OPTIMIZING RAPESEED PRODUCTIVITY THROUGH SOWING DATE ADJUSTMENT AND AGRO-CLIMATIC INDICES MODERATION

ABSTRACT

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| **Aims:** To optimize rapeseed variety TS 67 yield and agroclimatic indices through sowing date adjustment in Assam condition i.e. Eastern Himalayan agroclimatic region.  **Study design:** Split plot design  **Place and Duration of Study:** Instructional cum Research Farm, Assam Agricultural University Jorhat, during kharif season of 2022.  **Methodology:** The treatments were laid out in a split plot design with three replications. The treatments comprised of three different sowing dates *viz.,* D1: 15th November, D2: 30th November, D3: 15th December in main plots and four Jasmonic acid concentration JA1 (no JA), JA2 (50 micromole per litre), JA3 (100 micromole per litre), and JA4 (150 micromole per litre). From the study, the growth, physiological parameters, yield attributes, yield and agroclimatic indices were recorded and analyzed.  **Results:** Results revealed that among the different sowing dates, The crop sown on 15th November (D1) required significantly higher number of days to flower initiation (28.50 days), 50% flowering (34.50 days), siliqua formation (34.58 days) and physiological maturity (87.08 days) along with significantly higher accumulated growing degree days (1199.77 0C day), helio-thermal units (7567.22 0C day hours) and photo-thermal units (12766.70 0C day hours). Significantly higher seed yield of 6.66 q ha-1, stover yield of 14.11 q ha-1 and oil yield of 243.62 kg ha-1 were also obtained from the sowing of the crop on 15th November (D1). On the other hand, the crop sown on 15th December (D3) recorded lowest seed as well as stover yield of 4.99 q ha-1 and 12.21q ha-1 respectively. Correlation studies indicate significant interrelationship between agroclimatic indices and plant growth parameters having higher correlation coefficient which indicates that the optimum agroclimatic parameters improves growth and yield of rapeseed.  **Conclusion:** Based on growth, yield and agroclimatic indices, the sowing of the crop on 15th November can be considered best for enhancing the production of rapeseed (*Brassica campestris var. toria)* under rainfed condition. |

Keywords: Agroclimatic indices, accumulated growing degree days, accumulated helio-thermal unit, accumulated photothermal unit

1. INTRODUCTION

Rapeseed (*Brassica campestris var. toria*), commonly known as sarson or toria, is one of the major important oilseed crops containing 40–46% oil. India ranks third worldwide in production of rapeseed & mustard with an annual production of 11.10 metric tons per hectare (USDA, 2023). In north eastern part of the country, mainly in Assam, the crop is grown around 2.86 Lakh ha contributing annual production of 1.85 lakh tonnes with an annual average productivity of 6-7 q ha-1 which is quite low as compared to the national average of 14.99 q ha-1 (GoA, 2024). Every crop has an optimum range of sowing dates for the production of its potential yield. Sowing of crops at proper time resulted in efficient utilization of resources such as sunlight, water and air etc. which ultimately improved the uptake and distribution of nutrients, more crop growth and yield. The notable effect on yield of the crop mainly attributed to stress induced by delayed sowing as the crop is mainly grown under rain fed condition on residual soil moisture accompanied by poor nutrient management (Deka *et al.,* 2018). Apart from these, many biotic and abiotic stresses that have a negative impact on crop growth is responsible for poor crop yield (Kumari *et al.,* 2011). The critical stages *viz.,* flowering and siliqua formation were severely hampered due to reduced soil moisture and shortened growing season under delayed rainfed conditions (Deka *et al.,* 2018 and Singh *et al.,* 2017). Rapeseed being a thermo and photosensitive plant (Ghosh and Chatterjee, 1988) is highly influenced by both biotic and abiotic factors grown under different micro-climatic regimes. Hence, microclimatic environment could be modified by altering the dates of sowing. (Pandey *et al.,* 1981).

2. material and methods

The experimental site having humid subtropical climate with dry winters experiences annual average temperature of 78.21°F, an annual precipitation of approximately 96.46 mm over 66.44 rainy days. During the study, the weekly average maximum temperature ranged between 21.4°C and 29.3°C, while the minimum temperature recorded from 7.9°C to 15.7°C. The total rainfall measured throughout the experiment was 41.4 mm, distributed over four rainy days (**Figure-1,** **2**).

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| Figure-1: Weekly meteorological data of maximum temperature, minimum temperature and relative humidity (morning and evening), during the experimentation (2022-2023). | Figure-2: Weekly meteorological data of rainfall, evaporation, number of rainy days and bright sunshine hours during the experimentation (2022-2023). |

The experiment followed in a split-plot design having three replications. The main plot involved three different sowing dates to create distinct microclimatic conditions: D1 (15th November), D2 (30th November), and D3 (15th December). The sub-plots included four levels of jasmonic acid (JA) application: JA1 (no JA), JA2 (50 micromole per litre), JA3 (100 micromole per litre), and JA4 (150 micromole per litre).

Each individual plot measured 3.6 m × 2.4 m, with three replications. The TS-67 variety was cultivated during the *rabi* season of 2022-23, adhering to the recommended package of practices under rainfed conditions. The experimental soil was sandy loam, acidic (pH 5.62), medium in organic carbon (0.54%), and low in available nutrients N (239.54 kg/ha), P2O5 (22.40 kg/ha), K2O (112.42 kg/ha), and **S** (6.61 kg/ha). Fertilizers were applied at a rate of 40-35-15 kg ha⁻¹ (N-P₂O₅-K₂O).

**Growing degree days (0C day):**

The growing degree days were the measure of accumulation of heat units, calculated in terms of maximum minimum and base temperature i.e., 5.0 0 C (Nanda *et al.,* 1996):

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| **Growing degree days =** | **(Tmax +Tmin)/2 - Tt** |

where, Tmax = maximum temperature (0C)

Tmin = minimum temperature (0C)

Tt = base or threshold temperature (0C)

**Helio-thermal Unit (0C hours)**

Helio-thermal units were measure by multiplying GDD and corresponding sunshine hours.

**HTU = GDD x actual sunshine hours**

**Photo thermal Unit (0C hours)**

The photo-thermal unit was measured in terms of day length and growing degree days.

**PTU = GDD x Day length**

**Statistical analysis**

The experimental findings for various parameters were statistically analyzed following the standard procedures of analysis for split-plot design (Panse and Sukhatme, 1985). The critical difference (CD) at 5% probability level was calculated when the F value was found significant. The analysis of variance (ANOVA), S.Em. (±), CD, CV (%), means and S. Ed, were calculated using the software MS Excel and OP Stat. Duncan’s Multiple Range test (DMRT) was followed for multiple comparison, using the software OP Stat. The different letters *viz.,* a, b and c indicated significant differences among treatments (P < 0.05).

For correlation and multiple regression analysis, computer software SPSS (version 21) was used.

CD = Sed (±) × √2 × × t value at 5% (2.447) for error (a) d.f.

3. results and discussion

**3.1 Crop phenology:**

The data on crop phenology due to different sowing condition has been presented in **Table 1** and **Figure 3**. Results revealed that different sowing condition greatly influenced the crop phenology of rapeseed. The timely sown crop *i.e.* 15th November (D1) reported to have maximum duration in flower initiation (28.50 days), 50% flowering, siliquae formation (34.50 days) and physiological maturity (87.08 days) followed by 15 days delay sowing from optimum (D2). While, 30 days delayed sowing from optimum reported to have the shortest crop phenology in all the growing stages. However, the crop phenology remained unaffected due to the application of different concentrations of jasmonic acid.

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| **Table 1: Effect of sowing date adjustment and growth hormone application on crop phenology (days) of *toria*** | | | | | | |
| **Treatments** | **Days to**  **emergence** | **Days to**  **flower**  **initiation** | | **Days to**  **50%**  **flowering** | **Days to**  **siliqua**  **formation** | **Days to**  **physiological**  **maturity** |
| **Micro-climatic regimes (D)** | | | | | | |
| D1: 15th Nov | 6.42c | 28.50a | 34.50a | | 34.58a | 87.08a |
| D2: 30th Nov | 7.67b | 26.50b | 30.75b | | 30.67b | 83.28b |
| D3: 15th Dec | 8.50a | 20.75c | 27.17c | | 25.67c | 77.18c |
| S. Em (­­±) | 0.16 | 0.31 | 0.55 | | 0.38 | 0.35 |
| C.D (0.05) | 0.61 | 1.21 | 2.17 | | 1.50 | 1.40 |
| Here, different letters indicate significant differences among treatments (P < 0.05) according to Duncan’s Multiple Range test. | | | | | | |

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| **Output image** |
| Figure 3.: Effect of sowing date adjustment on rapeseed phenology. |

**3.2 ACCUMULATED GROWING DEGREE DAYS (AGDD):**

The accumulated growing degree days (AGDD) determined at different phenological stages i.e., emergence, flower initiation, 50% flowering, siliqua formation and physiological maturity were significantly influenced by different micro-climatic regimes (**Figure 4**). The result revealed that the crop sown on 15th November (D1) availed significantly higher AGDD at flower initiation (435.35 0C day), 50% flowering, (510.25 0C day) siliqua formation (511.56 0C day) and physiological maturity (1199.77 0C day) which was significantly superior over the crop sown on 30th November (D2) that availed 375.88 0C day for flower initiation, 423.11 0C day for 50% flowering, 422.59 0C day for siliqua formation and 1132.59 0C day for physiological maturity. Whereas, the lowest AGDD was availed by the crop sown on 15th December (D3) at flower initiation (258.66 0C day), 50% flowering, (331.54 0C day) siliqua formation (316.78 0C day) and physiological maturity (1068.37 0C day). In case of emergence, the crop sown on 15th December (D3) (119.42 0C day) availed significantly higher AGDD which was at par with the crop sown on 30th November (D2) (114.56 0C day) and both of them were significantly superior over the crop sown on 15th November (D1) (100.46 0C day). Whereas, jasmonic acid did not bring any significant effect on accumulated growing degree days.

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| Figure 4: Effect of sowing date adjustment on accumulated growing degree days of toria |

**3.2 ACCUMULATED HELIO-THERMAL UNIT (AHTU):**

The accumulated helio-thermal unit (AHTU) at different crop growth stages viz., emergence, flower initiation, 50% flowering, siliqua formation and physiological maturity were significantly influenced due to different micro-climatic regimes (Figure 5). The micro-climatic regime created by sowing the crop on 15th November (D1) availed significantly higher AHTU at flower initiation (3664.50 0C day hours), 50% flowering (4604.76 0C day hours), siliqua formation (4261.02 0C day hours) and physiological maturity (7567.22 0C day hours) which was significantly superior over the crop sown on 30th November (D2) which availed comparatively lower AHTU of 2988.30 0C day hours for flower initiation, 3354.31 0C day hours at 50% flowering, 2895.79 0C day hours at siliqua formation and 6209.52 0C day hours at physiological maturity. Whereas, the lowest AHTU was availed by the crop sown on 15th December (D3) at flower initiation (1368.65 0C day hours), 50% flowering, (2414.94 0C day hours), siliqua formation (1821.72 0C day hours) and physiological maturity (5422.36 0C day hours). On the other hand, at emergence, the crop sown on 30th November (D2) availed significantly higher AHTU (980.88 0C day hours) which was found to be significantly superior over the crop sown on 15th November (D1) (841.90 0C day hours). The lowest AHTU was recorded by crop sown on 15th December (D3) (836.02 0C day hours) which was statistically at par with crop sown on 15th November (D1) (841.90 0C day hours). The accumulated helio-thermal unit remain unaffected due to the application of jasmonic acid.

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| Output image |
| Figure 5: Effect of sowing date adjustment on accumulated helio-thermal unit of *toria* |

**3.3 ACCUMULATED PHOTO-THERMAL UNIT (APTU):**

The micro-climatic regimes significantly influenced the accumulated photo-thermal unit (APTU) at different phenological stages (Figure 6). Among different micro climatic regimes, the crop sown on 15th November (D1) availed significantly higher APTU at different growth stages *viz.,* flower initiation (4528.28 0C day hours), 50% flowering, (5413.43 0C day hours), siliqua formation (5427.10 0C day hours) and physiological maturity (12766.70 0C day hours). Whereas, the crop sown on 30th November (D2) availed comparatively lower APTU at flower initiation (3968.84 0C day hours), 50% flowering (4442.26 0C day hours), siliqua formation (4436.84 0C day hours) and physiological maturity (12196.77 0C day hours) followed by crop sown on 15th December (D3) i.e., 2708.65 0C day hours at flower initiation, 3477.34 0C day hours at 50% flowering, 3290.36 0C day hours at siliqua formation and 11629.53 0C day hours at physiological maturity. On the other hand, at emergence, the crop sown on 15th December (D3) availed significantly higher APTU (1249.58 0C day hours) which was at par with 30th November (D2) (1210.04 0C day hours) and the lowest APTU was availed for the crop sown on 15th November (D1) (1084.14 0C day hours). There was no any significant influence of jasmonic acid on accumulated photo-thermal unit.

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| Output image |
| Figure 6: Effect of sowing date adjustment on accumulated photo-thermal unit of *toria* |

**4. CORRELATION STUDIES**

**4.1 CORRELATION STUDIES OF DRY MATTER PRODUCTION, YIELD ATTRIBUTING CHARACTERS AND YIELD WITH GDD (GROWING DEGREE DAYS) AT DIFFERENT STAGES OF *TORIA***

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Table 2: Pearson correlation of dry matter production, yield attributing characters and yield with GDD (growing degree days) at different stages of *toria* | | | | | | | | | | | |
|  | Dry matter 25 DAS | Dry matter 50 DAS | Dry matter 75 DAS | GDD E-FI | GDD FI-SF | GDD  SF-PM | No. of  Siliquae per plant | Seed per  siliqua | Seed yield | Oil yield | Oil  Content |
| Dry matter  25 DAS | 1 | 0.997\*\* | 0.975\*\* | 0.870\*\* | 0.828\*\* | 0.786\*\* | 0.911\*\* | 0.880\*\* | 0.929\*\* | 0.943\*\* | 0.636\* |
| Dry matter  50 DAS | 0.997\*\* | 1 | 0.975\*\* | 0.870\*\* | 0.828\*\* | 0.786\*\* | 0.911\*\* | 0.880\*\* | 0.929\*\* | 0.943\*\* | 0.504 |
| Dry matter  75 DAS | 0.975\*\* | 0.975\*\* | 1 | 0.948\*\* | 0.918\*\* | 0.878\*\* | 0.932\*\* | 0.811\*\* | 0.919\*\* | 0.969\*\* | 0.527 |
| GDD E-FI | 0.870\*\* | 0.870\*\* | 0.948\*\* | 1 | 0.988\*\* | 0.957\*\* | 0.929\*\* | 0.667\* | 0.883\*\* | 0.960\*\* | 0.545 |
| GDD FI\_SF | 0.828\*\* | 0.828\*\* | 0.918\*\* | 0.988\*\* | 1 | 0.977\*\* | 0.927\*\* | 0.647\* | 0.872\*\* | 0.949\*\* | 0.545 |
| GDD SF\_PM | 0.786\*\* | 0.786\*\* | 0.878\*\* | 0.957\*\* | 0.977\*\* | 1 | 0.894\*\* | 0.642\* | 0.835\*\* | 0.902\*\* | 0.615\* |
| No. of siliquae per plant | 0.911\*\* | 0.911\*\* | 0.932\*\* | 0.929\*\* | 0.927\*\* | 0.894\*\* | 1 | 0.823\*\* | 0.931\*\* | 0.971\*\* | 0.719\*\* |
| Seeds per  siliqua | 0.880\*\* | 0.880\*\* | 0.811\*\* | 0.667\* | 0.647\* | 0.642\* | 0.823\*\* | 1 | 0.859\*\* | 0.793\*\* | 0.582\* |
| Seed yield | 0.929\*\* | 0.929\*\* | 0.919\*\* | 0.883\*\* | 0.872\*\* | 0.835\*\* | 0.931\*\* | 0.859\*\* | 1 | 0.965\*\* | 0.591\* |
| Oil yield | 0.943\*\* | 0.943\*\* | 0.969\*\* | 0.960\*\* | 0.949\*\* | 0.902\*\* | 0.971\*\* | 0.793\*\* | 0.965\*\* | 1 | 0.624\* |
| Oil content | 0.636\* | 0.504 | 0.527 | 0.545 | 0.545 | 0.615\* | 0.719\*\* | 0.582\* | 0.591\* | 0.624\* | 1 |
| \*\* Correlation is significant at the 0.01 level (2-tailed), \* Correlation is significant at the 0.05 level, E-FI: Emergence to flower initiation, FI-SF: Flower initiation to siliquae formation, SF-PM: Siliquae formation to physiological maturity | | | | | | | | | | | |

A perusal of data presented in Table 2 revealed that dry matter production at different stages *viz.,* 25, 50 and 75 DAS was highly significant and positively correlated with accumulated growing degree (GDD) days at different phenological stages. The yield attributing parameters such as the number of siliquae per plant and number of seeds per siliqua was also, significantly and positively correlated with growing degree days at different crop growth stages. The number of siliquae per plant was highly significant and positively correlated (0.01 level) with GDD from emergence to flower initiation (r = 0.929 \*\*), flower initiation to siliquae formation (r = 0.927\*\*), and siliquae formation to physiological maturity (r = 0.894\*\*). Significant (0.01 level) and positive correlation of seeds per siliqua was recorded with GDD from emergence to flower initiation (r = 0.667 \*\*), flower initiation to siliquae formation (r = 0.647\*\*), and siliquae formation to physiological maturity (r = 0.642\*\*).

Similarly, the seed yield and oil yield were highly significant (0.01 level) and positively correlated with GDD from emergence to flower initiation (r = 0.883 \*\* and r = 0.960\*\*, respectively), flower initiation to siliquae formation (r = 0.960\*\* and r = 0.949\*\*, respectively), and siliquae formation to physiological maturity (r = 0.835\*\* and r = 0.902 \*\*, respectively). Whereas, the oil content of *toria* was also significant (0.05 level) and positively correlated with GDD from siliqua formation to physiological maturity (r = 0.615\*), but, non- significant with GDD from emergence to flower initiation (r = 0.545) and flower initiation to siliquae formation (r = 0.545).

**4.2 CORRELATION STUDIES OF DRY MATTER PRODUCTION, YIELD ATTRIBUTING CHARACTERS AND YIELD WITH HTU (HELIO-THERMAL UNIT) AT DIFFERENT STAGES OF *TORIA***

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Table 3: Pearson correlation of dry matter production, yield attributing characters and yield with HTU (helio-thermal unit) at different stages of *toria*** | | | | | | | | | | | |
|  | Dry matter 25 DAS | Dry matter 50 DAS | Dry matter 75 DAS | HTU EFI | HTU FISF | HTU SFPM | No. of  Siliquae per  plant | Seed per siliqua | Seed yield | Oil yield | Oil Content |
| Dry matter  25 DAS | 1 | 0.998\*\* | 0.975\*\* | 0.865\*\* | 0.801\*\* | 0.770\*\* | 0.911\*\* | 0.880\*\* | 0.929\*\* | 0.943\*\* | 0.636\* |
| Dry matter  50 DAS | 0.998\*\* | 1 | 0.975\*\* | 0.865\*\* | 0.801\*\* | 0.770\*\* | 0.911\*\* | 0.880\*\* | 0.929\*\* | 0.943\*\* | 0.504 |
| Dry matter  75 DAS | 0.975\*\* | 0.975\*\* | 1 | 0.943\*\* | 0.887\*\* | 0.856\*\* | 0.932\*\* | 0.811\*\* | 0.919\*\* | 0.969\*\* | 0.527 |
| HTU E-FI | 0.865\*\* | 0.865\*\* | 0.943\*\* | 1 | 0.941\*\* | 0.918\*\* | 0.899\*\* | 0.659\* | 0.843\*\* | 0.927\*\* | 0.51 |
| HTU FI-SF | 0.801\*\* | 0.801\*\* | 0.887\*\* | 0.941\*\* | 1 | 0.995\*\* | 0.924\*\* | 0.649\* | 0.871\*\* | 0.936\*\* | 0.636\* |
| HTU SF-PM | 0.770\*\* | 0.770\*\* | 0.856\*\* | 0.918\*\* | 0.995\*\* | 1 | 0.907\*\* | 0.637\* | 0.852\*\* | 0.912\*\* | 0.622\* |
| No. of  Siliquae per plant | 0.911\*\* | 0.911\*\* | 0.932\*\* | 0.899\*\* | 0.924\*\* | 0.907\*\* | 1 | 0.823\*\* | 0.931\*\* | 0.971\*\* | 0.719\*\* |
| Seed per siliqua | 0.880\*\* | 0.880\*\* | 0.811\*\* | 0.659\* | 0.649\* | 0.637\* | 0.823\*\* | 1 | 0.859\*\* | 0.793\*\* | 0.582\* |
| Seed yield | 0.929\*\* | 0.929\*\* | 0.919\*\* | 0.843\*\* | 0.871\*\* | 0.852\*\* | 0.931\*\* | 0.859\*\* | 1 | 0.965\*\* | 0.591\* |
| Oil yield | 0.943\*\* | 0.943\*\* | 0.969\*\* | 0.927\*\* | 0.936\*\* | 0.912\*\* | 0.971\*\* | 0.793\*\* | 0.965\*\* | 1 | 0.624\* |
| Oil content | 0.636\* | 0.504 | 0.527 | 0.510 | 0.636\* | 0.622\* | 0.719\*\* | 0.582\* | 0.591\* | 0.624\* | 1 |
| \*\* Correlation is significant at the 0.01 level (2-tailed), \* Correlation is significant at the 0.05 level, E-FI: Emergence to flower initiation, FI-SF: Flower initiation to siliquae formation, SF-PM: Siliquae formation to physiological maturity | | | | | | | | | | | |

The data regarding correlation studies of dry matter production, yield attributing character and yield with the helio-thermal unit (HTU) at different stages of *toria* are presented in **Table 4** revealed that dry matter production at different stages *viz.,* 25, 50 and 75 DAS was significantly and positively correlated with the accumulated helio-thermal unit at different crop

growth stages. The number of siliquae per plant was highly significant (0.01 level) and positively correlated with HTU from emergence to flower initiation (r = 0.899 \*\*), flower initiation to siliquae formation (r = 0.924\*\*), and siliquae formation to physiological maturity (r = 0.907\*\*). Significant (0.05 level) and positive correlation of seeds per siliqua was recorded with HTU from emergence to flower initiation (r = 0.659 \*), flower initiation to siliquae formation (r = 0.649\*), and siliquae formation to physiological maturity (r = 0.637\*).

Similarly, the seed yield and oil yield were highly significant (0.01 level) and positively correlated with HTU from emergence to flower initiation, flower initiation to siliquae formation, and siliquae formation to physiological maturity. Whereas, the oil content of *toria* was also significantly (0.05 level) and positively correlated with HTU from flower initiation and to siliquae formation (r = 0.636\*) and siliqua formation to physiological maturity (r = 0.622\*), but, non-significant with HTU from emergence to flower initiation (r = 0.510).

**4.3 CORRELATION STUDIES OF DRY MATTER PRODUCTION, YIELD ATTRIBUTING CHARACTERS AND YIELD WITH PTU (PHOTO-THERMAL UNIT) AT DIFFERENT STAGES OF *TORIA***

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Table 4: Pearson correlation of dry matter production, yield attributing characters and yield with PTU (photo-thermal unit) at different stages of *toria*** | | | | | | | | | | | |
|  | Dry matter 25  DAS | Dry matter 50 DAS | Dry matter 75 DAS | PTU E-FI | PTU FI-SF | PTU  SF-PM | Siliquae per plant | Seed per siliqua | Seed yield | Oil yield | Oil  Content |
| Dry matter 25  DAS | 1 | 0.997\*\* | 0.975\*\* | 0.877\*\* | 0.828\*\* | 0.788\*\* | 0.911\*\* | 0.880\*\* | 0.929\*\* | 0.943\*\* | 0.636\* |
| Dry matter 50  DAS | 0.997\*\* | 1 | 0.975\*\* | 0.877\*\* | 0.828\*\* | 0.788\*\* | 0.911\*\* | 0.880\*\* | 0.929\*\* | 0.943\*\* | 0.504 |
| Dry matter 75  DAS | 0.975\*\* | 0.975\*\* | 1 | 0.954\*\* | 0.916\*\* | 0.878\*\* | 0.932\*\* | 0.811\*\* | 0.919\*\* | 0.969\*\* | 0.527 |
| PTU E-FI | 0.877\*\* | 0.877\*\* | 0.954\*\* | 1 | 0.982\*\* | 0.942\*\* | 0.925\*\* | 0.673\* | 0.881\*\* | 0.959\*\* | 0.545 |
| PTU FI-SF | 0.828\*\* | 0.828\*\* | 0.916\*\* | 0.982\*\* | 1 | 0.973\*\* | 0.929\*\* | 0.654\* | 0.877\*\* | 0.949\*\* | 0.601\* |
| PTU SF-PM | 0.788\*\* | 0.788\*\* | 0.878\*\* | 0.942\*\* | 0.973\*\* | 1 | 0.894\*\* | 0.646\* | 0.823\*\* | 0.894\*\* | 0.593\* |
| No. of Siliquae per plant | 0.911\*\* | 0.911\*\* | 0.932\*\* | 0.925\*\* | 0.929\*\* | 0.894\*\* | 1 | 0.823\*\* | 0.931\*\* | 0.971\*\* | 0.719\*\* |
| Seed per siliqua | 0.880\*\* | 0.880\*\* | 0.811\*\* | 0.673\* | 0.654\* | 0.646\* | 0.823\*\* | 1 | 0.859\*\* | 0.793\*\* | 0.582\* |
| Seed yield | 0.929\*\* | 0.929\*\* | 0.919\*\* | 0.881\*\* | 0.877\*\* | 0.823\*\* | 0.931\*\* | 0.859\*\* | 1 | 0.965\*\* | 0.591\* |
| Oil yield | 0.943\*\* | 0.943\*\* | 0.969\*\* | 0.959\*\* | 0.949\*\* | 0.894\*\* | 0.971\*\* | 0.793\*\* | 0.965\*\* | 1 | 0.624\* |
| Oil content | 0.636\* | 0.504 | 0.527 | 0.545 | 0.601\* | 0.593\* | 0.719\*\* | 0.582\* | 0.591\* | 0.624\* | 1 |
| \*\* Correlation is significant at the 0.01 level (2-tailed), \* Correlation is significant at the 0.05 level, E-FI: Emergence to flower initiation, FI-SF: Flower initiation to siliquae formation, SF-PM: Siliquae formation to physiological maturity | | | | | | | | | | | |

A perusal of data presented in Table 3 revealed that dry matter production at different stages *viz.,* 25, 50 and 75 DAS was significantly and positively correlated with the accumulated photo-thermal unit (APTU) at different phenological stages. The number of siliquae per plant was highly significant (0.01 level) and positively correlated with PTU from emergence to flower initiation (r = 0.925 \*\*), flower initiation to siliquae formation (r = 0.929\*\*), and siliquae formation to physiological maturity (r = 0.894\*\*). Significant (0.05 level) and positive correlation of seeds per siliqua was recorded with PTU from emergence to flower initiation (r = 0.673\*), flower initiation to siliquae formation (r = 0.654\*), and siliquae formation to physiological maturity (r = 0.646\*). Similarly, the seed yield and oil yield were also highly significant (0.01 level) and positively correlated with PTU from emergence to flower initiation (r = 0.881 \*\* and r = 0.959\*\*, respectively), flower initiation to siliquae formation (r = 0.877\*\* and r = 0.949\*\*, respectively), and siliquae formation to physiological maturity (r = 0.823\*\* and r = 0.894 \*\*, respectively). Whereas, the oil content of *toria* was also significantly (0.05 level) and positively correlated with PTU from flower initiation to siliquae formation (r = 0.601\*) and siliqua formation to physiological maturity (r = 0.593\*), but, non- significant with PTU from emergence to flower initiation (r = 0.545).

**5. REGRESSION STUDIES**

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| **Table 5: Predictive equation for seed yield of rapeseed as influenced by sowing date adjustments** | |
| **Multiple regression equations** | **R2** |
| **Seed yield** (kg ha-1) = 352.448 + 0.178\* GDD E-FI (0C day) - 0.002 \* HTU E-FI (0C day hours) +0.068 \* PTU E-FI (0C day hours) | 0.894 |
| **Seed yield** (kg ha-1) = 1549.041 + 1.729 \* GDD SF-PM (0C day) – 0.076 \* HTUSF-PM (0C day hours) -0.251 \* PTU SF-PM (0C day hours) | 0.877 |
| **Seed yield** (kg ha-1) = -182.183 + 0.749 \* AGDD (0C day) + 0.046 \* AHTU (0C day hours) - 0.032 \* APTU (0C day hours) | 0.822 |

The correlation studies among agro-meteorological indices with dry matter accumulation, yield attributes and yield indicated a significant and strong positive correlation between the parameters. Based on this, with the help of stepwise regression analysis three predictive models were framed, for the prediction of the yield (**Table 5, Figure 7,8,9**). The prediction of seed yield from the first equation can be carried out during the initial stage of the crop growth i.e., from emergence to flower initiation period by consideration of growing degree days, helio-thermal unit and photo-thermal unit as the independent variable, while seed yield as the dependent variable. While the second equation can predict the yield by considering of values of the independent variable from siliqua formation to the physiological maturity stage. The yield prediction with the third equation is mainly based on the accumulated growing degree days, helio-thermal unit and photo-thermal unit throughout the crop growing period. This model can be used as a short-term prediction model for succeeding years for estimation of yield component of the crop, in relation to various agrometeorological parameters.

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| **Predicted**  **Observed** |
| Figure 7: Regression model for seed yield prediction based on GDD, HTU and PTU (from emergence to flower initiation). |
| **Observed**    **Predicted** |
| Figure 8: Regression model for seed yield prediction based on GDD, HTU and PTU (from siliquae formation to physiological maturity). |
| **Predicted**  **Observed** |
| Figure 9: Regression model for seed yield prediction based on AGDD, AHTU and APTU. |

**5. DISCUSSION**

The micro-climatic regimes significantly influenced the crop phenology of toria. Among the different micro-climatic regimes, the crop sown on 15th November (D1) required significantly higher number of days for the occurrence of different phenophase *viz.,* flower initiation, 50% flowering, siliquae formation and physiological maturity followed by crop sown on 30th November (D2) and 15th December (D3). In case of agro-meteorological indices also, the crop sown on 15th November (D1) availed significantly higher growing degree days, helio-thermal unit and photo-thermal unit as compared to the crop sown on 30th November (D2) and 15th December (D3). The significant variation in accumulated thermal units i.e., growing degree days, helio-thermal units and photo-thermal units might be responsible for the variation in crop phenology. The reduction in the number of days for the occurrence of various phenological events under the crop sown on 30th November (D2) and 15th December (D3) might be due to the lesser availability of thermal units which was in conformity with the results of Keerthi et al. (2016), Kumar et al. (2017), Rana et al. (2017), Das et al. (2021) and Reddy et al. (2021).

A positive and significant relationship between dry matter production, yield attributing characters and yield with GDD (growing degree days) at different stages of toria was observed. The growing degree days at different stages viz., emergence to flower initiation, flower initiation to siliquae formation and siliquae formation to physiological maturity were highly significant and positively correlated with dry matter accumulation, yield attributes and yield, which indicated that with increase in growing degree days, the other growth parameters also tend to increase. Similarly, in case of other agrometeorological indices such as helio-thermal unit and photo-thermal unit at different growth stages was found to have positive correlation with dry matter production, yield attributing characters, yield. This indicated that with the increase in agrometeorological indices such as helio-thermal units, other related parameters also tend to increase. Further correlation was done to investigate the relationship among dry matter production at different growth stages i.e., 25, 50 and 75 DAS with crop phenology viz., days to emergence, days to 50% flowering, days to siliquae formation and days to physiological maturity. A significantly strong correlation was found between dry matter accumulation and crop phenology. This signifies that availing more crop duration under the crop sown on 15th November (D1) resulted in better dry matter accumulation than the crop sown on 30th November (D2) and 15th December (D3).

The correlation studies among agro-meteorological indices with dry matter accumulation, yield attributes and yield indicated a significant and strong positive correlation between the parameters. Based on this, with the help of stepwise regression analysis three predictive models were framed, for the prediction of the yield. The prediction of seed yield from the first equation can be carried out during the initial stage of the crop growth *i.e.,* from emergence to flower initiation period by consideration of growing degree days, helio-thermal unit and photo-thermal unit as the independent variable, while seed yield as the dependent variable. While the second equation can predict the yield by considering of values of the independent variable from siliqua formation to the physiological maturity stage.

The yield prediction with the third equation is mainly based on the accumulated growing degree days, helio-thermal unit and photo-thermal unit throughout the crop growing period. This model can be used as a short-term prediction model for succeeding years for estimation of yield component of the crop, in relation to various agrometeorological parameters.

**7. CONCLUSION**

In response to different micro-climatic regimes, the crop sown on 15th November (D1) recorded significantly higher value of plant growth parameters *viz.,* plant height, number of both primary and secondary branches and dry matter production at different growth stages. In case of physiological parameters also, the same micro-climatic regime (D1) recorded significantly higher leaf area, leaf area index, leaf area duration, crop growth rate, relative growth rate, chlorophyll content and relative water content throughout the crop growing period. The overall crop growing period was found to be higher for the crop sown on 15th November (D1), while delayed sowing reduces the crop duration. Marked variation on agrometeorological indices was recorded due to the effect of different micro-climatic regimes. Significantly higher accumulated growing degree days, helio-thermal unit and photo-thermal unit were recorded under the crop sown on 15th November (D1) over 30th November (D2) and 15th December (D3). The crop sown on 15th November (D1), registered better yield attributing characters over the crop sown on 30th November (D2) and 15th December (D3). Likewise, significantly higher seed yield, stover yield, harvest index and oil yield were documented in the crop sown on 15th November (D1). Based on plant growth, physiological parameters, seed yield, oil yield and economics, the sowing of the crop on 15th November can be considered best for enhancing the production of rapeseed (*Brassica campestris var. toria)* under rainfed condition.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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