to the crop and in case of early sowing reason may be due to high temperature which led to decreased spike length. Among row spacing S_4 produced significantly higher ear length, number of grains and 1000 grain weight than S_1, S_2 and S_3 but S_2 being at par with S_1. Superiority of S_4 over all other row spacing may be due to better interception of light from both sides i.e. plant-plant spacing and row-row spacing. These results are in line with the findings of Gupta *et al.* (2006) [2].

Grain yield

Grain yield, a complex phenomenon is primarily the outcome of genetic constitution of the crop plant as expressed under influence of nutritional, hormonal, environmental and other management factors. It is the most important character regarding economics value of crop for comparing efficiency of various treatments. The data presented in the Table 4.6 and Fig 4.6 revealed that sowing dates had a significant influence on grain yield of barley. The highest yield produced by D_2 may be attributed due to favorable climatic conditions, better plant growth and yield contributing characters. Delayed sowing results in reduced grain yield due to unfavorable weather conditions. The percent increase in D_2 from D_1 and D_3 was 6.1 and 13.5 respectively.

Superior results were observed in S_4. S_4 recorded the maximum grain yield (34.05 qha^{-1}) which was significantly higher than S_1, S_2 and S_3. S_1 and S_2 remained statistically at par with each other. Increase in yield may be due to increased photosynthetic activity which may be resultant of maximum utilization of sunlight in bidirectional spacing. Higher productivity under bi-directional spacing might be due to improved growth parameters *viz.* plant height, LAI, dry matter accumulation and development of yield components such as no. of effective tillers, ear length, number of grains per ear and thus finally increased grain yield. These results are in close agreements with the findings of Gupta *et al.* (2006) [2] and Pandey and Kumar (2005) [3].

The possible explanation here can be that, there is closer crop canopy which we can say lesser spacing between plants in all three spacing treatments *viz* S_1, S_2, S_3 as compared to S_4 *viz* bidirectional due to a constant seed rate. Due to this in all treatments except S_4 there is lesser area available because of next plant. However, the row spacing is more which is not fully utilized by plant. So, in case of S_4 (Bi-directional), whole area which is in shape of square fully utilized by plant. It might be the reason of more growth, yield and yield contributing characters.

Similarly, straw yield time D_2 gives superior results as compared to other sowing times. D_2 produced higher straw yield which was significantly higher D_3 but remained at par with D_1. However, D_1 also produced higher straw yield than D_3 but both remained at par with each other. In straw yield percent increase with D_2 was 10.8 and 15.9 over D_1 and D_3. Lower straw yield of D_3 was due to reduced temperature as compared to other sowing. Crop sown at D_1 faces higher temperature, due o which plant could not established fully at their vegetative growth period which leads to poor performance in straw yield. However, at D_2 more vegetative growth possibly due to relatively optimum prevailing temperature and proper day length might be the reason for higher straw yield in D_2 sown crop

In sub plots amongst all treatments that is, row spacing, S_4 shows its superiority to all other treatments. S_4 produced highest straw yield which was significantly higher thanS_1, S_2, and S_3. Higher straw yield of S_4 was due to uniform distribution of plants and higher plant population amongst all other row spacing. It was observed that percent increase with S_4 was 2.3, 9.1 and 21.1 over S_1, S_2 and S_3. In bi-directional row spacing crop intercepts more sunlight as compared to other row spacings i.e S_1 (15 cm), S_2 (22.5 cm) and S_3 (30cm). More sunlight more will be photosynthesis which leads to better performance of bi-directional row spacing.

Economics

Benefit cost ratio expresses the extent of benefit or profit earned by applying a particular treatment over its cost of cultivation. According to the data given in the Table 4.12 it is revealed that maximum benefit cost ratio of 2.51 was obtained with D_2 (5 Nov), followed by D_1 (20 Oct) with B:C ratio of 2.33. However, B:C ratio of 2.19 observed with D_3 that was lower than all other treatments.

On the other hand, in sub plot treatments that is row spacing maximum B:C ratio was obtained with S_4(22.5cm bi-dir), followed by S_1(15 cm) with B:C ratio of 2.10 and S_2(22.5cm) with B:C ratio of 2.07. However, B:C of 1.94 was observed with S_3(30cm) that remained lower than all other treatments.

Heat Units

Growing degree days (GDD): Growing degree days (GDD) for barley crop under different sowing dates from sowing to maturity are presented in Table 5. The data presented in Table 5 revealed that the growing degree days was reported during D1 to D2 i.e. 1467 to 1346 and again decreased from D2 to D3 i.e. 1237. It may be due to dry spell occurred during crop life cycle. Whereas, D1 treatment indicated more heat load than other treatment of date of sowing i.e.1467. It may be due to maximum air temperature observed at the time of sowing. The lowest heat unit required for attaining various phenophase in D3 treatment due to effect of temperature and delayed sowing during the crop growing season. It is cleared that when the temperature of air was maximum then it will definitely affect GDD of soybean crop.

Photo thermal units (PTU): The data presented in Table 4. Photo-thermal units for each phenophase were different required by different dates of sowing. The PTU were higher in first date of sowing i.e. 15394. In D2 decreasing slowly up to delayed sowing i.e. 14201. The lowest PTU were in D3 i.e. 13256 than rest of the treatments due to variation of temperature, daylength and dry spell occurred during the crop growing season. The photo thermal units directly or indirectly affect the grain yield of barley by delaying flowering, pod formation. These results are in confirmatory with the work done by Singh *et al.* (2007) [6] and Neog *et al.* (2008) [5].

Table 1: Effect of Sowing time and row spacing on number of growth and yield attributing characters

Treatments	Plant Height (cm)	LAI	Dry Matter Accumulation (g/plant)	No. of effective tillers	Ear length (cm)	Grains per ear	1000-grain weight(g)
Sowing time							
D_1 (20Oct)	98.22	3.28	19.35	3.43	17.66	53.58	38.20
D_2 (5Nov)	99.22	4.34	22.82	3.70	18.65	57.00	40.00
D_3 (20Nov)	92.56	3.73	17.16	3.03	16.40	49.16	36.20
CD (P=0.05)	5.17	1.6	3.62	0.39	1.08	4.05	1.9
Row spacing							
S_1 (15cm)	95.53	3.17	19.10	3.10	17.28	54.88	41.83
S_2 (22.5cm)	96.23	4.04	20.59	3.27	18.75	58.55	43.33
S_3 (30cm)	91.30	3.04	17.87	3.06	15.86	51.66	40.41
S_4 (22.5Bi-dir)	97.81	4.98	23.42	3.50	19.53	59.88	45.45
CD(P=0.05)	4.15	1.17	2.68	0.18	0.83	3.14	1.51

Table 2: Effect of Sowing time and row spacing on grain yield and straw yield.

Treatments	Grain yield(q ha^{-1})	Straw yield(q ha^{-1})	Harvest index
Sowing time			
D_1 (20Oct)	35.25	45.36	42.82
D_2 (5Nov)	37.65	50.27	43.59
D_3 (20Nov)	33.07	43.37	43.26
CD (p=0.05)	2.14	4.57	
Row spacing			
S_1 (15cm)	31.02	45.33	39.31
S_2 (22.5cm)	30.41	44.83	40.41
S_3 (30cm)	28.94	40.41	41.81
S_4 (22.5Bi-dir)	34.05	48.95	41.02
CD (p=0.05)	1.30	3.51	

No interaction was found to be significant

Table 3: Economic Studies

Treatment	Cost of cultivation	Net Returns	Gross Returns	BC Ratio
Sowing time				
D_1(20 Oct)	30000	40008	70008	2.33
D_2(5 Nov)	30000	45321	75321	2.51
D_3(20 Nov)	30000	35923	65923	2.19
Row spacing				
S_1 (15 cm)	30000	33231	63231	2.10
S_2 (22.5cm)	30000	32105	62105	2.07
S_3 (30cm)	30000	28427	58427	1.94
S_4 (22.5cm bi-dir)	30000	39163	69163	2.30

Table 4: Phenology during various phenophases of barley under different date of sowings.

Phenophases	Date of sowing		
	D_1 (20Oct)	D_2 (5Nov)	D_3 (20Nov)
Emergence	6	7	10
Tillering	23(32)	29(36)	29(39)
Jointing	41(67)	35(64)	32(61)
Booting	48(89)	51(86)	50(82)
Heading	47(95)	41(92)	38(88)
Anthesis	54(101)	56(97)	54(92)
Grain Filling	53(107)	46(102)	43(97)
Maturity	84(137)	86(132)	81(124)

Table 5: Growing degree days (ºC day) required for various phenophases of barley under different date of sowings.

Phenophases	Growing Degree days (GDD)		
	D_1 (20Oct)	D_2 (5Nov)	D_3 (20Nov)
Emergence	114	102	133
Tillering	391(505)	378(481)	261(394)
Jointing	359(864)	213(695)	174(569)
Booting	181(1046)	136(831)	138(708)
Heading	28(1074)	49(880)	50(759)
Anthesis	13(1087)	44(925)	37(796)
Grain Filling	49(1137)	42(968)	58(854)
Maturity	329(1467)	378(1346)	382(1237)

Table 6: Photo thermal units (PTU) required for various phenophases of barley under different date of sowings.

Phenophases	Photo thermal units (PTU)		
	D_1 (20Oct)	D_2 (5Nov)	D_3 (20Nov)
Emergence	1267	1065	1357
Tillering	4091(5359)	3862(4928)	2632(3990)
Jointing	3633(8992)	2148(7076)	1768(5759)
Booting	1833(10825)	1394(8471)	1446(7206)
Heading	289(11115)	511(8982)	547(7754)
Anthesis	135(11251)	471(9454)	414(8168)
Grain Filling	516(11767)	460(9914)	650(8818)
Maturity	3626(15394)	4286(14201)	4437(13256)

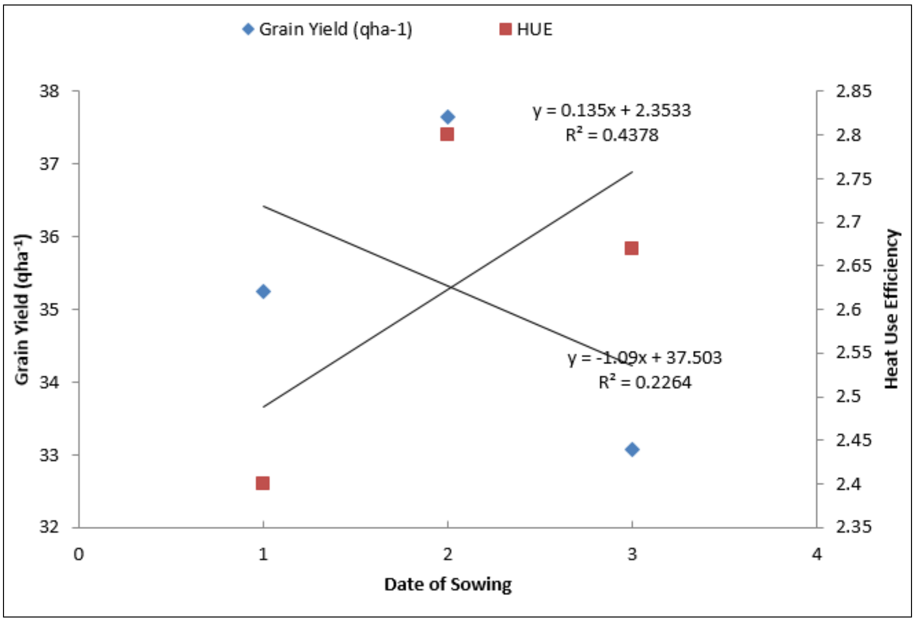

Fig 1: Correlation of grain yield and Heat use efficiency

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