Study on agrometeorological indices and heat use efficiency for black gram (*kharif*) crop under varied environmental conditions

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ABSTRACT

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| An investigation was carried out to determine the optimal sowing time and variety for *kharif* black gram under rainfed conditions at the AICRP on Agrometeorology farm, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, during the 2023-24 season. A factorial randomized block design (FRBD) was used with three sowing dates (28 MW - 10th July, 29 MW - 17th July, and 30 MW - 24th July) and three varieties (PDKV Black Gold, AKU-15, and AKU-23/5), replicated thrice. Accumulated growing degree days (GDD), helio-thermal units (HTU) and photo-thermal units (PTU) were computed to analyze the crop’s thermal response. The results revealed that crop sown in 28 MW (10th July) recorded the highest GDD, whereas delayed sowing (29 MW and 30 MW) led to reduced thermal accumulation and shortened crop duration. Among varieties, PDKV Black Gold accumulated the highest GDD, followed by AKU-15 and AKU-23/5. Similarly, PDKV Black Gold exhibited the highest HTU, indicating superior adaptability to varying thermal conditions. Yield analysis revealed that crop sown in 28 MW produced the highest seed yield, while delayed sowing (30 MW-24th July) resulted in a significant reduction in productivity. Among the varieties, PDKV Black Gold recorded significantly higher seed yield, straw yield and biomass yield over AKU-15 and AKU-23/5; however, it was at par with AKU-15 in terms of harvest index. Thus, it can be concluded that optimal sowing time for *kharif* black gram under rainfed conditions is the 28th MW (10th July), as it recorded the highest thermal accumulation (GDD, HTU, PTU) and resulted in the highest seed yield. Delayed sowing in the 29th MW (17th July) and 30th MW (24th July) led to reduced thermal accumulation, shortened crop duration, and lower productivity. Among Varieties, sowing PDKV Black Gold around 10th July is recommended for maximizing productivity under varied environmental conditions in Vidarbha. |

*Keywords: Black gram, Variety, Sowing dates, Yield and Agrometeorological indices*

1. INTRODUCTION

Black gram (Vigna mungo L.), commonly known as urdbean, is a vital pulse crop within the Leguminosae family, holding significant agronomic and economic importance, especially in India, its center of origin and largest producer. The crop is extensively cultivated across South and Southeast Asian countries, including India, Pakistan, Sri Lanka, Myanmar and parts of Africa and the Americas. In India, black gram ranks as the fourth most important pulse crop, predominantly grown in states such as Andhra Pradesh, Tamil Nadu, Karnataka, Maharashtra, Rajasthan, Gujarat, Madhya Pradesh, Punjab, Odisha, Bihar, Uttar Pradesh and West Bengal. In India black gram covers an area of 30.98 lakh hectare having the production of 17.68 Lakh tones with productivity of 570 kg ha-1 during *kharif*. In Maharashtra this occupies an area 3.58 lakh hectare with production and productivity of 2.26 Lakh tones and 630 kg ha-1, respectively (Anonymous, 2022).

Black gram is valued for its high nutritional content, making it an essential dietary component, particularly in vegetarian diets. Dried black gram contain about 9.7% water, 23.4% protein, 1.0% fat, 57.3% carbohydrate and 3.8% fibre along with 154 mg Calcium, 9.1 mg Iron, 0.37 g riboflavin and 0.42 g Thiamin in each gram of black gram (Verma *et al.,* 2011). Additionally, its by-products, such as seed coats and broken cotyledons from processing, serve as high-quality cattle feed. Due to its ability to fix atmospheric nitrogen through symbiotic association with Rhizobium spp., black gram plays a crucial role in soil fertility management.

Black gram thrives in warm, humid conditions with 600–800 mm rainfall and well-drained loamy soils. It grows in kharif and rabi seasons, requiring 65–85 days. Its cardinal temperatures range from 10–12°C (germination), 25–30°C (optimal growth), and up to 35–40°C, beyond which yield declines. Black gram cultivation faces significant challenges due to its susceptibility to abiotic stresses, which directly impact yield and overall productivity. In India, particularly in Vidarbha region, suboptimal yields often result from inadequate knowledge and implementation of essential agronomic practices. Among these, sowing time and variety selection are crucial determinants of crop performance, particularly during the *kharif* season. The ideal sowing period for black gram varies depending on seasonal conditions and varieties. Timely sowing ensures better synchronization between vegetative and reproductive phases while aligning with climatic patterns to maximize yield potential. To achieve higher yield, crop must be sown at appropriate time (Ahmad *et al.,* 2014). Varieties are important for successful crop production. Growing high-yielding varieties at the right time helps increase yield significantly. High-yielding varieties (HYVs) are of primary importance for potential yield production (Rehman *et al.,* 2009). So, there must be specific sowing period during the season for different variety in order to get maximum yield, as opined by Kalra *et al.* (2008). Favourable environment will be achieved only when crop is sown at correct time. Considering these aspects, the present study aims to identify the optimal sowing time and variety for *kharif* black gram in Vidarbha’s rainfed conditions.

2. material and methods

The field experiment was conducted at the research farm of AICRP on Agrometeorology farm, State Agricultural University, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola (220 42' N latitude, 720 02' E longitude and at an altitude of 307.42 m above MSL) in Vidarbha region of Maharashtra, during the *kharif* season of 2023-24. The gross plot size was 4.5 m x 5.0 m and net plot size was 3.6 m X 4.1 m. The experiment was laid out in Factorial Randomized Block Design with 9 treatment combinations comprising of 3 dates of sowing viz., D1- 28 MW (10th July), D2- 29 MW (17th July) and D3- 30 MW (24th July) and three variety viz., V1- PDKU Black gold, V2- AKU-15 and V3- AKU-23/5, replicated three times. The soil of experimental field was vertisols, almost neutral in reaction (pH 7.68), low in organic carbon (0.53%), medium in available phosphorus (17.8 kg ha-1) and medium in available potassium (291.7 kg ha-1). Black gram crop was sown at spacing of 45 cm x 10 cm. Recommended basal dose of nitrogen (20 kg N ha-1), phosphorus (40 kg P2O5 ha-1) and potassium (40 K2O kg ha-1) was applied through urea, di-ammonium phosphate and muriate of potash. Meteorological data viz, rainfall, relative humidity, maximum and minimum temperature, bright sunshine hours and day length were recorded from Agrometeorological observatory of Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India.

**Fig 1:** Rainfall (mm), Rainy Days, Bright Sunshine hours, Wind Speed and Evaporation for the year of 2023-24 recoreded at Meteorological Observatory, Department of Agronomy, Dr.PDKV, Akola

**Fig 2:** Temperature (0C) and Relative humidity (%) for the year 2023-24 recorded at Meteorological Observatory, Department of Agronomy, Dr.PDKV, Akola

The periodical observations on growth, micrometeorological parameters and yield contributing characters were recorded to assess the treatment effects.

**Growing degree days (°C Day)**

Thermal time or growing degree days were calculated according to the equation (Mali *et.al*.,2000). In this study, the base temperature for black gram was considered as 10°C.

The growing degree days (G.D.D.) were calculated using the formula

Where:

* **G.D.D.** = Growing Degree Days
* **Tmax**= Daily maximum temperature (°C)
* **Tmin** = Daily minimum temperature (°C)
* **Tb**= Base temperature

**Helio-thermal units (°C HTU)**

Helio-thermal units were calculated by multiplying the growing degree days (GDD) with the mean bright sunshine hours (BSS) at critical crop stages. Helio-thermal units (HTU) were determined by the equation proposed by Singh *et al.,* (1990).



Where:

* **HTU** = Helio-Thermal Units (°C day hours)
* **GDD** = Growing Degree Days
* **Mean BSS** = Mean Bright Sunshine Hours

**Photo-thermal unit (**°C **day hrs)**

Photo-thermal unit was defined as the product of growing degree days and the day length. Photo-thermal unit is expressed in terms of 0C day hrs. Photo-thermal unit was computed by using following formula. This was proposed by Gudadhe *et al.,* (2013).



**Thermal use efficiency (kg ha-¹**°C **day)**

Thermal use efficiency at harvest maturity was measured in terms of dry matter accumulation and seed yield following formula



Where,

* Seed yield or dry matter accumulation is measured in kg per hectare (kg ha-¹)
* Growing Degree Days (GDD) is measured in °C day-¹

3. results and discussion

**Growing degree days (°C day)**

Growing degree days (GDD) play a crucial role in determining crop phenology, as they influence key growth stages and final yield potential. The data presented in table 1highlights the variability in GDD accumulation across different sowing times and variety. The highest GDD accumulation was observed in the D1 - 28 MW sowing time (10th July) with an average of 1,139°C days, followed by D2 - 29 MW (17th July) with 1,078°C days, while the lowest accumulation was recorded in D3 - 30 MW (24th July) with 1,030°C days. The higher GDD accumulation in D1 - 28 MW sowing resulted from an extended crop growth duration, allowing more thermal energy absorption. In contrast, late sowing (D2 - 29 MW and D3 - 30 MW) led to a shortened growth period due to heat stress, forcing the crop to mature earlier and potentially reducing yield. Among varieties, PDKV Black Gold accumulated the highest GDD (1160°C days), followed by AKU-15 (1054°C days) and AKU-23/5 (1033°C days). The variations in GDD accumulation were likely due to genetic differences in heat tolerance and growth duration. It may be occurred due to different crop duration, from emergence to maturity of such Cultivars. Similar results were reported by Patil *et al*., (2014).

**Table 1. Growing degree days (**°C **day) across various phenophases as influenced by different treatments.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Phenophase** | **V1-** **PDKV Black Gold** | **V2-** **AKU-15** | **V3-** **AKU-23/5** | **Mean** |
| **D1- 28 MW (10th July)** |
| Sowing to Emergence | 93 | 93 | 93 | 93 |
| Emergence to Flower initiation | 501 | 484 | 468 | 484 |
| Flower initiation to Pod initiation | 134 | 103 | 119 | 119 |
| Pod initiation to Physiological maturity | 490 | 425 | 411 | 442 |
| Sowing to Physiological Maturity | 1218 | 1106 | 1092 | 1139 |
| **D2 - 29 MW (17th July)** |
| Sowing to Emergence | 101 | 88 | 88 | 93 |
| Emergence to Flower initiation | 442 | 443 | 430 | 438 |
| Flower initiation to Pod initiation | 156 | 119 | 101 | 125 |
| Pod initiation to Physiological maturity | 458 | 397 | 411 | 422 |
| Sowing to Physiological maturity | 1157 | 1047 | 1030 | 1078 |
| **D3 - 30 MW (24th July)** |
| Sowing to Emergence | 116 | 116 | 99 | 110 |
| Emergence to Flower initiation | 386 | 370 | 371 | 376 |
| Flower initiation to Pod initiation | 150 | 147 | 144 | 147 |
| Pod initiation to Physiological maturity | 455 | 375 | 362 | 397 |
| Sowing to Physiological Maturity | 1106 | 1008 | 977 | 1030 |
| Mean Sowing to Physiological Maturity | 1160 | 1054 | 1033 |  |

*\*V- variety of crop and D- date of sowing*

**Helio-thermal unit (**°C **day hrs)**

The helio-thermal units (HTU) varied across different phenophases and sowing times are presented in table 2 revealed that the crop sown in 30 MW (24th July) recorded the highest HTU (4142°C day hrs), followed by 28 MW (10th July) with 3874°C day hrs, while the lowest HTU was observed in 29 MW (17th July) with 3896°C day hrs. The variation in HTU among the sowing dates could be attributed to differences in solar radiation and cloudy conditions during the crop-growing period. The 30 MW sowing experienced relatively clearer weather conditions, leading to higher heat accumulation, while the presence of cloud cover in 28 MW and 29 MW resulted in lower HTU accumulation.

Among the varieties, PDKV Black Gold accumulated the highest HTU (4393°C day hrs), followed by AKU-15 (3818°C day hrs), while AKU-23/5 recorded the lowest HTU (3702°C day hrs). The variation in HTU requirements among variety is mainly due to genetic differences influencing their response to temperature and growth duration. Similar results were reported by Neog *et al.,* (2008) and Singh *et al.,* (2013).

**Table 2. Helio-thermal unit (°C day hrs) across various phenophases as influenced by different treatments.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Phenophase** | **V1- PDKV Black Gold** | **V2- AKU-15** | **V3- AKU-23/5** | **Mean** |
| **D1- 28 MW (10th July)** |
| Sowing to Emergence | 298 | 298 | 298 | 298 |
| Emergence to Flower initiation | 1341 | 1323 | 1292 | 1319 |
| Flower initiation to Pod initiation | 358 | 152 | 183 | 231 |
| Pod initiation to Physiological maturity | 2298 | 1942 | 1840 | 2027 |
| Sowing to Physiological Maturity | 4294 | 3715 | 3613 | 3874 |
| **D2 - 29 MW (17th July)** |
| Sowing to Emergence | 14 | 14 | 14 | 14 |
| Emergence to Flower initiation | 1375 | 1375 | 1375 | 1375 |
| Flower initiation to Pod initiation | 781 | 440 | 286 | 502 |
| Pod initiation to Physiological maturity | 2098 | 1951 | 1966 | 2005 |
| Sowing to Physiological Maturity | 4268 | 3779 | 3641 | 3896 |
| **D3 - 30 MW (24th July)** |
| Sowing to Emergence | 364 | 364 | 341 | 356 |
| Emergence to Flower initiation | 1230 | 1107 | 1097 | 1145 |
| Flower initiation to Pod initiation | 945 | 926 | 874 | 915 |
| Pod initiation to Physiological maturity | 2077 | 1562 | 1539 | 1726 |
| Sowing to Physiological Maturity | 4616 | 3959 | 3851 | 4142 |
| Mean Sowing to Physiological Maturity | 4393 | 3818 | 3702 |   |

*\*V- variety of crop and D- date of sowing*

**Photo-thermal unit (°C day hrs)**

The photo-thermalunits (PTU) varied significantly across different phenophases, sowing dates and variety are presented in Table 3 revealed that the highest PTU accumulation was observed in the 28 MW (10th July) sowing (15,369°C day hrs), followed by 29 MW (17th July) with 14,522°C day hrs, while the lowest accumulation was recorded in 30 MW (24th July) sowing (13,843°C day hrs). The higher PTU accumulation in the 28 MW (10th July) sowing (28 MW) could be attributed to longer crop growth duration, allowing more heat unit absorption and extending the reproductive phase. Among the varieties, PDKV Black Gold recorded the highest PTU (15,526°C day hrs), followed by AKU-15 (14,232°C day hrs), while the lowest PTU was recorded in AKU-23/5 (13,976°C day hrs). The genotypic variations in PTU accumulation highlight the role of genetic makeup in determining crop adaptability to different sowing times and thermal regimes. Similar results were reported by Chavan *et.al.,* (2018).

**Table 3. Photo-thermal unit (°C day hrs) across various phenophases as influenced by different treatments.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Phenophase** | **V1-PDKV Black Gold** | **V2-****AKU-15** | **V3-****AKU-23/5** | **Mean** |
| **D1- 28 MW (10th July)** |
| Sowing to Emergence | 1226 | 1226 | 1226 | 1226 |
| Emergence to Flower initiation | 7369 | 7165 | 6964 | 7166 |
| Flower initiation to Pod initiation | 1689 | 1296 | 1497 | 1494 |
| Pod initiation to Physiological maturity | 6046 | 5290 | 5113 | 5483 |
| Sowing to Physiological Maturity | 16330 | 14978 | 14800 | 15369 |
| **D2 - 29 MW (17th July)** |
| Sowing to Emergence | 1329 | 1160 | 1160 | 1217 |
| Emergence to Flower initiation | 6572 | 6585 | 6417 | 6525 |
| Flower initiation to Pod initiation | 1955 | 1505 | 1273 | 1578 |
| Pod initiation to Physiological maturity | 5623 | 4899 | 5085 | 5202 |
| Sowing to Physiological Maturity | 15479 | 14150 | 13936 | 14522 |
| **D3 - 30 MW (24th July)** |
| Sowing to Emergence | 1510 | 1510 | 1299 | 1440 |
| Emergence to Flower initiation | 5811 | 5604 | 5627 | 5681 |
| Flower initiation to Pod initiation | 1876 | 1857 | 1830 | 1854 |
| Pod initiation to Physiological maturity | 5573 | 4597 | 4436 | 4869 |
| Sowing to Physiological Maturity | 14771 | 13568 | 13192 | 13843 |
| Mean Sowing to Physiological Maturity | 15526 | 14232 | 13976 |   |

*\*V- variety of crop and D- date of sowing*

**Seed yield, straw yield, biological yield (kg ha-1) and harvest index (%) as influenced by various treatment**

The sowing date had a significant effect on seed yield, straw yield, biomass yield and harvest index, as presented in Table 4. Significantly higher seed yield (997 kg ha-¹), straw yield (1739 kg ha-¹) and biomass yield (2736 kg ha-¹) were obtained when the crop was sown on July 10 (28 MW), with a harvest index of 36.4%. However, it was at par with July 17 (29 MW) in terms of seed yield (869 kg ha-¹), straw yield (1558 kg ha-¹), biomass yield (2427 kg ha-¹) and harvest index (35.9%). The crop sown on July 24 (30 MW) recorded the lowest seed yield (671 kg ha-¹), straw yield (1228 kg ha-¹), biomass yield (1900 kg ha-¹) and harvest index (35.4%). This is due to higher number of pods plant-1, number of seeds plant-1, seed weight plant-1and thousand seed weight. Similar results were observed by Yadahalli and Palled (2004), Singh and Kumar (2014). Among the varieties, PDKV Black Gold recorded significantly higher seed yield (928 kg ha-¹), straw yield (1645 kg ha-¹) and biomass yield (2573 kg ha-¹) over AKU-15 and AKU-23/5; however, it was at par with AKU-15 in terms of harvest index (36.0%). AKU-23/5 recorded the lowest seed yield (788 kg ha-¹), straw yield (1422 kg ha-¹), biomass yield (2210 kg ha-¹) and harvest index (35.6%). The higher yields in variety PDKV Black Gold may be attributed to genetic makeup of cultivar and more number of branches plant-1 that helped in production of more number of matured or reproductive pods. These results are close in conformity with Patel and Munda (2001).

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| **Table. 4 Mean seed yield, straw yield, biological yield (kg ha-1) and harvest index as influenced by various treatments** |
| **Treatment** | **Seed yield****(kg ha-1)** | **Straw yield (kg ha-1)** | **Biomass yield****(kg ha-1)** | **Harvest Index (%)** |
| **Dates of sowing** |
| D1-28 MW (10 July) | 997 | 1739 | 2736 | 36.4 |
| D2- 29 MW (17 July) | 869 | 1558 | 2427 | 35.9 |
| D3-30 MW (24 July) | 671 | 1228 | 1900 | 35.4 |
| SE m + | 32.55 | 60.66 | 88.13 | - |
| CD (P=0.05) | 97.59 | 181.87 | 264.22 | - |
| **Varieties** |
| V1 – PDKV Black Gold | 928 | 1645 | 2573 | 36.0 |
| V2 – AKU-15 | 821 | 1459 | 2280 | 36.0 |
| V3 – AKU-23/5 | 788 | 1422 | 2210 | 35.6 |
| SE m + | 32.55 | 60.66 | 88.13 | - |
| CD (P=0.05) | 97.59 | 181.87 | 264.22 | - |
| **Interaction** |
| SE m + | 56.38 | 105.07 | 152.64 | - |
| CD (P=0.05) | NS | NS | NS | - |
| CV (%) | 11.55 | 12.06 | 11.23 | - |

*\*V- variety of crop and D- date of sowing*

**Thermal use efficiency (kg ha-1 °C day-1)**

Thermal use efficiency (kg ha-¹ °C day-¹) for seed yield and biomass production varied across different sowing dates in black gram are presented in table 5. The highest thermal use efficiency was observed in crops sown in 28 MW (July 10th), followed by 29 MW (July 17th), with both dates showing relatively higher values for seed and biomass production. In contrast, the lowest thermal use efficiency was recorded in crops sown in 30 MW (July 24th). The decline in thermal use efficiency (TUE) with delayed sowing could be attributed to a reduction in accumulated heat units and shortened growth duration, which restricted overall biomass production. Additionally, late-sown crops might have experienced suboptimal radiation use efficiency and higher temperatures during the reproductive phase, leading to stress-induced reductions in yield efficiency.

Among the varieties, PDKV Black Gold (V1) exhibited the highest thermal use efficiency for grain yield and biomass production, while AKU-23/5 (V3) recorded the lowest. The superior yield in PDKV Black Gold (V1) under high-temperature stress may be due to greater retention of photosynthetic pigments, enhanced dry matter partitioning (Pavithra *et. al.,* 2024), and its better thermal energy conversion, longer growth duration, and adaptability to agro-climatic conditions.

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**Table 5. Accumulated thermal use efficiency (kg ha-1 °C day-1) across various phenophases as influenced by different treatments**

|  |  |
| --- | --- |
| **Variety** | **Sowing times** |
| **D1-28 MW** **(10th July)** | **D2-29 MW** **(17th July)** | **D3-30 MW** **(24th July)** | **Mean** |
| **V1 – PDKV Black Gold** | 0.89 | 0.83 | 0.67 | 0.80 |
| **2.43** | **2.31** | **1.89** | **2.21** |
| **V2 – AKU-15** | 0.86 | 0.81 | 0.65 | 0.78 |
| **2.40** | **2.21** | **1.85** | **2.16** |
| **V3 - AKU-23/5** | 0.87 | 0.78 | 0.63 | 0.76 |
| **2.38** | **2.23** | **1.78** | **2.13** |
| **Mean** | 0.88 | 0.80 | 0.65 |   |
| **2.40** | **2.25** | **1.84** |  |

*\*V- variety of crop and D- date of sowing*

*Figures in parentheses indicate heat use efficiency in terms of biomass*

**Figure 3*.* Accumulated thermal use efficiency (kg ha-1 °C day-1) across various phenophases as influenced by different treatments for seed yield and biomass yield**

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4. Conclusion

This study underscores the importance of timely sowing and variety selection for optimizing yield in *kharif* black gram under rainfed conditions in Vidarbha. The crop sown in MW 27 (around 10th July) resulted in higher GDD accumulation, prolonged crop duration, and increased yield, making it the most suitable sowing time. In contrast, late sowing (29 MW and 30 MW) resulted in reduced GDD accumulation, shorter crop duration, and lower yield, highlighting the significance of timely sowing. Among variety, PDKV Black Gold demonstrated superior thermal adaptability and yield potential, making it the most promising variety for cultivation in the region.

## **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 writing or editing of this manuscript.

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