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Research Paper

Effect of sowing schedules and crop geometry on photo-thermal energy utilization and productivity of Indian mustard (*Brassica juncea*) in Jammu region

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ABSTRACT

A field experiment was conducted at the research farm of Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu and Kashmir during the winter (*rabi*) season of 2014–15 and 2015–16, to study the effect of different dates of sowing and planting geometries on photo-thermal energy utilization and productivity of Indian mustard [*Brassica juncea* (L.) Czernj.] var. 'Giriraj'. Results revealed that the crop sown on 15 October showed significant increase in yield attributes, viz. siliquae/plant (276.5), seeds/siliqua (17.2), test weight (3.54) and seed yield (1.31 t/ha) besides concomitant increase in utilization of thermal energy envisaged through accumulated growing degree-days (1671.2°C/day), helio-thermal units (9,336.6°C/day/hr) and photo-thermal units (17,859.7°C/day/hr) as well as heat-use efficiency (HUE) of seed (0.783 kg/ha/$^{\circ}$C/day) and biological yield (3.35 kg/ha/$^{\circ}$C/day) as compared to the other dates of sowing. Seed yield of Indian mustard declined progressively with advancement in sowing beyond 15 October. However, among the different planting geometries, the maximum average seed yield (1.14 t/ha) was observed at planting geometry of 30 cm × 10 cm, being at par with 30 cm × 20 cm spacing but significantly higher than the other planting geometries to the tune of 11.1, 17.2 and 23.7% over the spacings 30 cm × 30 cm, 45 cm × 15 cm and 45 cm × 30 cm, respectively. The heat-use efficiency of seed and biological yield was found higher in earlier-sown Indian mustard and decreased progressively with delayed sowing.

Key Words: Heliothermal units, Heat-use efficiency, Indian Mustard, North-west Himalayas, Planting geometry, Photothermal units, Sowing dates

Indian mustard [*Brassica juncea* (L.) Czernj.] is a winter season crop grown in diverse agro-climatic conditions, ranging from northern hills to down south under irrigated and rainfed conditions under vide range of temporal dimensions, namely early, timely and late-sown under irrigated and rainfed conditions. In Jammu and Kashmir, rapeseed-mustard group of crops are grown on an area of about 55,000 ha approximately, with an average productivity of 1,149 kg/ha (DAC and FW, 2020). Proper sowing time and planting geometry are important agronomic manipulations which mainly influence the crop growth and yield under a particular environment (Bana *et al*., 2022). Various critical phenological stages of Indian mustard like flowering and seed-setting stages could easily be scheduled during the favourable environment by selecting the appropriate sowing environment. Similarly, an appropriate plant stand and crop geometry help in harnessing the precious resources like moisture, space and light optimally in an efficient manner for realizing maximum yield and productivity in rapeseed-mustard, as the crops have shown a great elasticity under variable crop stand in different areas of the country (Bamboriya *et al.*, 2017). Also, maintenance of optimum plant population in an ideal spacing is important for achieving high yield of all crops in general and non-tillering like Indian mustard in particular.

Rapeseed-mustard is sensitive to weather as evidenced from the variable response to different dates of sowing and 1 month delay in sowing can decrease seed yield from about 10 to 50% in different canola cultivars (Shargi *et al.,* 2011). The quantification of heat-use efficiency (HUE) is useful for the assessment of yield potential of wheat and Indian mustard in different environments (Tyagi, 2014). The ability of the crop to utilize heat energy for dry-matter accumulation is determined by environmental conditions in addition to genetic factors. Also, the agronomic practices cause variation in the thermal energy utilization by altering the crop growth and development. Growing degree-days

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(GDD), which determine occurrence of various phenological events in the life-cycle of a plant, is the most common agro-climatic index used to estimate phenological development of a plant (Bonhomme, 2000).

The present investigation was planned to study photothermal energy utilization by newly developed Indian mustard variety 'Giriraj' under different sowing dates and crop geometries in Jammu region.

MATERIALS AND METHODS

The experiment was conducted during the winter (*rabi*) season of 2014–15 and 2015–16 at the Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Chatha, Jammu and Kashmir. Geographically, the experiment site is situated in low altitude sub-tropical Shiwalik foothills of Jammu region of Jammu and Kashmir (32°39' N and 74°58' at an elevation of 332 m above mean sea-level). The area receives a good amount of winter rainfall from western disturbances and cyclonic rains during winter and spring months.

The meteorological data for the winter season 2014–15 and 2015–16 were obtained from Meterological observatory of SKUAST-J, Chatha, located at about 200 m from the experimental site. The rainfall data for the crop-growing periods revealed that a total of 387.5, 477.5 and 535.7 mm and 162.3, 153.9 and 139.5 mm rainfall was received during first, second and third dates of sowing in the winter season of 2014–15 and 2015–16, respectively. The meteorological data for the crop seasons on standard meteorological week (SMW) basis are depicted in Fig. 1.

The soil of the experimental field was low in organic carbon (0.38%) and nitrogen (220.45 kg/ha), medium in available phosphorus (12.2 kg/ha) and potassium (140.30 kg/ha) and neutral in pH (7.08). The experiment consisted of 15 treatments which were arranged in split-plot design with 3 main plots and 5 subplots, with 3 replications. The main plots consisted of 3 dates of sowing, i.e. 15 October (D_1), 25 October (D_2) and 5 November (D_3). The subplots consisted of 5 planting geometries, i.e. 30 cm × 10 cm (P_1), 30 cm × 20 cm (P_2), 30 cm × 30 cm (P_3), 45 cm × 15 cm (P_4) and 45 cm × 30 cm (P_5). Indian mustard variety 'Giriraj' was used during both the years of experimentation. Recommended dose of 60 kg N + 30 kg P + 15 kg K+ 20 kg S/ha was uniformly applied to all the treatments using urea, diammonium phosphate, muriate of potash and Gypsum, respectively. Full dose of P, K and S besides half dose of N were applied as basal at the time of sowing, whereas rest of the N was given in 2 equal split doses during both the years. The crop was given light irrigation at 55 days after sowing (DAS) during the first years. The crop was harvested at variable dates ranging from the second fortnight of March to the first week of April at their respective physiological maturity.

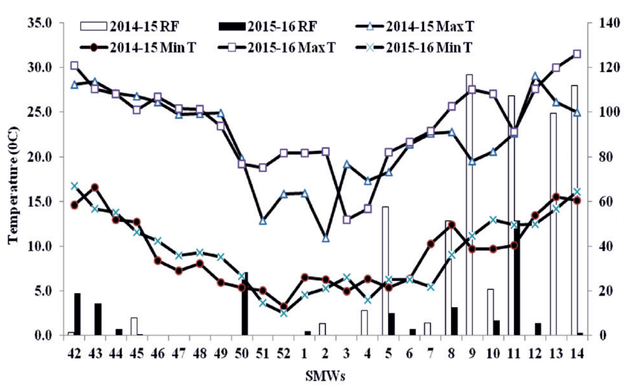

Fig. 1. Maximum and minimum temperature and rainfall during the winter season of 2014–15 and 2015–16

The different agro-meteorological indices were calculated as detailed below:

Growing degree-days (GDD)

The accumulated growing degree-days (GDD) were calculated as per Nuttonson (1955):

$$\text{GDD} = \Sigma\, a^b \;\frac{[\text{T max.} + \text{T min.}] - T_b}{2}$$

Where, T max is daily maximum temperature (°C); T min. is daily minimum temperature (°C); T_b is base temperature (5°C).

Heliothermal units

The accumulated heliothermal unit (HTU) was calculated using the formula given by Rajput (1980) as:

Heliothermal unit (HTU) = Σ GDD × bright (actual) sunshine hr (°C/day/hr)

Photothermal units (PTU)

The accumulated photothermal unit (PTU) was calculated as per formula given by Nuttonson (1955) as:

Photothermal unit (PTU) = Σ GDD × maximum day length (°C/day/hr)

Heat use efficiency (HUE)

The heat use efficiency (HUE) was computed as:

$$\text{Heat use efficiency (HUE)} = \frac{\text{Accumulated dry-matter (kg/ha)}}{\text{Accumulated GDD (}^{o}\text{C/day)}}\ (\text{kg/ha/}^{o}\text{C/day})$$

The treatment-wise data recorded for different crop parameters were subjected to statistical analysis according to split-plot design as per the procedure outlined by Cochran and Cox (1963).

RESULTS AND DISCUSSION

Weather parameters

A wide range of maximum and minimum temperature was observed for attaining phenophases like 50 and 100% flowering and physiological maturity in Indian mustard crop sown under different sowing dates (Table 1). Maximum and minimum temperature to the range of 20.5 to 26.4°C and 6.8 to 10.8°C were recorded under 3 different sowing dates of the crop during 50% flowering stage in the year 2014–15. However, for physiological maturity, range of maximum and minimum temperature under different dates of sowing was 21.3–21.9 and 8.4–8.8°C respectively, in the year 2014–15.

Phenological calendar

The calendar days taken by Indian mustard crop from sowing to physiological maturity under different sowing dates decreased with delay in sowing (Table 2). Physiological maturity got delayed by 3–5 days when sowing was done on 25 October (D_2) and further delayed by 6–11 days on 4 November sowing as compared to 15 October (D_1). In general, to accomplish the phenophases like 50 and 100% flowering, the late-sown Indian mustard crop (D_2 and D_3) took more days than earlier sown crop (D_1). It might be owing to favourable soil and air temperature during this sowing time which hastened the seed germination and emergence (Gupta *et al*., 2017). Similar findings were also reported by Hokmalipour *et al.,* (2011) that, early-sown crop reached the maturity later as compared to delayed sowing dates.

Agrometeorological indices

The duration of growth stages like days to flowering and physiological maturity is very much related with temperature and sunshine and can be well explained through accumulated growing degree-days (AGDD), heliothermal units (AHTU) and photothermal units (APTU). Various accumulated thermal units required by Indian mustard crop to attain different phenophases varied with sowing dates and planting geometries. The AGDD, AHTU and APTU accumulated from sowing to 50% flowering, sowing to 100% flowering and sowing to physiological maturity of Indian mustard under different temperature regimes (sowing dates) and planting geometries are depicted in Table 3. Among the sowing dates, the crop sown on 15 October (early sown) accumulated higher GDD, HTU and PTU values for different phenophases followed by the values evinced in 25 October and 4 November sowing dates, during both the years of experimentation. Indian mustard crop sown under various planting geometries (30 cm × 10 cm and 30 cm × 20 cm) accumulated similar values of AGDD, AHTU and APTU during 50 and 100% flowering, however, at physiological maturity there was not any difference among the planting geometries with respect to accumulation of various thermal indices during winter

Table 1. Phenophase-wise weather data to attain various phenophases of 'Giriraj' Indian mustard crop sown under different dates and planting geometries

Treatment	50% flowering						100% flowering						Physiological maturity					
	Max T(°C)		Min T(°C)		Rainfall (mm)		Max T(°C)		Min T(°C)		Rainfall (mm)		Max T(°C)		Min T(°C)		Rainfall (mm)	
	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
Dates of sowing																		
D_1, 15 October	26.4	26.6	10.8	12.0	9.6	37.2	22.4	26.0	8.7	11.6	9.6	65.6	21.9	22.9	8.8	8.6	387.5	162.3
D_2, 25 October	22.2	24.6	8.0	10.2	8.0	46.6	21.4	23.6	7.7	8.9	14.0	46.6	21.6	22.6	8.6	8.3	462.3	153.9
D_3, 4 November	20.5	22.5	6.8	7.3	14.0	34.0	20.2	21.8	6.7	7.2	11.2	34.0	21.3	22.7	8.4	8.2	534.5	139.5
Planting geometry																		
P_1, 30 cm × 10 cm	23.0	24.5	8.4	9.8	10.5	39.3	21.3	23.7	7.7	9.2	11.6	48.7	21.6	22.7	8.6	8.4	461.4	151.9
P_2, 30 cm × 20 cm	23.0	24.5	8.4	9.8	10.5	39.3	21.3	23.7	7.7	9.2	11.6	48.7	21.6	22.7	8.6	8.4	461.4	151.9
P_3, 30 cm × 30 cm	23.0	24.6	8.5	9.8	10.5	39.3	21.3	23.8	7.7	9.2	11.6	48.7	21.6	22.7	8.6	8.4	461.4	151.9
P_4, 45 cm × 15 cm	23.0	24.6	8.5	9.8	10.5	39.3	21.3	23.8	7.7	9.2	11.6	48.7	21.6	22.7	8.6	8.4	461.4	151.9
P_5, 45 cm × 30 cm	23.0	24.6	8.5	9.8	10.5	39.3	21.3	23.8	7.7	9.2	11.6	48.7	21.6	22.7	8.6	8.4	461.4	151.9

* Max T, maximum temperature; Min T, minimum temperature; Y_1, 2014–15; Y_2, 2015–16

Table 2. Days taken to attain different phenophases by Indian mustard crop under different sowing dates and planting geometries

Treatments	50% flowering		100% flowering		Physiological maturity	
	2014–15	2015–16	2014–15	2015–16	2014–15	2015–16
Dates of sowing						
D_1, 15 October	56.4	51.4	89.4	59.4	163.0	154.0
D_2, 25 October	75.4	54.4	87.4	65.4	158.0	151.0
D_3, 4 November	77.4	71.4	87.4	78.4	152.0	148.0
Planting geometry						
P_1, 30 cm × 10 cm	70.3	59.7	88.7	68.3	157.7	151.0
P_2, 30 cm × 20 cm	70.3	59.7	88.7	68.3	157.7	151.0
P_3, 30 cm × 30 cm	69.3	58.7	87.7	67.3	157.7	151.0
P_4, 45 cm × 15 cm	69.3	58.7	87.7	67.3	157.7	151.0
P_5, 45 cm × 30 cm	69.3	58.7	87.7	67.3	157.7	151.0

season of 2014–15 and 2015–16. Similarly, the planting geometries 30 cm × 30 cm, 45 cm × 15 cm and 45 cm × 30 cm also showed the similar trend regarding the accumulation of various thermal indices at different phenological stages.

The accumulation of GDD, HTU and PTU was decreased with the successive delay in sowing. This clearly described the effect of temperature on occurrence of the various phenological stages of Indian mustard crop when grown under different thermal regimes and needed specific amount of agrometerological indices to enter from one phenophase to another. The early sowing of the crop may have resulted in absorption of sufficiently higher thermal indices thereby getting relatively more time than the late-sown crop which was subjected to face higher maximum and minimum temperature especially at reproductive stages. This may have resulted in progressive reduction in consumption of thermal units by the late-sown Indian mustard crop. Gupta *et al*., (2017) reported that, the requirement of thermal units decreased for different phenological stages with delay in sowing in Indian mustard crop under the subtropical conditions of Jammu. Khushu *et al.,* (2008) also reported higher temperatures during the reproductive phase reduced the duration of the late sown *Brassica* crop.

Yield attributes and seed yield

The seed yield and yield attributes were significantly influenced by different planting dates and planting geometries. During winter season of 2014–15, the earlier sown Indian mustard crop (15 October) recoded significantly higher seed yield (1.30 t/ha) than 25 October (10.29 q/ha) and 4 November (0.86 t/ha)-sown crop. Similarly, during winter season of 2015–16, again statistically higher seed yield was recorded by the crop sown on 15 October (1.32 t/ha) and was significantly higher than when crop was sown on 25 October (0.96 t/ha) and 4 November (0.80 t/ha) (Table 4).

During 2014–15, significantly higher seed yield was observed with planting geometry of 30 cm × 10 cm (1.13 t/ha) which was however at par with planting geometry of 30 cm × 20 cm (1.11 t/ha) but significantly higher than the other planting geometries. Similar trend was observed during 2015–16.

In general, seed yield of Indian mustard declined progressively with an advancement of sowing beyond 15 October. Among the various crop geometries, higher yield attributes, viz. siliquae/plant, seeds/siliqua, 1,000-seed weight and harvest index, were recorded with 45 cm × 30 cm spacing during both the years, whereas the seed yield in these plots was observed to be the lowest because of lower plant population per m^2 due to wider spacing.

The increased yield per unit area might be due to efficient thermal energy utilization of the crop which improved with early sowing and adoption of optimum plant population, whereas wider spacing resulted in the maximum utilization of photo and thermal units by the individual crop plants thereby leading to significantly higher dry-matter production and yield attributes, viz. siliquae/plant, seeds/siliqua, 1,000-seed weight and harvest index, but realization of lower yield and productivity due to lower plant population in widely spaced Indian mustard. Our results confirm the findings of Khushu *et al.,* (2008) in Jammu region.

Heat-use efficiency

Among the sowing dates, heat-use efficiency (HUE) of seed and biological yield was found higher in earlier sown crop and it decreased with the delay in sowing (Table 5). Sowing of crop in closer spacing resulted in marginal increase in heat-use efficiency for both seed and biological yields. It might be owing to higher seed yield in early sowing which increased the thermal efficiency. Heat-use efficiency is directly proportional to dry-matter accumulation by the plant. So, higher dry matter accumulation due to higher crop-growth rate under earlier sown India mustard crop improved its heat-use efficiency (Gupta *et al.,* 2017).

Table 3. Variation in accumulated agromet indices for flowering and maturity of Indian mustard under different dates of sowings and planting geometries

Treatment	Agromet indices																	
	AGDD						AHTU						APTU					
	50% flowering		100% flowering		Physiological maturity		50% flowering		100% flowering		Physiological maturity		50% flowering		100% flowering		Physiological maturity	
	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
Dates of sowing																		
D_2, 25 October	758.2	672.0	827.9	735.9	1,596.6	1,579.1	4,317.7	3,265.3	4,617.8	3,644.2	8,389.1	8,421.7	7,775.1	6,915.2	8,477.3	7,548.2	17,179.7	16,798.9
D_3, 4 November	668.9	706.1	736.1	740.8	1,494.6	1,539.4	3,710.2	3,254.9	3,998.9	3,278.1	7,660.4	8,206.2	6,774.6	7,139.3	7,467.2	7,490.6	16,181.7	16,544.0
Planting geometry																		
P_1, 30 cm × 10 cm	734.5	709.3	837.9	768.6	1,591.6	1,592.3	4,462.7	3,604.2	4,819.3	3,800.6	8,525.9	8,591.0	7,578.7	7,330.3	8,616.5	7,920.5	17,148.5	16,992.8
P_2, 30 cm × 20 cm	734.5	709.3	837.9	768.6	1,591.6	1,592.3	4,462.7	3,604.2	4,819.3	3,800.6	8,525.9	8,591.0	7,578.7	7,330.3	8,616.5	7,920.5	17,148.5	16,992.8
P_3, 30 cm × 30 cm	728.0	700.8	832.4	761.6	1,591.6	1,592.3	4,433.1	3,563.2	4,795.8	3,760.7	8,525.9	8,591.0	7,514.2	7,245.3	8,560.8	7,851.0	17,148.5	16,992.8
P_4, 45 cm × 15 cm	728.0	700.8	832.4	761.6	1,591.6	1,592.3	4,433.1	3,563.2	4,795.8	3,760.7	8,525.9	8,591.0	7,514.2	7,245.3	8,560.8	7,851.0	17,148.5	16,992.8
P_5, 45 cm × 30 cm	728.0	700.8	832.4	761.6	1,591.6	1,592.3	4,433.1	3,563.2	4,795.8	3,760.7	8,525.9	8,591.0	7,514.2	7,245.3	8,560.8	7,851.0	17,148.5	16,992.8

* Y_1, 2014–15; Y_2, 2015–16

Table 4. Effect of dates of sowing and planting geometry on yield and yield attributes of 'Giriraj' Indian mustard

Treatment	Seed yield (t/ha)		Siliquae/plant		Seeds/siliqua		1,000-seedweight		Harvest index(%)	
	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
Dates of sowing										
D_1, 15 October	1.30	1.32	253.60	299.33	17.44	16.87	3.50	3.58	23.29	23.46
D_2, 25 October	1.03	0.96	200.53	226.93	15.17	14.31	3.06	3.09	21.87	22.22
D_3, 4 November	0.81	0.79	157.13	191.87	12.68	11.57	2.54	2.64	19.85	20.62
CD (P=0.05)	0.09	0.10	15.83	24.69	1.02	1.51	0.19	0.15	1.03	1.00
Planting geometry										
P_1, 30 cm × 10 cm	1.13	1.15	163.00	188.11	14.22	13.07	2.86	2.90	21.06	21.31
P_2, 30 cm × 20 cm	1.11	1.12	197.11	224.33	14.58	14.09	2.93	3.02	21.46	21.82
P_3, 30 cm × 30 cm	1.04	1.02	208.89	276.44	15.24	14.97	3.09	3.26	21.65	22.67
P_4, 45 cm × 15 cm	0.99	0.96	223.11	234.22	15.60	14.43	3.12	3.11	21.92	22.17
P_5, 45 cm × 30 cm	0.97	0.88	226.67	273.78	15.84	14.69	3.18	3.23	22.25	22.47
CD (P=0.05)	0.03	0.06	6.53	20.03	0.51	0.61	0.10	0.15	0.76	0.56
Interaction										
Factor A at same level of B	0.01	0.11	18.60	37.75	1.28	NS	0.25	NS	NS	NS
Factor B at same level of A	0.07	0.13	13.52	39.29	1.03	NS	0.20	NS	NS	NS

* Y_1, 2014–15; Y_2, 2015–16

Table 5. Grain and biological heat use efficiencies of Indian mustard crop under different dates of sowing and planting geometries

Treatment	Heat-use efficiency (kg/ha/°C/day)			
	Grain		Biomass	
	2014–15	2015–16	2014–15	2015–16
Dates of sowing				
D_1, 15 October	0.771	0.795	3.31	3.39
D_2, 25 October	0.645	0.611	2.95	2.76
D_3, 4 November	0.545	0.515	2.75	2.50
Planting geometry				
P_1, 30 cm × 10 cm	0.706	0.719	3.33	3.34
P_2, 30 cm × 20 cm	0.694	0.700	3.21	3.19
P_3, 30 cm × 30 cm	0.648	0.635	2.98	2.78
P_4, 45 cm × 15 cm	0.615	0.600	2.80	2.69
P_5, 45 cm × 30 cm	0.604	0.547	2.71	2.43

Relationship of seed yield with agro-meteorological indices

Indian mustard crop was exposed to a variety of weather variables during its growing period, resulting in great variations in rate of growth and seed yield. The agro-metrological indices like growing degree-days (GDD) and heat-use efficiency (HUE) have been used to describe modifications in phenological behaviour and various other growth factors. The GDD concept provides a reliable index for the progress of the crop that can be used to predict the yield of any crop (Gupta *et al.*, 2017).

Seed yield and accumulated growing degree days: The relationship between seed yield and accumulated GDD was calculated for both years (Fig. 2). A good linear relationship existed between seed yield and AGDD which explained about 77% variability. More the number of days taken by Indian mustard to complete phenophases like flowering and maturity stages, the more will be seed yield of Indian mustard. Kaur *et al.* (2016) also observed a highly significant relationship between seed yield and AGDD in wheat crop.

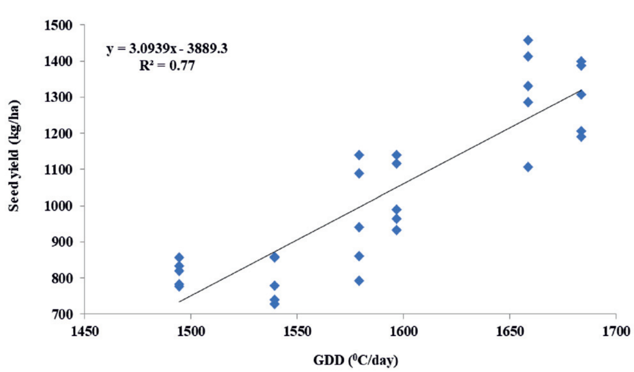

Fig. 2. Relationship between seed yield of Indian mustard and accumulated growing degree-days during the winter season of 2014–15 and 2015–16 (GDD, Growing degree-days)

Seed yield and heat use efficiency: The relationship between seed and biological yield and heat-use efficiency was also calculated for winter season of 2014–15 and 2015–16 (Fig. 3 and 4). A positive and linear relationship between seed and biological yields of Indian mustard crop with heat-use efficiency was observed with 99 and 97% variability respectively. Shirzad *et al*., (2020), also reported a highly significant relationship between seed yield and HUE in wheat crop,

For maximizing yield of 'Giriraj' Indian mustard, the crop may be sown by mid- October, i.e. 15 October, with crop geometry of 30 cm × 10 cm or 30 cm × 20 cm for maximum utilization of photo-thermal energy, increased photosynthetic activity which ultimately leads to efficient translocation of photosynthates to the sink and higher seed yields in Indian mustard crop in Jammu region.

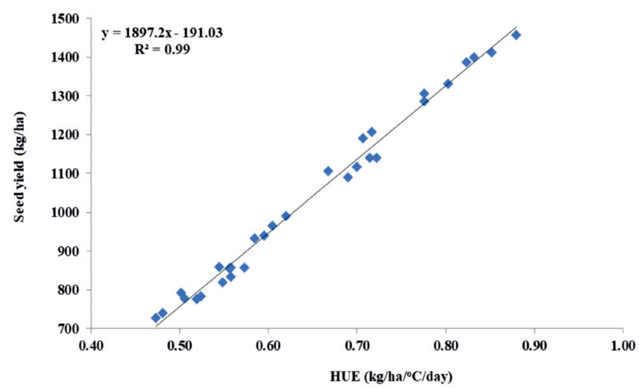

Fig. 3. Relationship between seed yield of Indian mustard and heat-use efficiency (HUE) during the winter season of 2014–15 and 2015–16

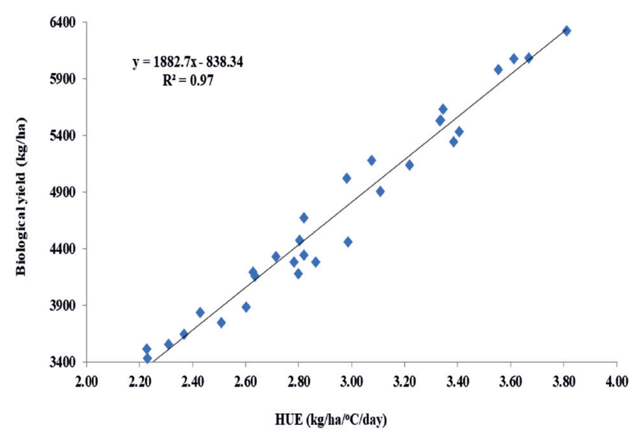

Fig. 4. Relationship between biological yield of Indian mustard and heat-use efficiency (HUE) during the winter season of 2014–15 and 2015–16.

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