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Agrometeorological indices of green gram (*Vigna radiata* L.) varieties under different growing environments in Chhattisgarh plain zone

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ABSTRACT

A field experiment was conducted during the summer season of 2026 at the Research Instructional Farm, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, to work out the agrometeorological indices of green gram varieties under different growing environments. The experiment was laid out in a factorial randomized block design with three replications comprising three sowing environments, viz., D1 (1 March 2026), D2 (11 March 2026) and D3 (21 March 2026), and three varieties, viz., V1 (IPM 410-3 Shikha), V2 (IPM 205-7 Virat) and V3 (PDM-139 Samrat). Accumulated growing degree days (AGDD), accumulated photo-thermal units (APTU), accumulated helio-thermal units (AHTU), radiation use efficiency (RUE), heat use efficiency (HUE) and thermal sensitivity index (TSI) were worked out. At physiological maturity, AGDD ranged from 1156.1 to 1290.1 °C day, APTU from 14237.2 to 16136.8 °C day hour and AHTU from 9791.6 to 11324.7 °C day hour. The maximum AGDD, APTU and AHTU were recorded in V3 under D3. Mean RUE increased from 0.951 g MJ⁻¹ under D1 to 1.081 g MJ⁻¹ under D3, while mean HUE increased from 0.464 to 0.541 g m⁻² °C⁻¹ day⁻¹. V3 recorded the highest mean RUE (1.105 g MJ⁻¹) and HUE (0.544 g m⁻² °C⁻¹ day⁻¹). TSI ranged from 5.04 to 6.89%, and all three varieties were classified as moderately tolerant to thermal variability. PDM-139 Samrat recorded the lowest TSI (5.04%), indicating comparatively greater stability across the tested thermal environments. Overall, D3 (21 March 2026) resulted in the highest accumulation of thermal indices and use efficiencies among the environments studied.

Keywords: Thermal sensitivity, Agro-meteorological indices, GDD, PTU, HTU, RUE, HUE, Green gram

Introduction

Green gram (*Vigna radiata* L.) is an important short-duration pulse crop grown under a range of agro-climatic conditions. Its growth and development are closely associated with temperature, sunshine duration and radiation. Changes in sowing time modify the weather conditions experienced by the crop during different phenological stages and consequently alter the accumulation and utilization of thermal and radiative resources.

Agrometeorological indices provide a useful way to quantify the weather requirement of a crop. Growing degree days describe accumulated thermal time, while photo-thermal and helio-thermal units incorporate photoperiod and actual sunshine duration, respectively. Radiation use efficiency indicates the efficiency with which intercepted radiation is converted into biomass, whereas heat use efficiency expresses biomass produced per unit of accumulated thermal time. Thermal sensitivity index can further indicate the stability of crop duration under varying thermal environments.

Earlier work on summer green gram has shown that sowing time and genotype can influence the accumulation of thermal indices. Tijare *et al.* (2017) [1], for example, reported differences in GDD, HTU and PTU among sowing windows and varieties. Studies cited in the present thesis also indicate variation in HUE and RUE among genotypes and growing environments. The present study was therefore undertaken to quantify these indices for green gram varieties under three growing environments at Raipur.

Materials and methods

Experimental site and treatments

The experiment was conducted during summer season 2026 at the Research Instructional Farm, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, using green gram (*Vigna radiata* L.) as the test crop. Three growing environments were used, viz., D₁ - 1st March 2026, D₂ - 11th March 2026 and D₃ - 21st March 2026. Three green gram varieties, viz., V₁ - IPM 410-3 Shikha, V₂ - IPM 205-7 Virat and V₃ - PDM-139 Samrat, were evaluated. The experiment was laid out in a factorial randomized block design with three

replications. The seed rate was 30 kg ha⁻¹ and fertilizer was applied at 25:50:25 kg ha⁻¹ of N:P₂O₅:K₂O, respectively. The crop was planted at a row-to-row and plant-to-plant spacing of 30 × 10 cm. The plot size was 3.5 × 6 m (21 m²).

Agrometeorological indices

Accumulated Growing Degree Days (AGDD) °C day

Growing degree days will be calculated by summation of daily mean temperature above base ($T_b - 10^\circ\text{C}$) temperature for a corresponding period from sowing as suggested by Monteith (1984) and expressed in degree Celsius using the following formula.

$$\text{GDD} = \sum_{i=1}^n \left(\frac{T_{\max} + T_{\min}}{2} - T_b \right) (\text{°C days})$$

Where,

$T_{\max}$ = Maximum temperature (°C) of the day.

$T_{\min}$ = Minimum temperature

T_b = Base temperature is defined as. "The temperature below which no plant physiological activity takes place" which is considered 10°C for green gram.

Accumulated Photo Thermal Unit (APTU) °C day hours

Accumulated photo thermal unit (APTU) is calculated by multiplying AGDD with maximum possible sunshine hours (N).

1. Heat Use Efficiency (HUE) g m⁻² °C⁻¹ day⁻¹

Heat use efficiency which indicates the amount of dry matter produced per unit of growing degree days or thermal time.

$$\text{HUE} (\text{g m}^{-2} / ^\circ\text{C}) = \frac{\text{Biomass} (\text{g} / \text{m}^2)}{\text{AGDD}}$$

Where,

AGDD = Accumulated growing degree day

HUE = Heat use efficiency

The values were expressed in grams per square meter per degree Celsius day (g m⁻² °C⁻¹ day⁻¹).

Thermal Sensitivity index:

$$\text{AHTU} = \text{AGDD} \times n$$

Where,

n = actual sunshine hour

The values were expressed in degree celsius day hours (°C day hours)

Radiation Use efficiency (RUE) g MJ⁻¹

It is the relationship between the accumulation of biomass relative to the light intercepted by the crop.

$$\text{RUE} = \frac{\text{Biomass} (\text{g} / \text{m}^2)}{\text{IPAR} (\text{MJ} / \text{m}^2 / \text{day})}$$

Where,

IPAR is cumulative intercepted photosynthetically active radiation.

The photosynthetic active radiation is calculated by using the following formula.

$$\text{PAR} = R_s$$

Where,

R_s = incoming solar radiation

The incoming solar radiation is calculated by the formula

$$R_s = R_{s0} (a + b \times n/N)$$

Where,

R_{s0} = Extraterrestrial radiation,

n/N = Percent sunshine hour,

a and b are Angstrom empirical coefficients ($a = 0.42$, $b = 0.30$)

The values were expressed in grams per megajoule (g MJ⁻¹)

$$\text{APTU} = \text{AGDD} \times N$$

Where,

N = maximum possible sunshine hour.

The values were expressed in degree celsius day hours (°C day hours)

Accumulated Helio Thermal Unit (AHTU) °C day hours

Accumulated helio thermal unit is calculated by multiplying AGDD with actual sunshine hours.

TSI used as parameter to estimate variability in duration of the crop under different thermal environments. (Gote *et al.*, 2008) [2].

$$\text{TSI} = \frac{\text{Range of Duration}}{\text{Average Duration}}$$

Based on TSI the thermal sensitivity index was categorized as follows:

TSI Values: Thermal Sensitivity.

1. < 5: Tolerant.
2. 5 to 10: Moderately Tolerant.
3. 10 to 15: Moderately susceptible.
4. > 15: Susceptible.

Results and discussion

Accumulated Growing Degree Days (AGDD)

Accumulated Growing Degree Days (AGDD) The accumulated GDD increased progressively with crop development from emergence to physiological maturity in all the varieties. At emergence, AGDD ranged from 61.1 to 90.0 °C day. The highest value was recorded in V₃ under D₃ (90.0 °C day), whereas the lowest was recorded in V₁ under D₂ (61.1 °C day). At branching, AGDD ranged from 256.1 to 338.4 °C day, with the maximum again in V₃ under D₃. At 50% flowering, AGDD varied from 652.2 to 842.3 °C day. The maximum value of 842.3 °C day was recorded by V₃ under D₃, followed by 810.2 °C day in V₃ under D₂. At pod formation, values ranged from 732.7 to 937.5 °C day, with the highest value in V₃ under D₃. At physiological maturity, AGDD ranged from 1156.1 to 1290.1 °C day. V₃ under D₃ recorded the maximum AGDD (1290.1 °C day), while V₁ under D₁ recorded the minimum (1156.1 °C day). The higher accumulation under the later sowing environment indicates greater thermal accumulation during the crop period. These results are broadly comparable with the variation in thermal requirements reported by Tijare *et al.* (2017) [1].

Table 1. Accumulated Growing Degree Days (AGDD) °C days values at different phenological stages of different green gram varieties under different growing environments.

Environment	Variety	Emergence	Branching	50% flowering	Pod formation	Physiological maturity
D ₁ (1 st March 2026)	V ₁ - (IPM 410-3 Shikha)	63.5	256.1	652.2	732.7	1156.1
D ₁ (1 st March 2026)	V ₂ - (IPM 205-7 Virat)	65.5	276.5	691.9	771.1	1206.5
D ₁ (1 st March 2026)	V ₃ - (PDM- 139 Samrat)	78.8	293.7	752.4	832.9	1234.0
D ₂ (11 th March 2026)	V ₁ - (IPM 410-3 Shikha)	61.1	284.7	757.6	888.1	1225.4
D ₂ (11 th March 2026)	V ₂ - (IPM 205-7 Virat)	78.8	306.3	782.8	860.6	1246.8
D ₂ (11 th March 2026)	V ₃ - (PDM -139 Samrat)	80.8	326.0	810.2	911.4	1268.2
D ₃ (21 st March 2026)	V ₁ - (IPM 410-3 Shikha)	69.7	278.1	762.9	867.0	1249.4
D ₃ (21 st March 2026)	V ₂ - (IPM 205-7 Virat)	82.7	317.9	789.0	890.8	1270.9
D ₃ (21 st March 2026)	V ₃ - (PDM -139 Samrat)	90.0	338.4	842.3	937.5	1290.1

Accumulated Photo Thermal Units (APTU)

APTU increased with advancement of crop growth and differed among sowing windows and varieties. At emergence, values ranged from 733.2 to 1080.0 °C Day hour. The maximum (1080.0 °C Day hour) was recorded in V₃ under D₃. At branching, the range was 3071.4–4060.2 °C Day hour, again with the highest value in V₃ under D₃. At 50% flowering, pod formation and physiological maturity, the highest values were also recorded in V₃ under D₃.

At physiological maturity, APTU ranged from 14237.2 to 16136.8 °C Day hour. The maximum value (16136.8 °C Day hour) was recorded

in V₃ under D₃ and the minimum value (14237.2 °C Day hour) in V₁ under D₁. The progressive increase reflects the combined effect of accumulated thermal time and photoperiod. Similar variation in APTU among cultivars has been reported in Kumar *et al.* (2020), who reported that growing environments significantly influenced the accumulation of photothermal units (PTU) and grain yield of summer green gram.

Table 2. Accumulated Photo Thermal Units (APTU) °C days hours values at different phenological stages of different green gram varieties under different growing environments.

Environment	Variety	Emergence	Branching	50% flowering	Pod formation	Physiological maturity
D ₁ (1 st March 2026)	V ₁ - (IPM 410-3 Shikha)	761.4	3071.4	7888.0	8903.0	14237.2
D ₁ (1 st March 2026)	V ₂ - (IPM 205-7 Virat)	775.5	3318.2	8388.2	9386.8	14872.2
D ₁ (1 st March 2026)	V ₃ - (PDM -139 Samrat)	945.2	3524.4	9151.2	10165.5	15218.7
D ₂ (11 th March 2026)	V ₁ - (IPM 410-3 Shikha)	733.2	3337.2	9382.4	9694.1	15486.5
D ₂ (11 th March 2026)	V ₂ - (IPM 205-7 Virat)	782.6	3737.8	9711.3	10722.0	15166.8
D ₂ (11 th March 2026)	V ₃ - (PDM -139 Samrat)	972.7	3986.0	10087.0	11373.1	16047.2
D ₃ (21 st March 2026)	V ₁ - (IPM 410-3 Shikha)	836.4	3465.7	9423.6	10068.5	15603.0
D ₃ (21 st March 2026)	V ₂ - (IPM 205-7 Virat)	805.1	3814.2	9741.1	10994.0	15884.6
D ₃ (21 st March 2026)	V ₃ - (PDM -139 Samrat)	1080.0	4060.2	10383.5	11582.4	16136.8

Accumulated Helio Thermal Units (AHTU)

AHTU also increased from emergence to physiological maturity. At emergence, AHTU ranged from 520.9 to 820.3 °C day hour, while at physiological maturity it ranged from 9791.6 to 11324.7 °C day hour. V₃ under D₃ recorded the highest AHTU at physiological maturity (11324.7 °C day hour), followed by V₃ under D₂ (11161.0 °C day

hour) and V₂ under D₃ (11100.0 °C day hour). The lowest value (9791.6 °C day hour) occurred in V₁ under D₁. The higher AHTU under D₃ was associated with the greater accumulation of thermal time together with actual sunshine hours during the crop period. Similar findings were reported by Kundu *et al.* (2021) [3], who observed that

sowing time had a significant effect on thermal indices and grain yield of mung bean.

Table 3. Accumulated Helio Thermal Units (AHTU) °C days hours values at different phenological stages of different green gram varieties under different growing environments.

Environment	Variety	Emergence	Branching	50% flowering	Pod formation	Physiological maturity
D ₁ (1 st March 2026)	V ₁ - (IPM 410-3 Shikha)	520.9	2216.2	5176.6	5787.1	9791.6
D ₁ (1 st March 2026)	V ₂ - (IPM 205-7 Virat)	555.9	2366.3	5438.9	6130.5	10225.5
D ₁ (1 st March 2026)	V ₃ - (PDM -139 Samrat)	663.2	2502.1	5958.5	6707.0	10514.3
D ₂ (11 th March 2026)	V ₁ - (IPM 410-3 Shikha)	627.3	2125.6	6230.5	7176.0	10834.3
D ₂ (11 th March 2026)	V ₂ - (IPM 205-7 Virat)	677.3	2417.8	6478.5	7411.7	11012.8
D ₂ (11 th March 2026)	V ₃ - (PDM -139 Samrat)	789.7	2526.2	6951.7	7867.2	11161.0
D ₃ (21 st March 2026)	V ₁ - (IPM 410-3 Shikha)	686.9	2237.2	6527.1	7458.9	10993.0
D ₃ (21 st March 2026)	V ₂ - (IPM 205-7 Virat)	698.3	2410.0	6761.4	7747.6	11100.0
D ₃ (21 st March 2026)	V ₃ - (PDM -139 Samrat)	820.3	2606.4	7025.0	7980.1	11324.7

Radiation Use Efficiency (RUE)

RUE varied with both growing environment and variety. Mean RUE across varieties was 0.951, 1.014 and 1.081 g MJ⁻¹ under D₁, D₂ and D₃, respectively. Thus, RUE increased with delay in sowing within the tested window. Among varieties, V₃ recorded the highest mean RUE (1.105 g MJ⁻¹), followed by V₂ (1.013 g MJ⁻¹) and V₁ (0.928 g

MJ⁻¹). The maximum individual RUE (1.140 g MJ⁻¹) was recorded in V₃ under D₃, while the minimum (0.892 g MJ⁻¹) was recorded in V₁ under D₁. The higher RUE of V₃ indicates comparatively efficient conversion of available intercepted radiation into biomass under the tested environments.

Table 4. Radiation Use Efficiency (RUE) for different green gram varieties under different growing environment

Variety	D ₁ (1 st March 2026)	D ₂ (11 th March 2026)	D ₃ (21 st March 2026)	Mean
V ₁ - (IPM 410-3 Shikha)	0.892	0.915	0.977	0.928
V ₂ - (IPM 205-7 Virat)	0.919	0.993	1.127	1.013
V ₃ - (PDM - 139 Samrat)	1.041	1.135	1.140	1.105
Mean	0.951	1.014	1.081	-

The present pattern is consistent with the cited work of Yousefi *et al.* (2020) [4], who reported differences in radiation use efficiency among mung bean genotypes, and with Kaushik *et al.* (2015) [5], who observed variation in RUE among varieties under different growing environments.

Heat Use Efficiency (HUE)

HUE showed a progressive increase from D₁ to D₃. Mean HUE was 0.464 g m⁻² °C⁻¹ day⁻¹ under D₁, 0.493 under D₂ and 0.541 under D₃. Among varieties, V₃ recorded the highest mean HUE (0.544 g m⁻² °C⁻¹ day⁻¹), followed by V₂ (0.499) and V₁ (0.456). The maximum HUE (0.571 g m⁻² °C⁻¹ day⁻¹) occurred in V₃ under D₃, whereas the minimum (0.435) occurred in V₁ under D₁. Higher HUE indicates greater biomass production per unit of accumulated thermal time under the corresponding environment.

Table 5. Heat Use Efficiency (HUE) for different green gram varieties under different growing environments

Variety	D ₁ (1 st March 2026)	D ₂ (11 th March 2026)	D ₃ (21 st March 2026)	Mean
V ₁ - (IPM 410-3 Shikha)	0.435	0.445	0.489	0.456
V ₂ - (IPM 205-7 Virat)	0.449	0.483	0.564	0.499
V ₃ - (PDM - 139 Samrat)	0.508	0.552	0.571	0.544
Mean	0.464	0.493	0.541	-

The higher HUE recorded by V₃ agrees with the thesis literature review, where Kumar *et al.* (2017) [6] reported a positive association between HUE and seed yield in green gram. Kumar *et al.* (2016) [7]

also identified HUE as an important index for evaluating terminal heat tolerance.

Thermal Sensitivity Index (TSI)

TSI varied from 5.04 to 6.89% among the varieties. V₂ recorded the highest TSI (6.89%), followed by V₁ (6.77%), whereas V₃ recorded the lowest TSI (5.04%). According to the classification used in the study, all three varieties fell in the 5–10% range and were therefore

categorized as moderately tolerant. The lower TSI of V₃ indicates comparatively lower variation in crop duration across the tested thermal environments.

Table 6. The computed TSI values for different green gram varieties are presented below:

Variety	Maximum duration (days)	Minimum duration (days)	Range (days)	Average duration (days)	TSI (%)	Category
V ₁ - (IPM 410-3 Shikha)	61	57	4	59.0	6.77	Moderately tolerant
V ₂ - (IPM 205-7 Virat)	60	56	4	58.0	6.89	Moderately tolerant
V ₃ - (PDM 139 Samrat)	61	58	3	59.5	5.04	Moderately tolerant

Overall discussion

Across the six indices considered, D₃ (21st March 2026) generally recorded the highest accumulated thermal indices and the highest mean RUE and HUE. V₃ (PDM-139 Samrat) consistently recorded the highest AGDD, APTU and AHTU at physiological maturity and also the highest mean RUE and HUE. These results show that both growing environment and varieties influenced the way the crop accumulated and utilized temperature, sunshine and radiation. The response also demonstrates why agrometeorological indices are useful for comparing crop performance under different growing environments.

Conclusion

The study showed Among the different sowing dates in agrometeorological indices of green gram varieties under different growing environments at Raipur. Accumulated GDD, PTU and HTU increased with crop development, and the highest values at physiological maturity were recorded in PDM-139 Samrat under D₃ (21st March 2026). Mean RUE and HUE were also highest under D₃, while PDM-139 Samrat recorded the highest varietal means for both efficiencies. Thermal Sensitivity Index ranged from 5.04 to 6.89%, with all varieties classified as moderately tolerant; PDM-139 Samrat showed the lowest TSI and therefore comparatively greater stability in crop duration. Within the environments and varieties evaluated in this experiment, D₃ (21st March 2026) and PDM-139 Samrat showed the most favourable response for accumulation and utilization of agro-meteorological resources.

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