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Research Article

Thermal Requirement and Performance of Mustard (*Brassica juncea*) under Varying Growing Environments

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ABSTRACT

Indian mustard [*Brassica juncea* (L.) Czern & Coss.] is a long day plant as it require the periodic exposure of light exceeding the critical period to induce flowering. It is a crop of temperate and tropical zones, require cool and dry weather for growth and development. However, higher temperatures at flowering stage deterrent seed yield. Therefore, GDD requirement for different phenological stages under varying growing environment was studied during two consecutive *rabi* seasons of 2015-16 and 2016-17 at Rajasthan Agricultural Research Institute, Durgapura, Jaipur. Field experiment treatment were comprised of three sowing dates (15th October, 25th October and 5th November) four cultivars of mustard (Laxmi, Varuna, Kranti and RRN-573) and two fertilizer levels 100% RDF and 75 % RDF. The results revealed that days taken to physiological maturity and yield reduced significantly with delayed sowing. Mustard crop sown on 15th October utilised almost same thermal and heat units as in 25th October and 5th November sown crops. The shortening of the duration of late sown crop was due to forced maturity because of higher temperature during reproductive phase of the crop. There was significant correlation between growing degree days and crop growth parameters. The normal sown mustard crop (25th October) accumulated optimum AGDD, APTU and AHTU, PTI and HUE as compared to early and late sown crops and by record higher seed and biological yield under semi-arid eastern plain zone conditions. Mustard cultivars with recommended dose of fertilizer differed significantly for yield attributes and yield.

Key words: Thermal regime, Sowing dates, Growing degree days, Helio thermal units and photo-thermal units

Introduction

India is one of the largest oilseed producers in the world. Indian mustard [*Brassica juncea* (L.) Czern & Coss.] is an important oilseed crop of India and is cultivated on 6.86 m ha with production of 9.1 m tones and productivity of 1331 kg ha^{-1} in 2019-20 (Anonymous, 2019-20). Rajasthan is one of the major rapeseed and mustard growing state and is grown in an area of 27.12 m ha, producing 42.88 m tones with an average productivity of 1581 kg ha^{-1} (Anonymous, 2019-20). The factors like weather, lack of suitable time of sowing and appropriate dose of fertilizers limits the crop growth and development of mustard. Since the time of sowing is the main factor which decides the environmental conditions of a crop during different phenophages and being the important non monetary input which affects crop yield, therefore, optimization of sowing time of mustard is necessary. Uzan *et al*. (2009) have reported that both the early and late sowing are unfavorable and optimum time of sowing results in optimum light

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interception, optimum utilization of nutrients and moisture during all growth stages. High temperature at flowering stage impacts reproduction and thus reduces seed yield due to pollen sterility. The late sown mustard crop is also exposed to high temperature stress during reproductive phase resulting into forced maturity and low productivity. Growing degree days (GDD), photo-thermal unit (PTU), helio thermal unit (HTU), photo-thermal index (PTI) and heat use efficiency (HUE) have frequently been used as weather based parameters for assessing crop phenology. Therefore, all growth and development stages of crop may be estimated more accurately on the basis of GDD rather than calendar method (Warthington and Hatchinson, 2005) as it is used to quantify the effect of temperature and described the timing of different biological process (Qiao-yan *et al*., 2012; McMaster and Wilhelm, 1997).

Plant nutrition is also one of the important inputs to increase the productivity of mustard crop. Nitrogen is one of the major nutrients, which plays an important role in Brassica crops by helping in the better partitioning of photosynthates to reproductive parts. Most of the Indian soils are deficient in nitrogen. Keeping in view the above facts, the present investigation was carried out to quantify relationship of GDD, PTU, HTU, PTI and HUE with phenological development of mustard crop and plant responses to different growing environments and nitrogen levels.

Materials and Methods

Experimental site

The field experiment was conducted on field of Rajasthan Agricultural Research Institute, Durgapura, Jaipur (Raj.) during 2015-16 and 2016-17, respectively. Geographically this place is situated at 750°47′ East longitude at an 260° 51′ North latitude and at altitude of 390 meters above mean sea level in Jaipur district of Rajasthan. This region falls under Agro-climatic zone IIIa (Semi-arid eastern plain zone) of Rajasthan. The soil of experimental field was loamy sand in texture, slightly alkaline in reaction, poor in organic carbon (0.27%), low in available nitrogen (134.2 kg ha^{-1}), medium in available phosphorus (78.6 kg ha^{-1}) and potassium.

Treatment details

Twenty four combinations of the experiment comprised of three sowing dates *viz.* 15th October (D_1), 25th October (D_2) and 5th November (D_3) and four cultivars of mustard (Laxmi (V_1), Varuna (V_2), Kranti (V3) and RRN-573 (V_4) and two fertilizer level 100% RDF (F_1) and 75% RDF (F_2) replicated three times in split plot design during *rabi* seasons of 2015-16 and 2016-17 under semi-arid eastern conditions. The spacing adopted for four cultivars of mustard was 30 × 10 cm. Mustard crop was fertilized with recommended dose *i.e.*, 60:30:40 kg ha^{-1}. The NPK nutrients were supplied through urea, diammoniam phosphate (DAP) and muriate of potash (MOP). Five plants were tagged in each plot and data of plant height and various yield attributes were calculated at harvest to assess their contribution to yield. Seed and stover yield of mustard crop was calculated on net plot basis.

Weather data gathering

Weather data *viz.*, maximum temperature, minimum temperature, relative humidity (morning), relative humidity (evening), rainfall, evaporation and bright sunshine hours were recorded from sowing to harvest of the crop in both the years study Agro-meteorological observatory, RARI, Durgapura, Jaipur.

Plant measurements

The different phenological stages of mustard *viz.* emergence, fifth true leaf exposed, flower bud visible from above, first flower open, lowest pod more than 2 cm long, most seed green, most seed brown, fully ripened and physiological maturity, seed and biological yield were observed.

Agroclimatic index computation

The following agro- me meteorological indices were calculated.

(i) *Growing degree days (GDD):* The concept of heat units, measured in growing degree-days (GDD), has greatly improved description and prediction of phenological stages. It was calculated using following formulae:

$$GDD = \frac{T\max + T\min}{2} - T_{base}$$

T_{max} – Daily maximum temperature (°C)

T_{min} – Daily minimum temperature (°C)

T_{base} – Base temperature of 5°C

Calculation of GDD when mean temperature is lower than the base temperature or more than the maximum temperature: If $T_{max} < T_{base}$, then $T_{max} = T_{base}$, and if $T_{min} < T_{base}$, then $T_{min} = T_{base}$

(ii) Heliothermal units (HTU) = GDD × Actual sunshine hours

(iii) Photothermal units (PTU) = GDD × Day length

(iv) Photothermal Index

$$\text{Photothermal index} = \frac{\text{Degree days consumed}}{\text{Number of days}}$$

(v) Heat Use Efficiency

$$\text{Heat use efficiency (HUE)} = \frac{\text{Seed yield/Total dry matter}}{\text{Accumulated heat units (°C)}}$$

The GDD, HTU and PTU were accumulated from the date of sowing and a particular date of phenophase to give accumulated indices.

Statistical analysis

The correlation coefficient is a statistical measure of the strength of a linear relationship between two variables. The Correlation analysis among weather and growth parameters during different phenophases *viz.* 5th true leaf exposed, Pod Development, Most seed brown and physiological maturity were worked out using excel and SPSS software.

Results and Discussion

Phenological calendar

The calendar days taken from planting to physiological maturity of four cultivars (Laxmi, Varuna, Kranti and RRN-573 decreased with delay in sowing. Physiological maturity was delayed by one to three days when sown under normal conditions (D_2) and 7-8 days when sown under late condition (D_3) as compared to early sown mustard (D_1). Mustard planted early on 15th October took lesser number of days for fifth true leaf exposure and pod development than later sowing (Table 1). It might

Table 1. Days taken by to attain different phenophases and mustard yield under different sowing dates and varieties (Mean of two years)

Treatments	5th true leaf exposed	Pod development	Most seed brown	Physiological maturity	Seed yield (kg/ha)	Biological yield (kg/ha)
D1	24.13	66.98	120.76	152.9	2230.6	8436.2
D2	25.39	72.49	127.30	150.4	2177.8	8202.3
D3	27.86	80.21	133.01	145.3	1889.1	7127.9
SED	0.43	1.13	2.17	3.0	39.2	130.5
CD 5%	1.18	3.13	6.02	8.4	108.8	362.4
F1V1	25.42	69.19	120.78	142.0	1990.5	7534.6
F1V2	25.49	71.10	124.77	146.5	2066.2	7850.3
F1V3	25.78	72.61	127.42	147.9	2085.0	7846.3
F1V4	25.70	71.37	122.69	144.8	2034.8	7672.5
F2V1	25.61	72.85	125.12	147.4	2067.8	7795.4
F2V2	25.86	75.39	133.42	158.7	2215.6	8326.3
F2V3	26.18	76.78	130.36	153.9	2156.5	8140.1
F2V4	26.31	76.53	131.64	155.1	2177.0	8211.6
SED	0.27	2.12	6.03	11.1	2060.9	29797.1
CD 5%	1.05	2.94	4.95	6.7	91.6	348.4

be due to favourable soil and air temperature during this growing time which hastened the seed germination and emergence. However, early sowing crop (15th October) took more number of days for flowering and maturity as compared to normal (25th October) and late sowing (5th November). The early, normal and late sown crop matured in 152, 150 and 145 days respectively under semi-arid conditions of Rajasthan (Table 1). Late sown crop took more days to complete early stages *viz.* fifth true leaf exposure and pod development. Whereas, from flower bud initiation stage. This might be due to higher temperature after flower bud initiation stage which fulfilled growing degree day's requirement and thermal units of crop for achieving different phenological stages, in lesser days as compared to early sown crop when day and light temperature was lower at later stages. Similar finding were reported by Hokamilipur *et al*. (2011) that early sown crop reached to maturity late as compared to delayed sowing dates. However, 75% recommended dose of fertilizer with three cultivars of Laxmi (V_1),Varuna (V_2), Kranti (V3) and RRN-573 (V_4) took slightly lesser number of days to complete various phenophases than 100% recommended dose of fertilizer with Laxmi (V_1),Varuna (V_2), Kranti (V3) and RRN-573 (V_4).

Agrometeorological indices

The accumulated thermal unit's requirement of mustard crop to attain different phenophases varied with sowing dates and varieties (Table 2). The crop sown on 15th October (D_1) accumulated more GDD (2337 ºC) to attain physiological maturity than 2nd (2302 ºC) and 3rd (2150 ºC) date of sowing. Regarding cultivars and two fertility variance, little variation in thermal requirement was observed. Mustard cultivar Varuna (V_2) with 75% Recommended dose of fertilizer recorded more (2479 ºC) thermal units than other treatments at physiological maturity. Earlier sown crop availed higher accumulated heliothermal units (AHTU), however, with delay in sowing HTU consumption deceased. At physiological maturity, accumulated HTU was 20343, 20095 and 18732 ºC hrs when mustard was sown early (D_1), normal (D_2) and late (D_3), and 20896 ºC hrs for cultivar RRN-573 (V_4) recorded more than other treatments.

An accumulated photothermal unit (APTU) of mustard at physiological maturity was 25012, 24628 and 23005 ºC hrs under the three dates of sowing, *i.e.*, early (D_1), normal (D_2) and late (D_3), respectively. Between cultivars and fertility variance, 75% Recommended dose of fertilizer with RRN-573 (V_4) acquired higher PTU (25618 ºC hrs) than other

Table 2. AGDD(ºC), AHTU (ºC hrs) and APTU (ºC hrs) for various phenological stages under different sowing dates and cultivars (mean of two years)

Treat-	5th true leaf exposed			Pod development			Most seed brown			Physiological maturity		
ments	AGDD	AHTU	APTU	AGDD	AHTU	APTU	AGDD	AHTU	APTU	AGDD	AHTU	APTU
D1	697	5598	7438	1639	14019	17487	1772	14979	18957	2337	20343	25012
D2	665	5313	7097	1617	13794	17245	1804	15682	19307	2302	20095	24628
D3	760	6789	8122	1599	13782	17052	1895	16445	20282	2150	18732	23005
Mean	707	5900	7553	1618	13865	17261	1824	15702	19515	2263	19723	24215
F1V1	696	5775	7437	1547	13275	16501	1717	14718	18368	2090	18219	22361
F1V2	698	5798	7458	1575	13511	16795	1787	15410	19122	2192	19119	23456
F1V3	705	5883	7533	1605	13760	17122	1833	15783	19610	2232	19460	23885
F1V4	705	5863	7533	1584	13576	16896	1755	15093	18779	2154	18749	23049
F2V1	703	5840	7512	1615	13865	17231	1785	15337	19096	2205	19214	23593
F2V2	709	5931	7573	1654	14164	17646	1929	16615	20641	2479	21587	26526
F2V3	718	5966	7665	1684	14387	17964	1878	16176	20100	2358	20593	25230
F2V4	722	6008	7709	1681	14377	17932	1907	16435	20406	2394	20896	25618
Mean	707	5883	7553	1618	13864	17261	1824	15696	19515	2263	19730	24215

Table 3. Percent change in AGDD(ºC), AHTU (ºC hrs) and APTU (ºC hrs) for various phenological stages under different sowing dates and cultivars (mean of two years)

Treat-ments	5th true leaf exposed			Pod development			Most seed brown			Physiological maturity		
	AGDD	AHTU	APTU	AGDD	AHTU	APTU	AGDD	AHTU	APTU	AGDD	AHTU	APTU
D1	0.05	0.05	0.05	0.01	0.02	0.01	-0.02	-0.04	-0.02	0.02	0.01	0.02
D2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D3	0.14	0.28	0.14	-0.01	0.00	-0.01	0.05	0.05	0.05	-0.07	-0.07	-0.07
F1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F2	0.02	0.02	0.02	0.05	0.05	0.05	0.06	0.06	0.06	0.09	0.09	0.09

treatments. Varietal variation for accumulation of GDD, HTU and PTU to complete different phenophases has also been reported by Bhat e*t al.* (2015) Ram *et al.* (2012). Normal sown varuna cultivar with optimum fertilizer level accumulated optimum thermal unit's for different phenophases to yield highest. The percent change from normal date of sowing and recommended fertilizer levels have been worked out (Table 3) and found variable change among delay in date of sowing and fertility levels.

Phenothermal index (PTI)

Among different date of sowing, 15th October sown crop recorded higher values of PTI at various phenophases than later two sowing dates. PTI values to the tune of 28.87, 26.18 and 27.29°C days^{-1} were observed during 5th true leaf stage at D_1, D_2 and D_3 sowing dates, respectively. Comparatively lower values of PTI were obtained for pod development (2 cm long) and most seeds brown stages than 5th true leaf stage (Table 4). PTI gradually decreased from

Table 4. Phenothermal index (°C days days^{-1}) and heat use efficiency (kg ha^{-1} °C day^{-1}) for different phenological stages of mustard crop sown under different dates of sowing and cultivars with fertilizer variance

Treatments	PTI (°C days days^{-1})				HUE (kg ha^{-1} °C day^{-1})			
	5th true leaf exposed	Pod develop-ment	Most seed brown	Physiological maturity	5th true leaf exposed	Pod develop-ment	Most seed brown	Physiological maturity
D1	28.87	24.47	14.67	15.28	3.20	1.36	1.26	0.95
D2	26.18	22.30	14.17	15.30	3.28	1.35	1.21	0.95
D3	27.29	19.93	14.25	14.80	2.49	1.18	1.00	0.88
SED	27.45	22.24	14.37	15.13	2.99	1.30	1.15	0.93
CD 5%	27.39	22.36	14.21	14.72	2.86	1.29	1.16	0.95
F1V1	27.40	22.15	14.32	14.96	2.96	1.31	1.16	0.94
F1V2	27.36	22.11	14.38	15.09	2.96	1.30	1.14	0.93
F1V3	27.45	22.19	14.30	14.87	2.88	1.28	1.16	0.94
F1V4	27.47	22.17	14.26	14.96	2.94	1.28	1.16	0.94
F2V1	27.42	21.94	14.46	15.63	3.12	1.34	1.15	0.89
F2V2	27.41	21.93	14.41	15.33	3.00	1.28	1.15	0.91
F2V3	27.44	21.97	14.49	15.43	3.02	1.29	1.14	0.91
F2V4	27.42	22.10	14.36	15.12	2.97	1.30	1.15	0.93
SED	28.87	24.47	14.67	15.28	3.20	1.36	1.26	0.95
CD 5%	26.18	22.30	14.17	15.30	3.28	1.35	1.21	0.95

emergence to later phenological stages in all three date of sowing, being highest at emergence and lowest at most seed brown, however, the values of PTI at physiological maturity were almost similar to emergence stage indicating a decrease in daily heat consumption towards maturity. This might be due to gradual decrease in day and night temperature, which resulted in decrease in PTI of that phenophase as the sowing was delayed (Neog *et al.,* 2018). Cultivar Laxmi (V_1) with 75% Recommended dose of fertilizer recorded more values at all phenological stages under study than other treatments.

Heat use efficiency (HUE)

HUE slightly decreased from vegetative growth to physiological maturity of the crop (Table 4). Among dates of sowing, heat use efficiency was found to be higher (0.95 kg ha^{-1} ºC days^{-1}) for earlier sown crop (15th October) and it decreased with delay in sowing (5th November).

Regarding fertilizer with cultivars, 75% recommended dose of fertilizer with Varuna (V_2) observed more HUE values than other treatments at various phenological stages under study. The higher heat use efficiency with 75% recommended dose of fertilizer with Varuna (V_2) might be due to its higher seed yield (Table 1.) Higher heat use efficiency (HUE) was recorded in the early sown crop as compared to late sown crop due to less biomass production and less number of heat units accumulation in delayed sown crop (Table 1-2). Similar findings were recorded by Kumar *et al.* (2013) and Keerthi *et al.* (2016).

Yield

Delayed planting of mustard resulted in a significant decline in the yield (Table 1). Significantly maximum seed and biological yield was obtained with mustard crop sown 25th October (D_2). Seed yield of mustard early (D_1) and late sown conditions (D_3) was 2.37 and 15.30 percent lower as compared to normal sown crop (D_2). Significantly higher seed yield under normal sowing dates may be due to the fact that normal sown crop utilize available resources and favourable temperature, whereas, shorter time was available for the late sown crop to utilize available growth factors (light, nutrients, moisture etc.) responsible for poor growth, which resulted in poor dry matter accumulation, leading to decline of yield. These results are in agreement with Shargi *et al.* (2011), Akther *et al.* (2016), Gupta *et al.* (2017) and Sandhu and Singh (2020).

Regarding fertilizer with cultivars, 75% recommended dose of fertilizer with Varuna (V_2) produced significantly higher seed and biological yield (Table 1) as compared to other cultivars. Better seed and biological yield of cultivars 75% recommended dose of fertilizer with Varuna (V_2) may be on account of accumulation of higher thermal units, which may be genotype character, suitable for semi-arid eastern plain zone conditions of Rajasthan.

Correlation studies

The correlation analysis among weather and growth parameters (Fig. 1-6) during different phenophases *viz.* 5th true leaf exposed, Pod Development, Most seed brown and physiological maturity reveled that GDD, relative humidity morning and evening during 5th true leaf exposed, pod development and most seed brown had significant positive correlations while maximum and minimum temperature and pan evaporation during 5th true leaf exposed, pod development and most seed brown showed negative correlations. While physiological maturity showed positive correlation with maximum and minimum temperature, GDD and PE but negative correlation showed with relative humidity. This indicated that lower night temperature during vegetative phase is favourable and higher day temperature during reproductive phase is not favourable for mustard yield. Jain and Sandhu (2018) studied the relationships between various heat units and crop yield. They concluded that different thermal indices like GDD (66 %), HTU (61 %) and PTU (63 %) explained the variability of seed yield.

Conclusion

It can be concluded from the present study that normal sown mustard crop (25th October) exhibited significantly higher growth and yield due to optimal thermal requirements as compared to early and late sown crops. The thermal requirement of late sown mustard (5th November) decreased. Among the

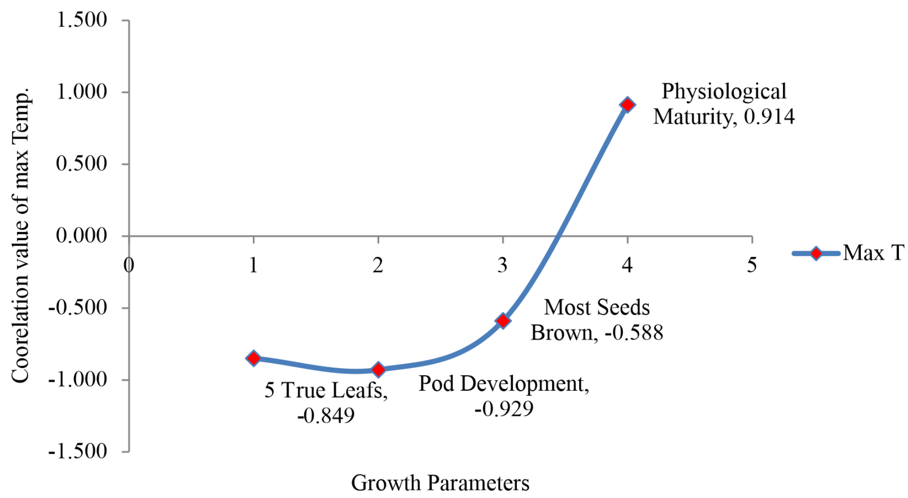

Fig. 1. Correlation between different growth parameters and maximum temperature

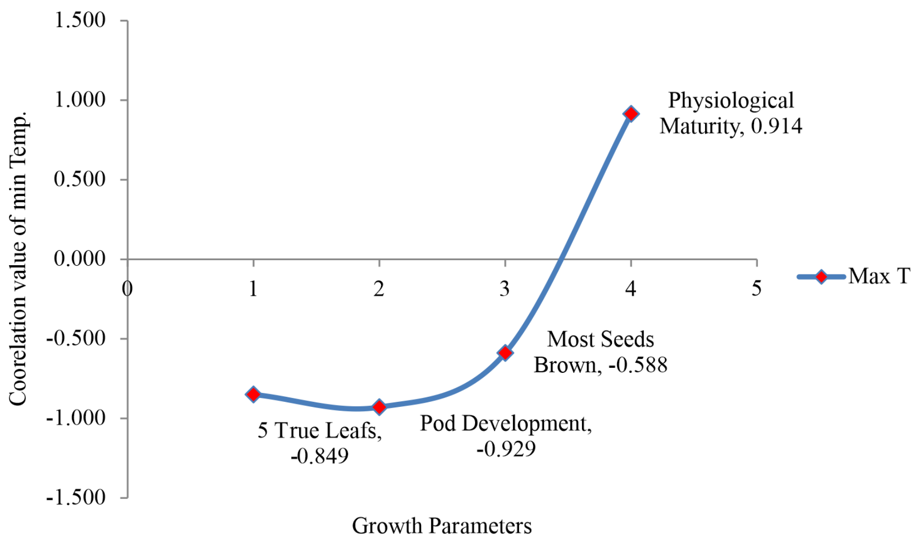

Fig. 2. Correlation between different growth parameters and minimum temperature

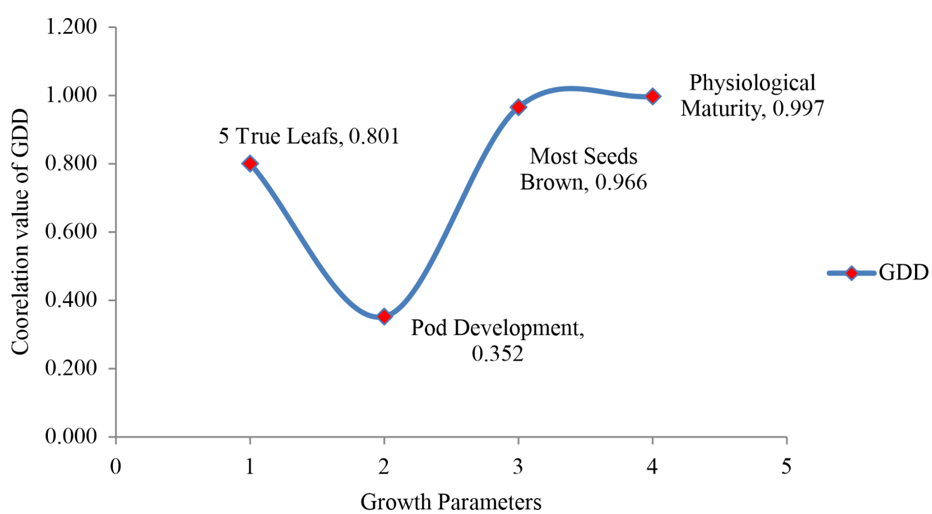

Fig. 3. Correlation between different growth parameters and GDD

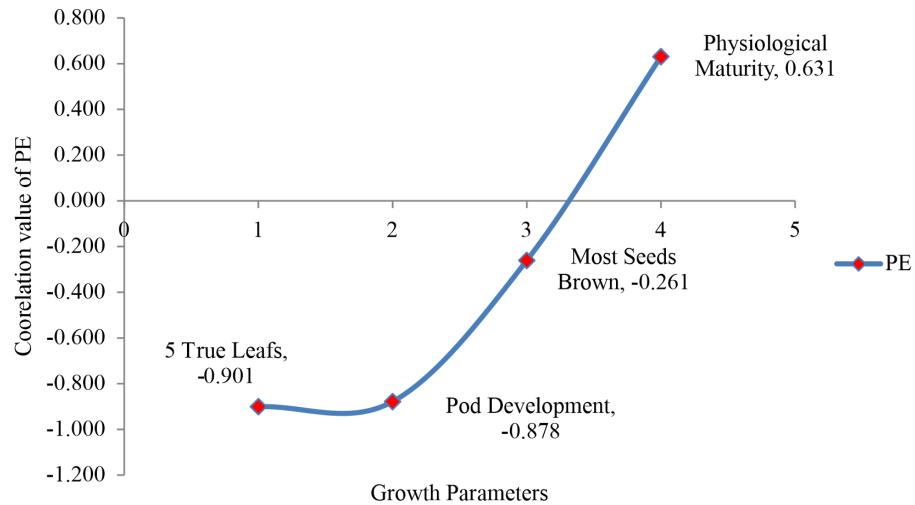

Fig. 4. Correlation between different growth parameters and pan evaporation

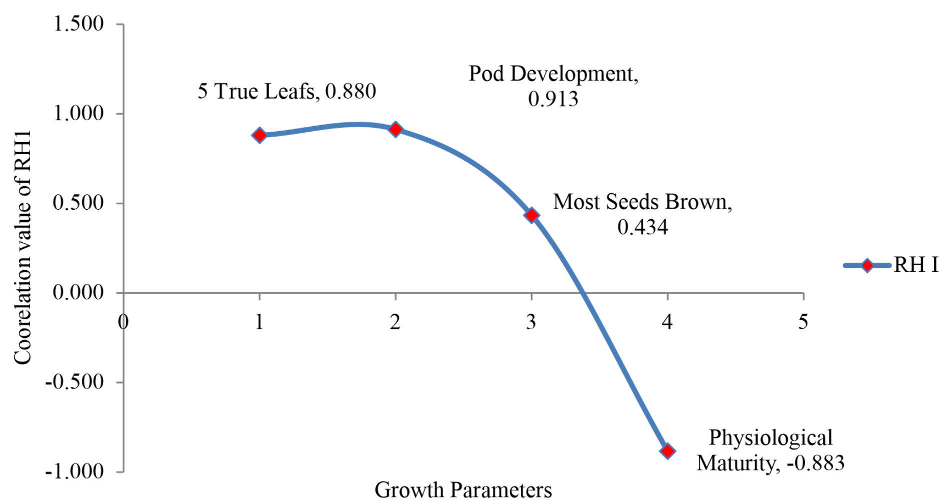

Fig. 5. Correlation between different growth parameters and evening relative humidity

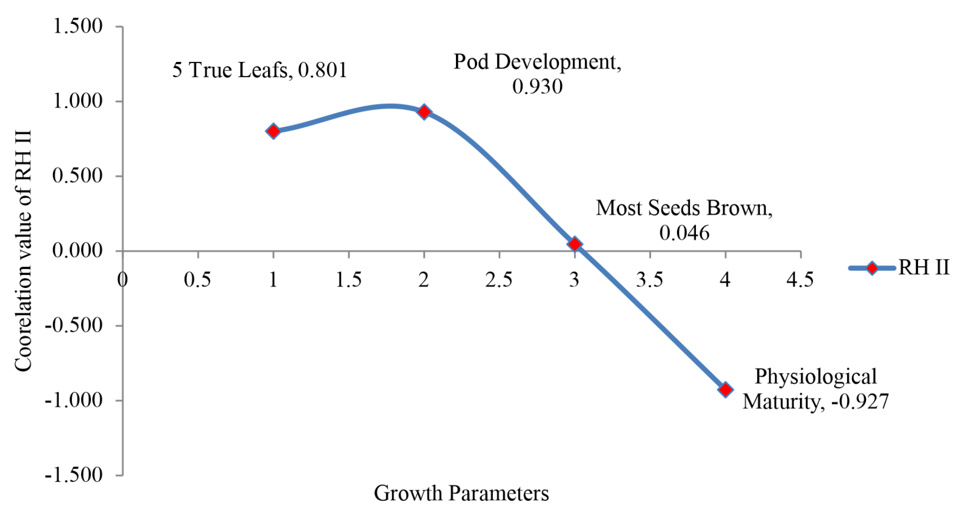

Fig. 6. Correlation between different growth parameters and morning relative humidity

different fertilizer levels, 100% RDF had higher growth and yield because of higher thermal unit requirement. Mustard cultivars with recommended dose of fertilizer differed significantly for yield attributes and yield.

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