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Analyzing the Thermal Indices of Mustard [*Brassica Junce*a (L.) Czern and Coss.] Under Varying Sowing Schedules and Spatial Arrangement Following BBCH Scale

Rachita Mishra[1]*, Subham Acharya[2] and Md Riton Chowdhury[1]

[1]Department of Agronomy, Faculty of Agricultural Sciences, SOADU, Bhubaneswar, Odisha, India
[2]Department of Agrometeorology, Faculty of Agricultural Sciences, SOADU, Bhubaneswar, Odisha, India

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ABSTRACT

An experiment was conducted at Agricultural Research Station, Binjhagiri, Chhatabar, Faculty of Agricultural Sciences (IAS), Siksha O Anusandhan (Deemed to be University), Bhubaneswar, Odisha during *Rabi* 2023-24 entitled "Analyzing the thermal indices of mustard [*Brassica juncea* (L.) Czern and Coss.] under varying sowing schedules and spatial arrangement following BBCH scale" to identify the suitable sowing time during rabi season by computing the thermal indices and its impact on yield of mustard. The experiment was comprised of four different dates of sowing i.e., D_1 (10th November), D_2 (24th November), D_3 (8th December) & D_4 (22nd December) and three different crop geometry i.e., S_1 (30 cm x 15 cm), S_2(45 cm x 15 cm) & S_3 (30cm x 30cm). The agro-meteorological indices shows that D_1(45th SMW) accumulated more GDD, HTU, PTU,HUE and PTI i.e., 1832.0 ^{0}C days,13225.2 ^{0}C days hours, 20171.5 ^{0}C days hours, 0.60 kg ha^{-1} ^{0}C^{-1} days and 20.2^{0}C days days^{-1} respectively at P_9 (senescence) stage according to BBCH scale. The highest seed yield (1087.0kg ha^{-1}) of mustard was noted under D_1 i.e., 10th November (45thSMW) followed by under D_2 (823.0kg ha^{-1}) i.e., 24th November. Among different crop geometry, the yield attributing characters were significantly higher in S_3 (30cm x 30cm) followed by S_1 (30cm x15 cm), however the highest seed yield (858.0 kg ha^{-1}) of mustard was found under narrow spacing of 30 cm x 15 cm. Highest seed yield (1151kg ha^{-1}) was obtained in the treatment combination of D_1S_1 and it is statistically similar with D_1S_3 having seed yield of 1145.33 kg ha^{-1}, S_3 (30 cm × 30 cm) proved to be more remunerative due to its lower input requirements (particularly seed), making it a more cost-effective option, despite the slightly lower seed yield than S_1. Throughout the study it has been concluded that the combination of sowing during 1st fortnight of November with a wider spacing of mustard under this agro-climatic conditions gives higher productivity in the state of Odisha.

Keywords: *Sowing schedules, BBCH schedule*

Introduction

Mustard is very important to the agricultural economy and contribute significantly to oilseed production in India. It contributes nearly 24% of the oilseed cultivation area in the country, along with 27% of oilseed production (Choudhary *et al.*, 2021). Mustard can sustain under a wide range of agro-climatic conditions, making it a key agricultural oilseed crop for the country (Mondal *et al.*, 1999). Generally about

67% of variation of any crop is governed by prevailing weather condition and 33% by other crop management factors. Biomass accumulation of mustard is significantly influenced by temperature and solar radiation and has a close relationship with the crop phenology. Moreover, each stage of the crop's phenology has an impact on the yield and its yield-attributing characteristics. Ideal sowing time increases yield potential by ensuring favourable conditions throughout all growth stages (Alam *et al.*, 2015). Delayed sowing faces excessive heat and high evaporative demand during the reproductive stage, resulting in stress that speeds up maturity and senescence (Porter, 2005). Day length and temperature have a significant impact on the phenological development of mustard. Each crop must accumulate a definite number of degree-days to advance through its growth stages. Mustard crop require different amount of GDD, HTU, PTU, PTI and HUE for growth and development stage. According to Miller *et al.*, 2001 mustard cultivars are available, each with specific GDD requirement, for emergence 110-136, for flowering 680-750, for maturity ranging from 1510-1710 growing degree days using 5 ^{0}C base temperature. Thermal indices, such as Growing Degree Days (GDD), Photo-Thermal Units (PTU), Helio-Thermal Units (HTU), Heat Use Efficiency (HUE) and Photo Thermal Index (PTI) are widely employed to evaluate and track crop phenology.

Materials and Methods

The experiment was conducted at the Agriculture Research Station, Binjhagiri, Chhatabar, Faculty of Agricultural Sciences, Siksha O Anusandhan Deemed to be University, Bhubaneswar, Odisha, during the rabi season of 2023-24. The soil of the experimental field had a sandy loam texture, having a pH of 5.44. The experiment was laid out in a split-plot design, with the four dates of sowing in the main plots: D_1 (10th November / 45th SMW), D_2 (24th November / 47th SMW), D_3 (8th December / 49th SMW), and D_4 (22nd December / 51st SMW). The three different crop geometries were kept in sub-plot, i.e. S_1(30 cm × 15cm), S_2(45 cm × 15cm) & S_3(30 cm × 30cm). The test variety of the experiment was Nirmal Bold (NML-64), with a seed rate of 6 kg/ha. The recommended fertiliser dose of 80 kg N, 40 kg P_2O_5 and 40 kg K_2O was applied through urea, Single Super Phosphate and Muriate of Potash. The daily weather data, including maximum annd minimum temperatures, bright sunshine hour (BSH), and other obligatory data towards calculating thermal indices, were collected from the agro-meteorological centre at the Agricultural Research Centre, Binjhagiri, Chhatabar, of SOADU. Mustard sown on 10th November (D_1) was harvested on 15th February 2024, 24th November (D_2) on 27th Feb 2024, 8thDecember (D_3) on 6th March 2024 and 22nd December (D_4) on 16th March 2024.

The different phonological stages of mustard were represented here using the BBCH (Biologische Bundesanstalt (Federal Biological Research Centre), Bundessortenamt (Federal Plant Variety Office), and Chemische Industrie (Chemical Industry) scale. This scale is a uniform coding system that summarises the phenological stages of different crops from their germination to senescence, was proposed by Bleiholder *et al.*, 1989. A more precise and extensive coding scheme was described by Hack *et al.* in 1992 and published under the name "extended BBCH scale, general". Ten principal growth phases make up this scale, which is further separated into secondary growth stages. The scale describes the phenological development of both mono and dicotyledonous plants from germination to senescence. This scale splits the plant's growth into nine (9) primary and ancillary growth stages ranging from 0-9 as described by Meier *et al.*, 2009. The details of the phenological phasesare as viz. principal phenophase 0- Germination(P_0), principal phenophase 1- Leaf development (P_1), principal phenophase 2-formation of side shoots(P_2), principal phenophase 3- stem elongation(P_3); principal phenophase 5- inflorescence emergence (P_5); principal phenophase 6- Flowering(P_6), principal phenophase 7- Development of fruit(P_7); Principal phenophase 8-ripening(P_8); principal phenophase 9-Senescence(P_9). In this experiment, the BBCH scale(0-9) has been grouped into four main growth phases: Germination to stem elongation (G_0 to P_3), Inflorescence emergence to flowering (P_5 and P_6), Fruit development to ripening (P_7 and P_8) and Senescence (P_9).

The Growing Degree Days (GDD) indicates that temperature has a direct and linear impact on plant growth and development. It assumes plant growth depends upon the total number of heat units it has accumulated over its lifetime. GDD (^{0}C days) can be calculated using the following formula as described by Nuttonson (1955).

$$GDD=\Sigma a^{b}\frac{Tmax+Tmin}{2}-Tb$$

Where T max is the daily maximum temperature (^{0}C), T min. is daily minimum temperature (^{0}C) and T base is Tb is base temperature, which is defined as the temperature below which all the physiological processes of a plant are retarded. For mustard, it is considered to be 5 °C.

Helio-thermal units (HTU) measure the thermal accumulation in terms of heat exposure over a specific time period, which is crucial for the progression of the concerned crop in relation to temperature. HTU (°C days) is the yield of the degree days and the corresponding actual bright sunshine hours. It can be calculated using the following formula (Rajput 1980).

HTU=ΣGDD × Actual bright sunshine hours (0.C/day/hr))

A photo thermal unit i.e., PTU combines temperature and photoperiod, illustrating how light and heat aid in plant development. PTU (^{0}C days hours) is the product of GDD and the corresponding day length for that day, and is computed daily (Nuttonson, 1955)

PTU= ΣGDD × Day length (^{0}C/day/hr))

The efficiency at which a crop converts heat units into biomass /yield is known as heat use efficiency. It is calculated with the help of the seed yield expressed in Kg^{-1} ^{0}C^{-1} days

$$HUE=\frac{\text{Seed yield}}{GDD}$$

Photo thermal index expressed in ^{0}C days days^{-1}, is a way to assess how much heat and light a plant accepts over a certain period, which is crucial for understanding its growth rate and development.

$$PTI=\frac{GDD}{\text{Number of days between two phenological stages}}$$

Results and Discussion

Weekly variation in temperature and sunshine hours at experimental site during cropping period.

The weekly temperature and sunshine hours variation at the experimental site during crop growth period exhibited clear seasonal patterns (Fig. 1), which strongly influenced crop performance under varying sowing dates. Bright sunshine hours fluctuated, with higher values observed in the early part of the season and gradual decline towards crop maturity. Maximum temperature remaining around 30^{0}C at the beginning (SMW 45-46), dipping slightly during late November and December and thereafter steadily increasing by March. Minimum temperature followed a typical winter pattern, starting at 22 ^{0}C in November, falling to the lowest levels (17-18 ^{0}C) during peak winter (SMW 2-3 ,January) and rising again to about 23-24 ^{0}C by March. These variations influenced crop performance across varying sowing dates.

Heat unit requirement as influenced by various treatments

The data in Table 1 revealed that the accumulated heat units regarding different phenological stages of mustard varied significantly with changes in sowing schedules. 10th November (D$_1$) sown crop showed progressively acquired higher GDD during all growth stages, with the highest of 1832.0 ^{0}C days at P$_9$ period. In contrast, the consequent delay in sowing led to noticeable decrease in GDD accumulation. The crop sown on 22nd December (D$_4$) accumulated the lowest heat unit. This suggests that the overall extent of the crop's growth is inherently reduced when sown later in the season. This phenomenon highlights that late sowing hampers the crop's capability utilize the available resources fully, probably leading to a shorter growing period and, thus, impacting its complete performance.

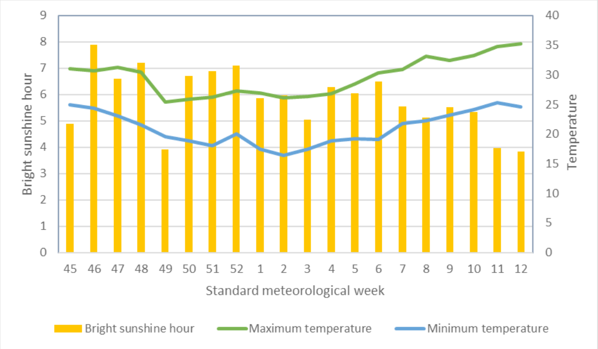

Fig. 1.

The accumulation of Helio-Thermal-Units (HTU) in mustard is significantly subjective by variation in GDD and BSH, which differ depending on sowing dates. Specifically, delayed sowing leads to a decrease in both GDD and sunshine hours, adversely affecting HTU accumulation. The helio-thermal unit was higher in D$_1$(45th SMW-10th Nov) at all growth stages, and with successive delays in sowing, HTU accumulation significantly reduced. The highest HTU accumulation of 13225.2 ^{0}C day hours was ob-

Table 1. Accumulated GDD (^{0}C days), HTU (^{0}C days hours), PTU (^{0}C days hours) and PTI (^{0}C days days^{-1}) at different phonological stages in Mustard under different sowing dates

Treatments	GDD				HTU				PTU			
Date of sowing	G_0-P_3	P_5-P_6	P_7-P_8	P_9	G_0-P_3	P_5-P_6	P_7-P_8	P_9	G_0-P_3	P_5-P_6	P_7-P_8	P_9
D_1(10th Nov/45th SMW)	308.1	701.8	1400.6	1832.0	2608.8	5520.9	10273.3	13225.2	3767.1	7970.8	15350.9	20171.5
D_2 (24th Nov/47th SMW)	232.5	656.8	1224.0	1666.5	1752.6	4019.4	8626.8	11507.0	2518.7	5857.4	13175.1	18135.5
D_3(8th Dec/49th SMW)	196.9	581.4	1132.0	1576.6	1412.9	3533.8	7795.3	10505.3	2171.1	5418.7	12386.4	17401.7
D_4(22nd Dec/51st SMW)	193.9	580.7	1087.2	1516.0	1347.6	3172.7	7244.4	9881.6	2045.0	4951.4	11918.0	16802.1
SEm±	0.20	0.42	0.22	0.23	0.17	0.22	0.15	0.17	0.09	0.11	0.11	0.75
CD(P=0.05)	0.70	1.46	0.79	0.73	0.58	0.78	0.53	0.58	0.33	0.40	0.38	2.55
Crop geometry												
S_1(30 cm × 15 cm)	232.9	637.6	1213.0	1648.9	1785.8	4069.5	8515.1	11298.0	2630.7	6053.5	13219.0	18128.8
S_2 (45 cm × 15 cm)	232.7	637.4	1208.9	1651.0	1785.4	4068.9	8515.5	11224.9	2631.0	6057.9	13215.7	18128.0
S_3 (30cm × 30cm)	232.9	637.4	1210.9	1649.3	1785.7	4069.4	8514.9	11316.3	2630.5	6051.8	13211.1	18125.5
SEm±	0.27	0.93	0.32	0.23	0.16	0.13	0.09	0.27	0.07	0.08	0.18	0.49
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

G_0-P_3; Germination to stem elongation , P_5-P_6; Inflorescence emergence to flowering , P_7-P_8; Fruit development to ripening , P_9; Senescence

served in P_9 followed by D_2(24th Nov) and D_3(8th Dec), respectively. The lowest HTU accumulation occurred during D_4(22nd Dec). The sowing time in mustard plays an acute role in influencing the crop's growth dynamics, principally through its effects on GDD and day length. Changing sowing dates significantly impacts the accumulation of Photo-thermal units (PTU). The highest PTU consumption was noted at 20171.5^{0}C day hours, which was observed in P_9. This was followed by PTU accumulation in D_2(24th Nov) and D_3(8th Dec), signifying a diminishing trend with late sowing dates. On the other hand, the lowest PTU consumption was observed during late sowing i.e., D_4(22nd Dec). This suggests that delayed sowing leads to a reduction in the PTU consumption, likely due to changes in GDD and day length. In the present study, earlier sown crop had higher accumulated GDD, HTU, PTU; however, with a delay in sowing GDD, HTU & PTU consumption decreased. Similar findings were reported by Gupta *et al*., 2017.

Seed yield and dry matter accumulation in crops are significantly influenced by various heat indices viz GDD, HTU, PTU. The highest seed yield and dry matter accumulation was observed with the first date of sowing (D_1) i.e., 45th SMW/ 10th Nov. This distinguished outcome is principally attributed to the higher accumulation of thermal units during the initial sowing period. Early sowing (D_1-10th Nov) provided a longer period for the crop to utilize all the available resources judiciously and experience favorable temperature range. On the contrary, late

Table 2. Seed yield of mustard and Heat use efficiency under varied sowing dates and crop geometry

Treatment	Seed yield (kg ha^{-1})	HUE (kg ha^{-1} ^{0}C^{-1}days)
Date of sowing		
D_1(10th Nov/ 45th SMW)	1087.0	0.601
D_2 (24th Nov/47th SMW)	823.0	0.493
D_3(8th Dec/49th SMW)	563.0	0.356
D_4(22nd Dec/51st SMW)	433.0	0.286
SEm±	42.9	0.034
CD @5%	148.6	0.119
Crop geometry		
S_1 (30 cm × 15 cm)	858.0	0.510
S_2 (45 cm × 15 cm)	607.0	0.368
S_3 (30cm × 30cm)	715.0	0.423
SEm±	22.5	0.014
CD @5%	67.4	0.043

sown crops had less time to utilize the available growth factors, favourable atmospheric conditions and BSH, which caused in poor dry matter accumulation, which ultimately led to yield loss. Akhter *et al*. (2016) also stated similar findings.

Mustard seed yield was significantly affected by varied sowing dates and different spacing (Table 2). Early sowing (D_1-45th SMW or 10th Nov) resulted in the highest seed yield of 1087 kg ha^{-1}. This yield ominously surpassed those recorded from all later sowing dates, emphasizing the significance of timely sowing towards achieving higher productivity. The crop sown on 24th November (2nd sowing-D_2) led to a substantial reduction in seed yield to 823kg ha^{-1}. Further delays to December 8th (D_3- 3rd sowing) and December 22nd(D_4- 4th sowing) resulted in even lower yields of 563kg ha^{-1} and 433 kg ha^{-1}. The seed yield under D_3 was statistically similar to that of D_4, indicating that by early to late December, the yield potential of the crop had significantly declined. This yield reduction with later sowing dates is primarily attributed to the period of the reproductive phase. Early sown crops (D_1) are promoted by a longer reproductive period, resulting in optimum development and effective resource utilisation under the favourable climatic conditions. This stretched period aids superior growth and grain formation, leading to higher crop yield. Equally, when the cropssown either late November (D_2-24th Nov.) or in December(D_3&D_4) experienced a reduced growth cycle, which ultimately reduced the grain-filling period. This restriction often leads to forced maturity, inhibiting the crops from getting their full growing potential before harvest, therefore, causing low seed yield. These findings align with similar research described by Aziz *et al*., 2011 and Ranabat *et al*., 2020, highlighting the significance of timely sowing for maximizing mustard yield. About crop geometry, the data showed that seed yield was significantly varied by crop geometry. The highest seed yield of 858.0 kg ha^{-1} was attained with a planting geometry of 30 cm × 15cm(S_1), followed by 30 cm × 30cm (S_3-wide spaced square planting) spacing, which produced 715.0 kg ha^{-1}. In contrast, the lowest seed yield (607 kg/ha) was noted when mustard was sown following wider spacing of 45cm × 15cm(S_2). This diminished yield can be attributed to wider spacing, which results in a lower plant population per unit area. A reduced plant per unit area cannot compensate for the yields achieved from denser plantings, even though individual plant produces more siliqua, where as a higher plant population, even with lower silique per plant, contributes more that leading to overall high productivity. Similar results were reported by Sharma *et al.* (2009), Chhonkar *et al.* (2011), and Mevada *et al.* (2017).

The data presented in Table 2 revealed that the Heat use efficiency (HUE) of mustard was significantly affected by varying dates of sowing. The highest HUE of 0.601 kg ha^{-1}^{0}C days^{-1}was recorded on 1st date of sowing (D_1-10th Nov/45th SMW). This elevated HUE in earlier planting is probably due to a comparative increase in dry matter accumulation/ unit of heat absorbed, representing more resourceful utilization of available thermal resources. Conversely, HUE declined significantly with successive delays in sowing. For example, D_2-24th Nov. sowing accumulated a HUE of 0.493 kg ha^{-1}^{0}C days^{-1}, and it

Table 3. PTI (^{0}C day's days^{-1}) at different phenological stages of mustard as affected by different sowing dates and crop geometry

Treatments	G_0-P_3	P_5-P_6	P_7-P_8	P_9
D_1(10th Nov/ 45th SMW)	18.5	14.5	18.6	20.2
D_2 (24th Nov/47th SMW)	14.5	11.7	17.1	19.1
D_3(8th Dec/49th SMW)	12.5	11.0	16.2	18.3
D_4(22nd Dec/51st SMW)	11.5	10.4	15.9	17.9
SEm±	0.15	0.03	0.02	0.05
CD @5%	0.54	0.13	0.09	0.12
S_1(30cm × 15 cm)	14.3	11.9	17.0	18.9
S_2(45cm × 15 cm)	14.2	11.9	16.9	18.8
S_3(30cm × 30cm)	14.3	11.9	16.9	18.9
SEm±	0.14	0.01	0.01	0.02
CD @5%	NS	NS	NS	NS

G_0-P_3: Germination to stem elongation , P_5-P_6: Inflorescence emergence to flowering , P_7-P_8: Fruit development to ripening , P_9: Senescence dropped further to 0.356 kg ha^{-1}°C days^{-1} in D_3(8th Dec). The lowest HUE of 0.286 kg ha^{-1}°C days^{-1} was calculated in D_4(22nd Dec). This drop in HUE under later sowing dates can be attributed to the accumulation of relatively lower GDD as compared to early sowing (Table 1). Quantification of the effects of temperature on crop growth can be evaluated by GDD. This quantification helps to know the thermal requirement for the start of different phenol phases of crops (Dutta *et al*., 2011). A reduced GDD accumulation means less thermal energy is available for crop development, leading to less effective trans formation of heat into biomass. Similar findings were reported by Jain *et al*., 2018, as they also highlighted the importance of timely sowing in enhancing heat use efficiency in mustard. HTU and PTU consumption decrease as the sowing gets delayed. The earlier sown crop availed higher heat units as compared to the later sown crop. Crop sown on 10th November resulted in accumulating more growing degree days due to high temperature and more sunshine hours, which resulted in early flowering. Similar findings were reported by Tripathy *et al*., 2007. Crop duration significantly affects the accumulation of GDD,HTU and PTU.A longer crop duration typically correlates with greater accumulation of these thermal units. The crop sown on November 10th exhibited the longest duration of 97 days, and subsequent delays in sowing led to a progressive decrease in crop duration. Similar findings were reported by Singh *et al*., 2014. The reduction in crop duration and the associated decrease in GDD, HTU and PTU accumulation due to delayed sowing have significant negative implications for mustard yield. 10th November sown crop allows for a longer duration, leading to higher accumulation of thermal units, which resulted in enhanced dry matter production and seed yield. Similar findings were reported by Rana *et al*., 2017.

The photo thermal index or PTI of mustard under varying sowing dates and different spacing has been depicted in Table 1. The data of PTI indicate that early sowing (D = 45th SMW) provides the highest PTI values in all phenophases, whereas late sowing (D) continuously provides the lowest PTI values. This may be due to early sowing permits the crop to grow in longer days and favourable temperatures. Thus, the crop can gather more thermal energy every day, which provides higher PTI values. Therefore, sowing of mustard as during *rabi* season earlier guarantees improved utilization of favourable winter temperatures and longer photoperiods during early crop growth periods. On the other hand, sowing the crop late sowing subjected to shorter days and low temperatures, restricts PTI, thus creating limitations on growth& development and seed yield. Crop geometry distresses the microclimate, interrupts light, and the overall thermal time, a major component of PTI, is not greatly impacted.

Conclusion

Sowing of mustard during the 45th standard meteorological week (SMW) in the east and south-eastern plain zones of Odisha performs better due to the accumulation of optimal thermal indices as compared to the late sowing, such as the 24th Nov/ 47th,8th Dec. or 49th, and 22nd Dec./51st SMW. All the Phenological stage manages to vary cumulative thermal build-up, prejudiced by varying sowing windows. The impact of different agro-meteorological indices and weather parameters, such as temperature, bright sunshine hours, and relative humidity, was highly influential in determining the phenophase of mustard during the reproductive period (inflorescence emergence and pod development) according to the BBCH scale. Therefore, it can be inferred that sowing of mustard during the 1st fortnight of November with a spacing of 30cm × 15 cm resulted in improved crop yield in this region.

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Authors contribution: Rachita Mishra: Conducted the experiment, data analysis and manuscript preparation; S. Acharya: Monitoring the experiment, manuscript preparation; Md R. Chowdhury: Data analysis, Manuscript modification.

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