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Agrometeorological evaluation of mustard (*Brassica juncea*) under organic production in North Western Indo-Gangetic Plains

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ABSTRACT

A field experiment was conducted to evaluate agrometeorological parameters associated with seed yield of Indian mustard (*Brassica juncea* L.) varieties in an organic production system. During the study, significant variation was recorded in crop phenophases, growth, yield attributes, and seed yield of mustard. Varieties NRCHB-101 and Pusa Mustard-25 have taken significantly minimum days to commence flowering (46–48 days) and attaining physiological maturity (89–90 days). Variety RGN-48 being at par with RH-406 and RGN-229, recorded significantly higher plant height, while RGN-229 recorded the significantly highest biomass accumulation at all the growth stages. Varieties RH-406, Pusa Bold, and DRMRIJ-31 recorded significantly higher seeds per siliqua (16.2–16.5), whereas significantly higher test weight was recorded in Pusa Bold (6.3 g) and DRMRIJ-31 (6.0 g). In seed yield, variety RH-406 (1.97 t/ha) and DRMRIJ-31 (1.42 t/ha) were found significantly highest and lowest, respectively. A significant positive correlations of mustard seed yield was noticed with biomass accumulation at 30 DAS (r=441**), 60 DAS (r=0.614**), 90 DAS (r=0.620**) and biological yield at harvest (r=0.496**). Contrary to test weight, seeds per siliqua had shown a positive effect (r=0.266*) on the seed yield of the mustard. Seed yield of mustard was also influenced by some agrometeorological indices with correlation coefficients (r) of mean minimum temperature at flowering and physiological maturity and mean maximum temperature at physiological maturity were -0.207*, -0.249*, and -0.241*, respectively. Net solar radiation and cumulative temperature difference at physiological maturity also had significant and positive effects on the seed yield of mustard.

Keywords: Agrometeorological indices, Correlation, Growing degree-days, Mustard, Organic production system, Phenophases

Mustard (*Brassica juncea* L.) plays a vital role in the edible oil economy of India (Reddy and Immanuelraj 2017). Mustard accounts for 21.6% (57.6 lakh ha) of the acreage and 22.2% (68.2 lakh tonnes) of the total oilseeds production in India, with the productivity of about 1184 kg/ha during 2015–16. In India, Uttar Pradesh alone produces about 10.3% of total mustard production (Anonymous 2016). However, the adverse impacts of excessive use of chemical fertilizers (Garai *et al*. 2014) and toxic chemical pesticides in conventional agriculture adversely affected soil fertility and the crop quality. Recently, with increased awareness about environment and human health, organic farming is considered a better option for producing healthy food and sustaining soil health (Das *et al.* 2010).

Extreme weather is one of the critical risk factors associated with crop production in western Indo-Gangetic alluvial plains (Shamim *et al*. 2013). In this agroecosystem, ambient temperature is vital in determining crop phenology, biomass accumulation, and seed yield under field conditions. As plants have a definite temperature requirement to attain a particular phenological stage, the impact of ambient temperature on crop growth and yield should be studied through an accumulated heat unit system. Several researchers have reported many studies on prevailing weather conditions on mustard yields under the inorganic production system. However, the scientific literature on the effects of weather parameters on mustard crop under the organic production system is very scanty. Hence, an attempt was made to identify major agrometeorological indices that are directly related to the yield performance of mustard varieties under the organic production system in Indo-Gangetic alluvial plains of western Uttar Pradesh.

MATERIALS AND METHODS

Field experiments were conducted at ICAR-IIFSR, Modipuram, Uttar Pradesh (29°4'N latitude, 77°5'E

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longitude, and 230 m AMSL) during 2013–14 and 2014–15. The sub-tropical semi-arid climate of Modipuram is characterized by scorching summers, cold winters with about 800 mm of average annual rainfall, and nearly 1600 mm of potential evapotranspiration. The soil was Typic Ustochrept, deep sandy loam, and slightly saline (*p*H 8.3).

The experiment evaluated 12 varieties of Indian mustard of different maturity duration and suitable sowing times in a randomized complete block design with three replications. The crop was sown at a spacing of 45 cm × 10 cm during the third week of October in each year by maintaining a gross plot area of 5.0 m × 4.0 m. For nutrient management, organic sources like FYM, vermicompost, and neem cake were applied equivalent to the recommended dose of nitrogen (120 kg N/ha). Seed treatment was done with *Pseudomonas fluorescence* and *Trichoderma harzianum* each at 4 g/kg of seed as prophylactic plant protection against soil borne diseases. Need-based irrigations at critical stages were applied, and weeding was done manually. For observations on biomass accumulation, five randomly sampled plants from each plot at different stages, viz. 30, 60, 90 DAS and at harvest were taken and oven-dried at 70°C until constant weight was attained. Observations on various phenophases, viz. 50% flowering and physiological maturity were recorded when 50% of plants in each plot selected in one-meter row length reached the respective stage. Plant height and yield attributes, viz. the number of seeds per siliqua, and test weight were determined from five randomly selected plants from each plot at harvest. The plant height was recorded from the base above the ground to the tip of the stem. The seeds per siliqua were recorded by random selection of 10 siliqua from each selected plant. Seed and biological yield were obtained from a segmented area of 2 m × 2 m of each plot by leaving border rows followed by sun-drying, threshing, and cleaning.

Daily meteorological data for the crop seasons recorded at the Agrometeorological Observatory of ICAR-IIFSR, Modipuram, were used to derive various agro-meteorological indices. A total of nine agrometeorological indices, viz. mean maximum and mean minimum temperatures, net solar radiation; cumulative index of temperature range, day temperature, night temperature, growing degree days (GDD), photo-thermal unit (PTU), and helio-thermal unit (HTU) were developed for flowering and physiological maturity phenophases following Shamim *et al.* (2013). The collected data were analyzed statistically through the SPSS software package (SPSS ver. 16, 2007) applying the ANOVA technique using Tukey's HSD test formultiple comparisons for the test of significance at 5% probability level of the means of different parameters. Pearson’s correlation coefficient (r) between seed yield and agrometeorological indices was calculated at 5% and 1% probability levels.

RESULTS AND DISCUSSION

Phenology: Significant variations in the attainment of phenophases like flowering and physiological maturity were recorded among the mustard varieties (Table 1). Mustard varieties like Pusa Tarak, NRCHB-101, and Pusa Mustard-25 took significantly minimum days (46–48 days) to attain flowering, while DRMRIJ-31 and RGN-48 have taken the maximum days (58–60 days) for attaining the flowering stage. Pusa Mustard-25 and NRCHB-101 varieties were recorded with minimum days to attain physiological maturity (89–90 days) in contrast to DRMRIJ-31 and RH-406 with significantly higher days (129 days) of physiological maturity. As no significant correlation of both the phenophases was found with seed yield of the mustard, short-duration varieties of mustard should be given priority under organic production systems for promoting

Table 1 Crop phenophases, growth and yield of mustard varieties

Variety	Days to 50% flowering	Days to Physiological maturity	Plant height at harvest (cm)	Biomass (g/plant)				Biological yield (t/ha)	Test weight (g)	Seeds/ siliqua	Seed yield (t/ha)
				30 DAS	60 DAS	90 DAS	At harvest				
DRMRIJ- 31	60^{f}	129^{e}	149^{ab}	4.3^{bc}	8.6^{ab}	12.8^{a}	53.8^{abc}	7.46^{ab}	6.0^{de}	16.2^{c}	1.42^{a}
NRCDR-02	54^{cde}	120^{d}	147^{ab}	4.2^{b}	8.5^{ab}	12.7^{a}	53.5^{abc}	7.53^{ab}	5.6^{cd}	13.6^{ab}	$1.67^{a\text{-}d}$
NRCHB-101	48^{ab}	90^{a}	149^{ab}	3.3^{a}	9.1^{b}	13.2^{a}	52.0^{a}	7.17^{a}	5.2^{c}	13.1^{ab}	1.57^{abc}
NRCHB-506	52^{bc}	103^{b}	156^{abc}	5.3^{de}	10.5^{c}	14.9^{b}	61.5^{cd}	8.79^{d}	5.1^{bc}	14.1^{abc}	1.83^{bcd}
Pusa Mustard-25	48^{ab}	89^{a}	142^{a}	5.0^{de}	8.4^{ab}	12.5^{a}	52.3^{a}	7.22^{a}	4.2^{a}	14.9^{abc}	1.58^{abc}
Pusa Mustard-26	50^{abc}	103^{b}	152^{abc}	4.9^{d}	8.1^{a}	12.3^{a}	52.9^{ab}	7.33^{a}	4.7^{ab}	15.5^{bc}	1.60^{abc}
Pusa Tarak	46^{a}	105^{b}	149^{ab}	4.8^{cd}	8.3^{ab}	12.4^{a}	54.7^{abc}	7.63^{abc}	5.7^{cd}	13.0^{a}	1.54^{ab}
RH-406	58^{ef}	125^{e}	172^{c}	5.5^{e}	12.5^{e}	16.7^{d}	60.7^{bcd}	9.23^{d}	5.6^{cd}	16.5^{c}	1.97^{d}
RGN- 229	53^{cd}	114^{c}	166^{bc}	6.1^{f}	14.9^{f}	18.9^{e}	65.2^{d}	9.14^{d}	5.2^{bc}	14.9^{abc}	1.91^{cd}
RGN-48	58^{ef}	119^{d}	173^{c}	5.2^{de}	12.2^{e}	16.3^{cd}	$59.0^{a\text{-}d}$	8.49^{bcd}	5.7^{cd}	14.7^{abc}	1.80^{bcd}
Urvashi	52^{bc}	104^{b}	162^{abc}	5.1^{de}	11.7^{de}	15.8^{bcd}	61.3^{cd}	8.64^{cd}	5.4^{c}	14.5^{abc}	1.87^{bcd}
Pusa Bold	57^{def}	120^{d}	161^{abc}	5.1^{de}	11.0^{cd}	15.2^{bc}	65.9^{d}	9.54^{d}	6.3^{e}	16.4^{c}	1.79^{bcd}

Within a column, means followed by different lowercase letters (a–f) are significantly different at $P \leq 0.05$ (Tukey’s HSD test). Mean data of 2 years.

bio-intensification of the existing cropping system in this agro-climatic zone.

Growth attributes: Mustard varieties varied significantly in growth attributes like plant height at harvest and biomass accumulation at different growth stages (Table 1). Varieties RH-406 (173 cm) and RGN-48 (172 cm) were recorded as tallest whereas, Pusa Mustard-25 (142 cm) as the shortest variety. However, no significant correlation was detected between plant height and seed yield. Mustard variety RGN-229 accumulated significantly higher biomass from the beginning (6.1 g/plant at 30 DAS) to the harvesting stage (65.2 g/plant), whereas NRCHB-101 recorded the least biomass at all the stages except at 60 DAS. Estimation of biomass accumulation provides the production ability of the photosynthates in the crop, which ultimately determines yield attributes and yield of the crop. These findings corroborate the results obtained by Mondal *et al*. (2017) in mustard.

Yield attributes and yield: Significant varietal differences in biological yield, seeds per siliqua, test weight, and seed yield are presented in Table 1. Among the mustard varieties, Pusa Bold (9.54 t/ha), RH-406 (9.23 t/ha), RGN-229 (9.14 t/ha), and NRCHB-506 (8.79 t/ha) recorded significantly higher biological yield whereas, Pusa Mustard-26 (7.33 t/ha), Pusa Mustard-25 (7.22 t/ha) 25 and NRCHB-101 (7.17 t/ha) were found to be the lowest biomass accumulator. It was observed that biological yield was significantly correlated with days to flowering (r=0.418**), physiological maturity (r=0.393**), plant height (r=0.431**) and biomass accumulations (30 DAS r=0.507** to 90 DAS r=0.713**). Similarly, it was found significantly correlated with seed yield (r=0.496**), test weight (r=0.361**), and seeds per siliqua (r=0.306**) of mustard varieties at maturity.

Varieties also differed significantly in terms of test weight and seeds per siliqua (Table 1). Varieties Pusa Bold and DRMRIJ-31 registered significantly higher test weight, i.e. 6.3 g and 6.0 g, respectively. The mean minimum temperature at flowering (r=-0.242*) and maturity (r=-0.365**) had a significant negative correlation with test weight. All other agrometeorological parameters at both the phenophases were positively associated with test weight, except HTU at flowering. Among the varieties, the significantly maximum seeds per siliqua were recorded in RH 406 (16.5), Pusa Bold (16.4), and DRMRIJ-31 (16.2). The number of seeds per siliqua were found to be positively associated with days to flowering (r=0.328*), physiological maturity (r=0.439**), biomass accumulation from 30 DAS, 60 DAS, and 90 DAS (r=0.213*, 0.235* and 0.211*, respectively), biological yield at harvest (r=0.306**) and seed yield (r=0.266*) at maturity. A significant negative correlation of mean maximum temperature ($r=-.404^{**}$) and mean minimum temperature ($r=-.351^{**}$) at flowering was recorded on the numbers of seeds per siliqua. Shekhawat *et al.* (2012) also documented the significant role of test weight and numbers of seeds per siliqua in determining seed yield of the mustard in an inorganic production system.

Regarding seed yields, variety RH-406 (1.97 t/ha) and RGN-229 (1.91 t/ha) being at par, recorded significantly higher seed yields, whereas Pusa Tarak (1.54 t/ha) and DRMRIJ 31 (1.42 t/ha) recorded significantly lower seed yields. These variations in seed yield were due to different genetic potential and the agrometeorological parameters to which the crop was exposed up to various pheonophases. Seed yield was found significantly correlated with mean minimum temperature at flowering (r=-0.207*) and the mean maximum and minimum temperature at physiological maturity (r=0.241*; -0.249*, respectively). Yadav (2019) also reported a positive effect of mean maximum and minimum temperature at flowering while a negative impact of minimum temperature at maturity on seed yield of mustard.

Agrometeorological indices: Days taken to attain flowering and physiological maturity were used for the development of different agrometeorological indices. Mustard varieties differed significantly in various agrometeorological indices at flowering phenophase (Table 2). The mean maximum temperature experienced by mustard varieties up to flowering was found significantly different, and it was highest for varieties NRCHB-101, Pusa Mustard-25, Pusa Mustard-26, and Pusa Tarak (27.8–28.2^{o}C). In contrast, it was lowest in the case of DRMRIJ-31, RH-406, RGN-48 (26.2–26.5^{o}C). Up to the flowering stage, the mean minimum temperature was found highest in Pusa Tarak (11.7^{o}C) and least in DRMRIJ-31 (10.5^{o}C). Mean minimum temperature was found significantly and negatively correlated with seed yield (-0.207*). These findings agree with those of Alam *et al.* (2014). They believed that high temperature during the reproductive stage significantly inhibited the export of photosynthates to both upper and lower pods of terminal raceme and thereby reduced sink strength.

Varieties, RGN-48, RGN-406, and DRMRIJ-31 were the significantly highest harvester of net solar radiation (569-575 MJ/m^2/day) at flowering over the remaining varieties (Table 2). Though the net solar radiation accumulated at flowering did not show any significant association with the seed yield, however, it was positively associated with plant height (r=0.457**), biomass accumulation at harvest (r=0.234*), and test weight (0.211*) of the mustard. At physiological maturity, DRMRIJ-31 was ranked first in the accumulation of net solar radiation (1469 MJ/m^2/day). In contrast, Pusa Mustard-25 and NRCHB-101 were recorded as the lowest net solar radiation accumulator with 993 and 1001 MJ/m^2/day values, respectively (Table 2). The total net solar radiation at physiological maturity was found to be positively associated with seed yield (r=0.242*), biomass accumulation from 60 DAS to harvest (r=0.203* to 0.280**), test weight (r=0.349**) and seed per siliqua (r=0.372**). These results highlight the role of solar radiation availability during post-anthesis to physiological maturity in the determination of seed yield in mustard.

The diurnal temperature difference, quantified in the cumulative temperature range, showed significant variations among the varieties in plant growth and yield (Table 2). Up to flowering, variety DRMRIJ-31 recorded 952^{o}C

Table 2 Agro-meteorological indices of mustard varieties at flowering (FL) phenophase and physiological maturity (PM) phenophase

Variety	Mean maximum temperature (°C)		Mean minimum temperature (°C)		Net solar radiation (MJ/m^2/day)		Cumulative temperature range (°C)		Cumulative day temperature (°C)		Cumulative night temperature (°C)		GDD (degree-days)		PTU (degree-days hour)		HTU (degree-days hour)	
	FL	PM	FL	PM	FL	PM	FL	PM	FL	PM	FL	PM	FL	PM	FL	PM	FL	PM
DRMRIJ- 31	26.2^{a}	130^{f}	10.5^{a}	20.5^{a}	575^{b}	1469^{f}	952^{d}	413^{a}	1208^{e}	1820^{e}	1018^{e}	2225^{f}	810^{c}	2043^{f}	8558^{c}	1391^{f}	5413^{a}	14750^{f}
NRCDR-02	27.3^{bc}	121^{d}	11.0^{abc}	22.7^{a}	549^{ab}	1344^{d}	900^{bcd}	387^{a}	1138^{cde}	1696^{cd}	958^{cde}	2046^{d}	773^{bc}	1876^{d}	8179^{bc}	1271^{d}	5359^{a}	13407^{d}
NRCHB-101	28.0^{c}	91^{a}	11.3^{bc}	23.0^{a}	502^{ab}	1001^{a}	816^{a}	326^{a}	1046^{ab}	1301^{a}	883^{ab}	1601^{a}	720^{ab}	1471^{a}	7632^{ab}	1015^{a}	5076^{a}	10655^{a}
NRCHB-506	27.3^{bc}	104^{b}	11.0^{abc}	22.7^{a}	538^{ab}	1119^{b}	879^{bc}	349^{a}	1114^{bcd}	1444^{b}	938^{bcd}	1780^{b}	759^{bc}	1636^{b}	8038^{abc}	1116^{b}	5307^{a}	11715^{b}
Pusa Mustard-25	28.2^{c}	90^{a}	11.2^{abc}	23.2^{a}	502^{ab}	993^{a}	816^{a}	326^{a}	1045^{ab}	1290^{a}	882^{ab}	1589^{a}	718^{ab}	1460^{a}	7622^{ab}	1009^{a}	5067^{a}	10587^{a}
Pusa Mustard-26	27.8^{c}	105^{b}	11.2^{abc}	22.7^{a}	517^{ab}	1126^{b}	842^{ab}	350^{a}	1072^{abc}	1452^{b}	904^{abc}	1788^{b}	735^{ab}	1643^{b}	7788^{ab}	1120^{b}	5179^{a}	11761^{b}
Pusa Tarak	28.2^{c}	106^{b}	11.7^{c}	22.5^{a}	486^{a}	1146^{b}	783^{a}	353^{a}	1014^{a}	1480^{b}	858^{a}	1816^{b}	700^{a}	1668^{b}	7438^{a}	1137^{b}	4948^{a}	11940^{b}
RH-406	26.5^{a}	126^{e}	10.7^{ab}	23.0^{a}	569^{b}	1416^{e}	940^{cd}	400^{a}	1195de	1768de	1007de	2150^{e}	805^{c}	1974^{e}	8499^{c}	1342^{e}	5407^{a}	14194^{e}
RGN- 229	27.3^{bc}	115^{c}	11.0^{abc}	22.5^{a}	542^{ab}	1260^{c}	889^{bcd}	372^{a}	1126^{b-e}	1606^{c}	948^{b-e}	1945^{c}	766^{bc}	1785^{c}	8108^{bc}	1210^{c}	5314^{a}	12734^{c}
RGN-48	26.3^{a}	120^{d}	10.7^{ab}	22.5^{a}	570b	1329^{d}	942^{cd}	385^{a}	1196de	1679^{cd}	1008de	2024^{d}	805^{c}	1856^{d}	8502^{c}	1257^{d}	5403^{a}	13246^{d}
Urvashi	27.5^{bc}	105^{b}	11.0^{abc}	22.5^{a}	541^{ab}	1132^{b}	886^{bc}	350^{a}	1119^{bcd}	1460^{b}	942^{bcd}	1795^{b}	762^{bc}	1649^{b}	8065^{bc}	1124^{b}	5322^{a}	11801^{b}
Pusa Bold	26.8^{ab}	121^{d}	11.0^{abc}	22.7^{a}	565^{ab}	1350^{d}	929^{cd}	391^{a}	1180de	1700^{cd}	995de	2051^{d}	797^{c}	1881^{d}	8425^{c}	1274^{d}	5415^{a}	13441^{d}

Within a column, numbers followed by different lowercase letters (a–f) are significantly different between treatments at $P \leq 0.05$ (Tukey's HSD test).
Mean data of two years.

cumulative temperature range followed by varieties RGN-42 (942°C), RH-406 (940°C), and least in the NRCHB-101 (816°C). The cumulative temperature range at flowering was positively associated with plant height (r=0.398**), biomass accumulation from 60 DAS to harvest (r=0.374** to 0.411**), test weight (r=0.388**) and the seeds per siliqua (r=0.289**). Mustard varieties registered non-significant differences in the cumulative temperature range at physiological maturity. However, cumulative temperature range at maturity was highly associated with the plant height (r=0.968**), biomass accumulation (r=0.324** to 0.386** at 60 DAS and 90 DAS, respectively), test weight (r=0.592**) and seeds per siliqua (r=0.458**). Varieties differed significantly in the cumulative day and night temperature at both the phenophases and variety DRMRIJ-31 ranked the highest (Table 2).

Temperature variation primarily alters the growth of the crop by affecting the onset of different phenophases, and it can be quantified by GDD (Kayacetin *et al*. 2019). This quantification helps to know the heat requirement of the crop for the induction of different phenophases (Dutta *et al*. 2011). For estimating the GDD of mustard, 5°C was taken as base temperature. Up to the flowering stage, the significantly highest GDD was recorded in varieties NRCHB-506 (759° days) and DRMRIJ-31 (810° days), while Pusa Tarak (700° days) was to record least GDD values (Table 2). A significant and positive correlation was noticed between GDD at physiological maturity (r=0.270* to 0.595**) with the plant height, biomass accumulation except at 30 DAS, test weight, and seeds per siliqua. In terms of PTU, three distinct categories of mustard varieties were observed at flowering stage. The mean PTU of the higher category was in the range of 8038 to 8558° days h represented by eight varieties, viz. DRMRIJ-31, NRCDR-02, NRCHB-506, RH-406, RGN-48, RGN-229, Urvashi and Pusa Bold. Due to less duration to attain the flowering stage Pusa Tarak registered the lowest PTU, i.e. 743° days h. There was significant positive correlation between PTU at flowering and plant height, biomass accumulation (except at 30 DAS), test weight, and seeds per siliqua. In contrast, HTU at the flowering phase did not show any correlation with the growth and yield attributes except plant height. However, PTU at physiological maturity showed a highly significant positive association with plant height, biomass accumulation, test weight, and the number of seeds per siliqua.

The non-significant association of seed yield of mustard with either day taken to flowering or physiological maturity suggested that crop duration cannot be considered as selection criteria of variety for organic production. Various agrometeorological indices indicated that the sowing window of mustard would be synchronized with the lowest mean minimum temperature and higher cumulative temperature range during flowering phenophase.

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