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Evaluation of Thermal Indices in Relation to Phenology of Green Gram (*Vigna radiata* L.) under Different Growing Environments of Navsari Region of South Gujarat

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A field experiment was conducted during the *rabi* season of 2021-22 at Research farm of Navsari Agricultural University, Navsari to study the thermal indices for green gram cultivars. The thermal indices *viz.*, growing degree day (GDD), photothermal unit (PTU), heliothermal unit (HTU), photothermal index (PTI) and thermal use efficiencies were worked out concerning green gram phenology under the different environments condition. The result revealed that the high units of thermal indices *viz.*, GDD, HTU, PTU, and PTI were observed in *cv*. GBM-1 followed by *cv*. CO-4 under the third sowing date. The HUE was reported higher in *cv*. CO-4 (1.212 kg ha^{-1} ℃ day^{-1}) followed by *cv*. GM-7 (1.040 kg ha^{-1} ℃ day^{-1}) under the third sowing date. The correlation between thermal indices *viz.*, GDD, HTU, PTU, and harvest days and seed yield were founded significant which means the temperature and sunshine hours significantly influenced the seed yield and duration of phenophases.

Introduction

Temperature is a very important weather parameter because it controls the plant's physiological processes *viz.*, photosynthesis, respiration, and physical processes *viz.*, evaporation, transpiration, water, and nutrient movement these processes are directly involved in plant and development. The plants required a specific amount of accumulated heat to develop the upcoming growth stage *i.e.*, from flowering to pod development (Gudadhe *et al.*, 2013). The time required for heat accumulation depended on temperature and sunshine duration which is decided the duration of a particular stage of growth. The duration of crop growth stages is inversely related to air temperature. The thermal indices *viz.*, Growing Degree Days (GDD), Photothermal units (PTU), Heliothermal unit (HTU), Photothermal index (PTI), Heat use efficiency (HUE), *etc.* can successfully be used for describing the phenological duration and explaining the direct and linear relationship between growth and temperature for the assessment of yield potential of a crop (Kumar *et al.,* 2014).

The experiment was conducted to determine the phenological behavior and thermal requirement of given green gram cultivars under different environments by manipulating their sowing dates.

Materials and Methods

A field experiment was carried out during the *rabi* season of 2021-22 at Agronomy farm of Navsari Agricultural University, Navsari campus situated at an altitude 9 m above mean sea level, 20° 57' N latitude, and 72° 54' E longitude.

The experiment was laid out in a split-plot design with three replication and 9 treatments combinations consisting of 3 varieties as main plot treatments (V_1: CO-4, V_2: GBM-1, and V_3: GM-7) and 3 dates of sowing (D_1: 27th Octo., D_2: 11th Nov., and (D_3: 26th Nov.) as subplot treatments. The growth of green gram was divided into five different phenophases *viz.*, seed emergence (SE), flower initiation (FI), pod initiation (PI), seed initiation (SI), and harvest maturity (HM).

The GDD was calculated by the average daily temperature which is subtracted from the base temperature. The base temperature taken for the green gram crop was 10 ℃. The HTU was calculated by GDD multiplied by actual sunshine hours and PTU was calculated by GDD to multiply with maximum possible sunshine hours.

The HUE was calculated by total seed yield (kg ha^{-1}) divided by accumulated GDD. The PTI was evaluated by GDD between two phenophase divided by days between two phenophase. The HTUE was calculated by total seed yield (kg ha^{-1}) divided by heliothermal unit and PTUE was calculated by total seed yield (kg ha^{-1}) divided by photothermal unit.

Results and Discussion

Growing Degree Days (℃ days)

The accumulated GDD of green gram in relation to crop phenology is presented in table 1. The GDD assumes that the amount of heat required for a crop to reach a specific phenological stage would either be higher or lower (Neog *et al.,* 2008).

The result revealed that the higher GDD was utilized by *cv.* GBM-1 and CO-4 of 1304℃, 1337℃, 1403℃ and 1260℃, 1295℃, 1374℃ under the first, second, third date of sowing, respectively.

The GDD was more consumed under the third sowing date followed by second and first sowing date for attaining the harvest maturity which might be attributed to increase the crop duration due to prevailing low temperature.

Due to the shorter duration of the crop on the first sowing date, less GDD was utilized by the crop this could have been caused by the high temperature. Our result was in good line with the finding of Kumar *et al.,* (2020).

Heliothermal Units (°C days hr)

The HTU of green gram cultivars according to crop phenology is presented in table 2. The HTU determines the combined impact of temperature and sunshine duration on crop growth. The result showed that the HTU was more consumed by *cv.* GBM-1 and CO-4 of 9435, 9958, 10542 and 8807, 9008, 10168 ℃ day hr on first, second, third sowing dates, respectively.

The HTU requirements for entire phenophases were observed higher on the third sowing date particularly from SI to HM stage which might be because of absorbed higher GDD and longer sunshine duration. Our result was supported by the finding of Tijare *et al.*, (2017).

Photothermal Unit (℃ days hr)

The PTU for different phenophases is present in table 3. The PTU requirements for the crop were increased on the third sowing date due to the fact that following the after autumn equinox (September 23), the length of the maximum possible sunshine hour decreases until December and increases starting in January, the crop sown on the third date the maximum duration falls between January to March. The second reason was the higher GDD consumed by the crop. Mean cultivars summed PTU at different growth stages were recorded as 870℃ hours (Sowing-SE), 6682℃ hours (SE-FI), 1417℃ hours (FI-PI), 1141℃ hours (PI-SI), 3602℃ hours (SI-HM) and 13735℃ hours (Sowing-HM). Our result was in good accordance with the finding of Pal *et al.*, (2013).

Photothermal index (℃ day)

The PTI indicated the rate of development of different phenophases by using the GDD. The PTI of green gram according to phenology is presented in table 4. The low PTI value on the third date of sowing suggested that, except between SI and HM, the phenophases were developing at a slow rate due to the low temperature. The value of PTI was high under the first sowing date because of the high temperature, which suggested a quicker rate of growth stage development. The average cultivar PTI at various phenophases for different sowing dates was recorded as 13.84, 13.28 and 12.67 for first, second and third date of sowing, respectively. A similar kind of result was also reported by Mote *et al.*, (2015).

Thermal use efficiencies

The HUE, PTUE, and HTUE under the different sowing dates are presented in table 5. Because of the high yield potential with relatively small and efficient usage of the number of heat units, the *cv*. CO-4 showed superior thermal use efficiencies. In *cv*. GBM-1, the thermal use efficiencies were lower because consumed a greater number of heat units and had low yield potential compared to other cultivars.

These types of relations were also founded by Bhuva and Detroja (2018). The mean cultivar's heat use efficiency (HUE) under the different sowing dates was observed as 0.993, 1.043 and 1.080 kg ha^{-1} ℃ day^{-1} for first, second and third date of sowing, respectively.

Correlation between thermal indices, harvest days and seed yield

The correlation studies revealed that the harvest days were significantly influenced by GDD (r = 0.9758*), PTU (r = 0.9688**) and HTU (r = 0.9892**) and there was no correlation between harvest days and PTU (r = 0.095), HUE (r = 0.1908) which means that the harvest days was not affected by PTI and HUE. The seed yield was significantly influenced by GDD (r = 0.8270**), HTU (r = 0.7547**), PTU (r = 0.8288**) and HTU (r = 0.7600**) but there was no significant association between seed yield and PTI (Table 6). Our result was supported by Medhi *et al.*, (2019). Correlation studies concluded that the temperature and bright sunshine hours (day length) significantly influenced the seed yield and maturity days.

The thermal indices were varied with different growing environments and cultivars. Thermal indices might be used to identify the suitability of new agroclimatic for better crop growth and development.

Thermal indices are also used for forecasting the harvesting date and yield, insect and pest management, cultural management and checking the climatic suitability of newly introduced variety in a given locality. The above study revealed that the temperature and sunshine hours significantly influenced the seed yield and crop duration.

Table.1 Accumulated growing degree days (GDD) (°C day) requirements for attainment of phenophases of green gram cultivars under variable weather conditions

Cultivars	Sowing dates	Sowing-SE	SE-FI	FI-PI	PI-SI	SI-HM	Total
CO-4	27/10/2021	61.5 (4)	636.5 (42)	116.2 (9)	100.8 (8)	345.9 (26)	1260.9 (90)
	11/11/2021	72.7 (5)	630.6 (45)	110.3 (11)	125.8 (9)	355.8 (25)	1295.2 (96)
	26/11/2021	96.0 (7)	660.4 (49)	135.6 (15)	111.9 (10)	370.6 (22)	1374.5 (101)
GBM-1	27/10/2021	76.8 (4)	620.4 (44)	124.6 (10)	101.4 (9)	380.9 (29)	1304.1 (97)
	11/11/2021	89.2 (5)	641.7 (49)	137.4 (11)	98.2 (8)	371.2 (28)	1337.8 (101)
	26/11/2021	88.1 (6)	688.4 (54)	141.3 (12)	122.9 (10)	362.7 (23)	1403.4 (107)
GM-7	27/10/2021	61.5 (4)	501.3 (34)	119.2 (7)	83.2 (7)	225.2 (25)	990.4 (77)
	11/11/2021	72.7 (4)	520.5 (38)	137.7 (8)	88.7 (7)	212.2 (22)	1031.8 (81)
	26/11/2021	72.1 (6)	560.0 (41)	133.5 (10)	90.6 (9)	230.9 (19)	1087.1 (85)

(Parenthesis show days between two phenophases)

Table.2 Heliothermal units (HTU) (°C day hr.) requirements for attainment of phenophases of green gram cultivars under variable weather conditions

Cultivars	Sowing dates	Sowing-SE	SE-FI	FI-PI	PI-SI	SI-HM	Total
CO-4	27/10/2021	558.2 (4)	4337.8 (42)	800 (10)	721.6 (8)	2390.1 (26)	8807.7 (90)
	11/11/2021	670.1 (5)	3987.3 (45)	928.5 (11)	674.8 (10)	2747.4 (25)	9008.1 (96)
	26/11/2021	710.5 (7)	3510.6 (49)	1029.1 (13)	1005.6 (10)	3912.4 (22)	10168.2 (101)
GBM-1	27/10/2021	693.2 (4)	4696.6 (44)	646.0 (9)	749.7 (9)	2649.3 (29)	9435.1 (97)
	11/11/2021	709.9 (5)	4153.9 (49)	628.5 (11)	772.9 (8)	3693.6 (28)	9958.9 (101)
	26/11/2021	710.7 (6)	3510.6 (54)	1041.4 (15)	806.8 (10)	4473.1 (23)	10542.8 (107)
GM-7	27/10/2021	558.2 (4)	3546.8 (34)	782.2 (7)	591.1 (7)	1491.5 (25)	6969.8 (77)
	11/11/2021	612.5 (4)	3312.2 (38)	939.0 (8)	604.2 (7)	1745.4 (22)	7213.3 (81)
	26/11/2021	631.0 (6)	3387.9 (41)	918.6 (10)	733.7 (9)	2109.6 (19)	7780.8 (85)

(Parenthesis show days between two phenophases)

Table.3 Photothermal units (PTU) (°C day hr.) requirements for attainment of phenophases of green gram cultivars under variable weather conditions

Cultivars	Sowing dates	Sowing-SE	SE-FI	FI-PI	PI-SI	SI-HM	Total
CO-4	27/10/2021	719.5 (4)	7128.8 (42)	1267.1 (10)	1108.8 (8)	3908.6 (26)	14132.9 (90)
	11/11/2021	814.2 (5)	6873.5 (45)	1268.4 (11)	1446.7 (10)	4091.7 (25)	14494.6 (96)
	26/11/2021	1075.2 (7)	7198.3 (49)	1505.1 (13)	1242.0 (10)	4261.9 (22)	15282.7 (101)
GBM-1	27/10/2021	898.5 (4)	6948.4 (44)	1370.6 (9)	1115.4 (9)	4304.1 (29)	14637.2 (97)
	11/11/2021	999.6 (5)	6995.0 (49)	1511.4 (11)	1129.3 (8)	4268.8 (28)	14904.1 (101)
	26/11/2021	986.9 (6)	7503.5 (54)	1568.4 (15)	1364.1 (10)	4171.0 (23)	15594.1 (107)
GM-7	27/10/2021	719.5 (4)	5614.5 (34)	1299.2 (7)	906.8 (7)	2477.2 (25)	11017.4 (77)
	11/11/2021	814.2 (4)	5777.5 (38)	1500.9 (8)	966.8 (7)	2334.2 (22)	11393.7 (81)
	26/11/2021	807.5 (6)	6104.0 (41)	1468.5 (10)	996.6 (9)	2609.1 (19)	11985.7 (85)

(Parenthesis show days between two phenophases)

Table.4 PTI (°C day) required for attainment of phenophases of green gram cultivars under variable weather conditions

Cultivars	Sowing dates	Sowing-SE	SE-FI	FI-PI	PI-SI	SI-HM	Mean
CO-4	27/10/2021	15.38	15.15	11.63	12.60	13.30	13.61
	11/11/2021	14.54	14.01	10.03	12.58	14.23	13.08
	26/11/2021	13.71	13.47	9.69	10.17	16.85	12.78
GBM-1	27/10/2021	19.20	14.10	13.84	11.27	13.13	14.30
	11/11/2021	17.85	13.10	12.49	12.28	13.26	13.79
	26/11/2021	14.69	12.75	9.42	12.29	15.77	12.98
GM-7	27/10/2021	15.38	14.74	17.03	11.89	9.01	13.61
	11/11/2021	14.54	13.70	17.21	9.86	9.65	12.99
	26/11/2021	12.02	13.66	13.35	10.07	12.15	12.25

Table.5 Thermal use efficiencies of green gram cultivars under variable weather conditions

Cultivars	Sowing dates	Heat use efficiency (HUE) (kg ha^{-1} ℃ day^{-1})	Heliothermal use efficiency (HTUE) (kg ha^{-1} ℃ day^{-1} hr^{-1})	Photothermal use efficiency (PTUE) (kg ha^{-1} ℃ day^{-1} hr^{-1})
CO-4	27/10/2021	1.086	0.156	0.097
	11/11/2021	1.164	0.167	0.104
	26/11/2021	1.212	0.164	0.109
GBM-1	27/10/2021	0.936	0.129	0.083
	11/11/2021	0.957	0.130	0.086
	26/11/2021	0.990	0.132	0.089
GM-7	27/10/2021	0.959	0.136	0.086
	11/11/2021	1.009	0.144	0.091
	26/11/2021	1.040	0.145	0.094

Table.6 Correlation between thermal indices, harvest days and seed yield

Characters	**GDD**	**PTU**	**HTU**	**PTI**	**HUE**
	Correlation coefficient (r)				
Seed yield	0.8270**	0.8288**	0.7547**	-0.0911	0.7600**
Harvest days	0.9758**	0.9688**	0.9892**	0.0956	0.1908

** Significant at 0.05 level

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