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Strategic cultivar and sowing time selection for weed management and higher redgram productivity in semi-arid Indian regions

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Introduction: Redgram (*Cajanus cajan* L. Mill sp.), a leguminous crop commonly grown in tropical and subtropical climates, is highly valued for its high protein content (21%), which contributes significantly to food and nutritional security. However, its production faces challenges primarily due to terminal dryness experienced during critical growth stages because of changing rainfall patterns. To overcome this, adaptive techniques become imperative as the productivity of this crop is intricately linked to environmental factors and the crop's growth cycle.

Methods: Hence, the field experiment was conducted at the National Pulses Research Centre, Vamban, Pudukkottai, Tamil Nadu, in South India under rainfed condition, during the kharif (monsoon) seasons of 2017–18 and 2018–19. The primary objectives were to determine the optimal sowing time and identify suitable redgram cultivars, especially in the context of the late onset of the monsoon in Tamil Nadu, a common issue under changing climate conditions. The experiments tested six different sowing dates with three redgram cultivars.

Results and discussion: The findings highlighted the substantial influence of different redgram cultivars and sowing times on the crop's growth characteristics and yield. Among the six sowing dates tested, planting in later half of June (S_6) resulted in notably higher plant height (201 cm), a greater number of pods per plant (287), a seed yield of 1,112 kg ha–1, and a benefit-cost ratio of 2.61 Notably, this sowing period (S_6) demonstrated comparable performance with the treatment of redgram sowing in the latter part of September (S_4). CO 6 (V_1) is the most productive of the three redgram cultivars, with the highest mean pant height (200 cm), number of pods per plant (237), grain yield (1,017 kg ha–1), and benefit cost ratio (2.38). Extended phenological phases along with extra days to reach phenological stages could account for the increased yield in comparison to the other cultivars. Among the two short-duration cultivars, VBN (Rg) 3 (V_3) had a significantly higher mean grain yield of 958 kg ha–1 with the benefit-cost ratio of 2.24. Even though CO 6 (V_1) obtained a higher yield due to its long duration nature, it matured in 187 days whereas VBN (Rg) 3 (V_3) matured within 129 days. Consequently, the short-duration redgram cultivars emerge as highly suitable choices for integrating into crop sequences, thereby augmenting farm cropping intensity.

KEYWORDS

redgram cultivars, time of sowing, weed growth, yield, economics

1 Introduction

Global crop production must increase by 60% by 2050 to satisfy an increasing demand for food, driven by population growth and rising *per capita* incomes (Fischer et al., 2014). This challenge is further compounded by the impacts of climate change, which threaten agricultural productivity and necessitate the adoption of resilient and adaptive farming practices. (Surendran et al., 2021). Climate plays a crucial role in crop adaptation, influencing farmers' decisions on which crops to cultivate based on their suitability for the local environment. Approximately 67% of the fluctuations in crop production over a season can be attributed to weather, which significantly impacts crop growth and development. The remaining variations in production are due to agronomic factors such as soil and nutrient management (Sasane, 2017; Grigorieva et al., 2023). In dryland environments, instability in crop production is primarily caused by an imbalance between rainfall distribution and crop water demand. This issue is particularly pronounced in dryland agriculture, where soil moisture levels during the crop season are highly variable and largely dependent on the amount and distribution of rainfall (Pawar et al., 2020). In India, the activity of the South-West monsoon and the associated weather patterns are critical determinants of agricultural success. Agroclimatic conditions strongly influence crop selection, yield, and sustainability, underscoring the need for strategies that account for the variability and unpredictability of weather in dryland farming systems (Ravi et al., 2022). In the semi-arid regions of India, agricultural productivity is heavily influenced by climatic variability, particularly the distribution and timing of rainfall. Redgram (*Cajanus cajan* L. Mill sp.), a vital leguminous crop, plays a crucial role in providing food and nutritional security due to its high protein content. However, its cultivation faces significant challenges owing to terminal dryness during critical growth stages, exacerbated by the erratic nature of monsoons.

Redgram is one of the most important tropical legumes in India playing a crucial role in the diet and agriculture of the region. Redgram is made by splitting and boiling grains, and redgram green pods are used as vegetables. It is a significant protein rich component of our regular vegetarian diet and has 22 percent protein content, with an average cooked protein digestibility of 70 percent (Reed et al., 1989; Mallikarjuna and Devaraja, 2023). Furthermore, it is adaptable to many cropping systems without altering the main oilseed and cereal crops, and enhances soil health through biological nitrogen fixation. Residual plant parts provide good fodder (Patel et al., 2019). Understanding plant-environment interactions is essential for improving crop yield. Optimum sowing time and the selection of appropriate cultivars play a crucial role in harnessing the yield potential of crops under complex agro-climatic conditions. The sowing date has been proven to be one of the most significant non-monetary factors affecting pulse yields. Suboptimal thermal conditions during the growing season can significantly affect crop productivity. Therefore, determining the optimum sowing time is vital to maximize production by exploiting favourable environmental conditions during the growth of pulses.

Because of its distinctive morphological characteristics that encourage deep roots and drought endurance, redgram is suited to a wide range of unfavourable growing conditions, including varied soil depth and irregular rainfall (Islam et al., 2008). Rainfed cultivations are the primary growing conditions in Tamil Nadu. Most oilseeds, millets, and pulses (80–90%) are restricted to dryland habitats. Dryland habitat is characterized by small and marginal farmers, lack of resources, poor infrastructure, and little investment in inputs and technologies. The main cause of this region's declining redgram grain production is erratic rainfall, which severely impacts the timing of planting. Developing the right time of sowing and identifying suitable redgram cultivars can assist these financially constrained farmers in avoiding crop failure, as they are unable to invest additional costs (Sunil Kumar et al., 2020). Due to its photo-sensitivity redgram growth, including plant height, number of branches, the height at which branching begins, flowering, and pod formationis influenced by the sowing time. Consequently, Channabasavanna et al. (2015) discovered that planting time significantly affects redgram vegetative and reproductive growth stages. The growth, development, and yield of redgram crops were mostly determined by cultivars and the sowing date. Since the planting date determines the types of climates to which the crop's difficult phenological stages are exposed, it has a major impact on crop performance (Kumar et al., 2023). To maximize the benefits of all available natural resources, such as nutrients, sunlight, and soil moisture, as well as to ensure a sufficient yield, it is essential to maintain a desired plant population by optimizing the sowing date as well the cultivars. Developing the right time of sowing and identifying suitable redgram cultivars can assist these financially constrained farmers in avoiding crop failure, as they are unable to invest additional costs. Crop environments affect yield and yield components, according to Sharifi et al. (2009). Delays in sowing cause more harm to redgram (Padhi, 1995). A significant decrease in the number of branches per plant and dry weight per plant at harvest occurs when delayed planting is done in contrast to regular sowing. (Reddy et al., 2012). In contrast to early sowing, late seeding shortened the time required to reach harvest maturity (Ram et al., 2011). Delays in sowing cause more harm to redgram, as crop environments affect yield and yield components. Maintaining optimum plant population under poor soil moisture conditions is very difficult, given the significant role plant population plays in determining crop yield. Delayed sowing, compared to regular sowing, leads to a significant decrease in the number of branches and dry weight per plant at harvest, while also shortening the time to reach harvest maturity. Regular efforts are being undertaken to shorten the redgram growth season, and as a result, cultivars with medium (155–170 days) and short (120 days) durations are being produced. Additionally, short-duration cultivars are noted for their seamless integration into intensive cropping areas year-round, attributed to their thermo- and photo-insensitivity (Aruna and Sunil Kumar, 2023). Selecting the optimal sowing date for each genotype is a crucial decision in agricultural production, especially when aiming to maximize the genetic potential of crops (Krsti et al., 2023).

Redgram holds a significant position in the global agricultural economy, cementing its status as one of the most important pulse crops worldwide. However, the crop's duration and genotype vigour are crucial factors influencing its success. In recent years, unpredictable and delayed rainfall has challenged redgram cultivation, particularly when planting occurs after its optimal period. Therefore, this study aims to standardize the sowing date

TABLE 1 Treatment structure of the experiment.

Factor A: Sowing schedule	Factor B: Cultivars
S_1: 1–14th August (1st fortnight) S_2: 15–30th August (2nd fortnight) S_3: 1–14th September (1st fortnight) S_4: 15–30th September (2nd fortnight) S_5: 1–14th October (1st fortnight) S_6: 15 to 30th June (2nd fortnight) (Control)	V_1:CO 6 V_2: CO(Rg)7 V_3: VBN (Rg) 3

for the late advent of the monsoon in the southern zone of Tamil Nadu by utilizing potential redgram genotypes from this region. By addressing the timing and selection of genotypes, this research aims to enhance redgram productivity under changing climatic conditions, offering valuable insights for improving agricultural resilience and sustainability in semi-arid regions.

2 Materials and methods

A field experiment was carried out at the National Pulses Research Centre, Vamban, Pudukkottai, Tamil Nadu, part of Tamil Nadu Agricultural University, during the *kharif* seasons of 2017–18 and 2018–19. The main objectives were to find out the optimum time of sowing and the suitable redgram cultivars during the late onset of the monsoon in Tamil Nadu under rainfed condition and to assess the weed growth due to different sowing dates and redgram cultivars. The experiment site is located at 8 ⁰ 30′ to 10 ⁰ 40′ N latitude and 78,⁰24′to 79⁰ 4′ E longitude, with an altitude of 120 m above the mean sea level of Pudukkottai district in TamilNadu, South India. The weather data collected from the National Pulses Research Centre in Vamban, Pudukottai, is available from a B-class meteorological observatory. In this observatory, weather parameters were collected regularly during the cropping period. The average annual rainfall was 940 mm, with 52 rainy days and 38.74°C and 22.14°C mean annual maximum and minimum temperatures, respectively. The soil characteristics of the experimental site were sandy clay loam, a mean pH of 6.55, EC of 0.21 dsm^{-1},organic carbon of 0.3 percent, and 220, 33.5, and 159.5 kg ha^{-1} of available N, P, and K respectively. The experiment was laid out in a factorial randomized complete block design and replicated three times with the following treatments: factor ‘A’ comprising of six dates of sowing schedule and factor ‘B’ consisting of three redgram cultivars are given in Table 1.

Redgram VBN (Rg) 3 (110–120 days) and CO (Rg) 7 (130 days) are short-duration cultivars, and CO6 is a long-duration (180 days) cultivar. Both years of study, the recommended seed rates of 15 kg ha^{-1} for CO (Rg) 7 and VBN (Rg) 3 and 8 kg ha^{-1} for CO 6 were used for this study. Seeds were treated with *rhizobium* and *phosphobacteria* at the rate of 600 g per hectare using rice gruel. The sowing was taken on 11.8.2017, 24.8.2017, 09.9.2017, 29.9.2017, 6.10.2017, and 30.6.2017 during the first year, and 10.8.2018, 22.8.2018, 06.9.2018, 19.9.2018, 05.10.2018, and 21.6.2018 in the second year of the experiment, respectively. The spacing of 60 × 25 cm was adopted for short-duration redgram var. CO (Rg) 7 and VBN (Rg) 3, and 90 × 30 cm for long-duration redgram var. CO 6. The recommended dose of 12.5: 25: 12.5: 10 kg ha^{-1} of nitrogen through urea, phosphorus through single super phosphate, potassium through muriate of potash, and sulphur through gypsum, respectively, at basal. The crop was harvested from 09.11.2017 to 17.03.2018 and 01.11.2018 to 15.3.2019 in first- and second-year experiments, respectively.

Weed counts, namely, weed density (nos/m^2) and weed dry matter (g/m^2) were recorded 30 days after sowing (DAS). The weed count was assessed using quadrat method and the size of the quadrat was 0.25 m^2. The collected weeds were first air-dried and subsequently oven-dried at 75°C ± 2°C until a constant weight was achieved using an electronic balance, and then expressed in kilograms per hectare. Prior to statistical analysis, weed dry weight and weed density data underwent transformation using the square root method ($\sqrt{x+0.5}$).

To calculate Weed Control Efficiency (WCE) at both 30 and 45 days after sowing (DAS), the following formula was employed:

$$WCE = \frac{X\,(X - Y)}{X}\,x\,100$$

Where: X = Number or dry weight of weeds in the unweeded plot
Y = Number or dry weight of weeds in the treated plot.

Ten plants were randomly chosen and marked with waxy-coated labels in each treatment to monitor growth and yield parameters. At the time of maturity, observations were made on plant height, number of branches per plant, and yield parameters such as pod count per plant, number of seeds per pod and 100-grain weight. The matured pods were harvested plot-wise using a sickle, cut above the soil surface, bundled according to treatment, and transported to the threshing floor. The harvested produce was left to sun dry for 3 days, then beaten with bamboo sticks to separate grains, and dried again to facilitate winnowing. The produce continues drying until it reaches a moisture content of 12 percent. The total plot yield was weighed according to treatment. To convert this weight to kilograms per hectare, the measured weight was multiplied by a conversion factor based on the net plot size.

Based on the local market price cost incurred for this experiment, gross and net income and benefit cost ratios were worked out. The costs associated with the application of organic matter, major and micronutrients, and plant growth regulators were calculated using current market prices of inputs and redgram seeds. The cost of cultivation encompasses expenses from field preparation to harvest, expressed in Indian rupees (₹.) per hectare. Gross return is determined by calculating the crop yield per hectare and multiplying it by the prevailing minimum market rate at the time of the study, which was 60 ₹. per kilogram of redgram. Net return is then calculated by subtracting the cost of cultivation from the gross return for each treatment: Net return = Gross return (₹./hectare) - Cost of cultivation (₹./hectare). Finally, the Benefit-Cost (B: C) ratio is calculated using the formula: B: C ratio = Gross return (₹./hectare)/Total cost of cultivation (₹./hectare).

2.1 Statistical analysis

The collected data were subjected to R studio statistical analysis and tabulation. Statistical scrutiny was conducted following the methods suggested by Gomez and Gomez (1984). Fisher's Least Significant Difference was employed to test for significant differences between means at a probability level of $p \leq 0.05$ via ANOVA. The analysis focused on the impact of different sowing dates and redgram cultivars as independent variables on the growth and yield parameters of redgram,

TABLE 2 Effect of different date of sowing and redgram varieties on growth, yield attributes and grain yield.

Treatments	Plant height (cm)	No. of branches/plant	No. of pods/Plant	No. of seeds/pod	100 seed weight (g)	Grain yield (kgha^{-1})	B:C ratio
Factor A: Sowing schedule							
S_1: August 1st fortnight	190	9.82	204	3.98	9.04	926	2.17
S_2: August 2nd fortnight	178	8.43	200	3.96	8.95	917	2.15
S_3: September 1st fortnight	182	9.07	223	4.02	8.98	967	2.27
S_4: September 2nd fortnight	179	10.25	259	4.11	8.82	1,045	2.45
S_5: October 1st fortnight	155	8.71	155	3.91	8.82	773	1.81
S_6: June 2nd fortnight	201	11.82	287	4.00	8.97	1,112	2.61
S: SE	2.59	0.33	6.90	0.16	0.16	26.20	-
CD (p = 0.05)	8.15	1.03	21.73	0.50	NS	82.56	-
Factor B: Variety							
V_1:CO 6	200	10.90	237	3.98	8.94	1,017	2.38
V_2: CO(Rg)7	171	8.23	201	4.09	8.91	892	2.10
V_3:VBN (Rg) 3	173	9.92	226	3.92	8.93	958	2.24
V: SE	2.04	0.21	3.85	0.07	0.10	9.82	-
CD (p = 0.05)	5.96	0.63	11.24	NS	NS	28.64	-
Interaction S x V: SE	5.00	0.53	9.43	0.18	0.23	24.04	-
CD (p = 0.05)	14.59	NS	NS	NS	NS	70.15	-
CV (%)	7.94	9.44	7.38	5.27	4.58	8.22	-

with a one-way ANOVA conducted using Tamil Nadu Agricultural University AGRES Statistical softwarev 7.01. Non-significant treatment differences were denoted as "NS."

3 Results

During the cropping period, a total of 415.1 and 556.9 mm of rainfall were recorded over 30 and 34 rainy days during 2017–18 and 2018–19, respectively (Figure 1). The mean maximum and minimum temperatures during these seasons were 33.96°C and 32.84°C, and 24.38 °C and 23.06°C, respectively. In 2018–19, a 25.5% increase in rainfall with a more uniform distribution was observed during the cropping period.

3.1 Influence of treatments on growth parameters

The result of the present experiment revealed that redgram cultivars and different dates of sowing significantly influenced growth characteristics namely, plant height and number of branches per plant. Among the six different dates of sowing, crop sown during the 15 to 30thof June (S_6) recorded a significantly higher plant height of 201 cm and a number of branches of 11.82 per plant (Table 2). Sowing redgram during the 1to 14thof September (S_3) resulted in favourable plant height, which was statistically comparable to sowing in the 15 to 30th of September (S_4) and the 15 to 30th of August (S_2) in both years of the study. The lowest plant height (155 cm) was recorded in the 1 to 14th of October (S_5) sown redgram crop. From the three redgram cultivars, var. CO 6 (V_1) recorded a significantly higher plant height of 200 cm and a number of branches of 10.90 per plant. Among the two short-duration cultivars, VBN (Rg) 3 (V_3) registered significantly higher plant height (173 cm), which was on par with CO (Rg) 7 and the number of branches (9.92 per plant). The interaction effect between different dates of sowing and redgram cultivars on plant height was found to be significant. Sowing of CO6, in 15 to 30th the 2nd fortnight of June (V_1S_6), exhibited the tallest plant height at 234 cm among the six sowing dates and three redgram cultivars. Following closely was CO 6 sown in the 1st fortnight of September (1–14) (V_1S_3), which reached a height of 206 cm.

3.2 Influence of treatments on yield parameters

Among the six different dates of sowing, crop sown during the 15 to 30th of June (S_6) recorded the significantly highest number of

TABLE 3 Effect of different date of sowing and redgram varieties on weed density and weed dry matter on 30 DAS.

Treatments	Weed density (nos/m^2)	Weed dry matter (g/m^2)
Factor A: Sowing schedule		
S_1: August 1st fortnight	8.29	11.84
	(64.83)	(141)
S_2: August 2nd fortnight	7.98	11.12
	(71.83)	(124)
S_3: September 1st fortnight	7.86	10.76
	(60.17)	(116)
S_4: September 2nd fortnight	7.82	10.52
	(66.83)	(111)
S_5: October 1st fortnight	7.87	10.47
	(61.67)	(110)
S_6: June 2nd fortnight	8.16	12.26
	(66.67)	(142)
S: SE	0.08	0.24
CD (p = 0.05)	0.24	0.76
Factor B: Variety		
V_1:CO 6	7.80	10.49
	(63.33)	(111)
V_2: CO(Rg)7	8.29	11.96
	(67.33)	(140)
V_3:VBN (Rg) 3	7.90	11.03
	(65.33)	(122)
V: SE	0.10	0.12
CD (p = 0.05)	0.29	0.36
Interaction S x V: SE	0.25	0.30
CD (p = 0.05)	0.72	0.88
CV (%)	5.35	4.67

Note: Square root log transformed value and Figures in parenthesis indicate original values.

pods per plant of 287, followed by the sowing of redgram during 15 to 30thof September (S_4), which recorded 259 pods per plant. Crops grown during 1 to 14th of October (S_5) recorded the lowest number of 155 pods per plant. Among the three redgram cultivars, var. CO 6 (V_1) recorded the significantly highest number of 237 pods per plant. Of the two short-duration cultivars, VBN (Rg) 3 (V_3) registered the significantly highest number of 226 pods per plant. The number of seeds per pod and 100 seed weight were not significantly influenced by the treatments (Table 2; Figure 2). The interaction effect between various sowing dates and redgram cultivars on yield attributes, including the number of pods per plant, number of seeds per pod, and 100-seed weight, did not show statistical significance.

3.3 Influence of treatments on grain yield

The treatments exerted a significant influence on grain yield (Table 2; Figure 3). Among the six different sowing dates, a higher mean redgram seed yield of 1,112 kg ha^{-1} was recorded in crops sown during 15 to 30th of June (S6), which was comparable to the yield obtained from redgram sown during 15 to 30thof September (S_4). Sowing of redgram at September 1 to 14th (S_3) was on par with 1-14thofAugust (S_1) and 15–30thofAugust (S_2). The lowest seed yield of 773 kg $ha^{-1}$was recorded for the sowing of redgram on October 1 to 14th (S_5). From the three redgram cultivars, CO 6 (V_1) recorded a significantly higher mean grain yield of 1,017 kg ha^{-1}. Among the two short-duration cultivars, VBN (Rg) 3 (V_3) had a significantly

TABLE 4 Effect of different date of sowing and redgram varieties on economics.

Treat	Cost of cultivation (Rs. ha^{-1})	Gross income (Rs. ha^{-1})	Net income (Rs. ha^{-1})
S_1	32,000	69,485	37,485
S_2	32,000	68,782	36,782
S_3	32,000	72,491	40,491
S_4	32,000	78,381	46,381
S_5	32,000	57,938	25,938
S_6	32,000	83,433	51,433
V_1	32,000	76,252	44,252
V_2	32,000	67,252	35,252
V_3	32,000	71,751	39,751

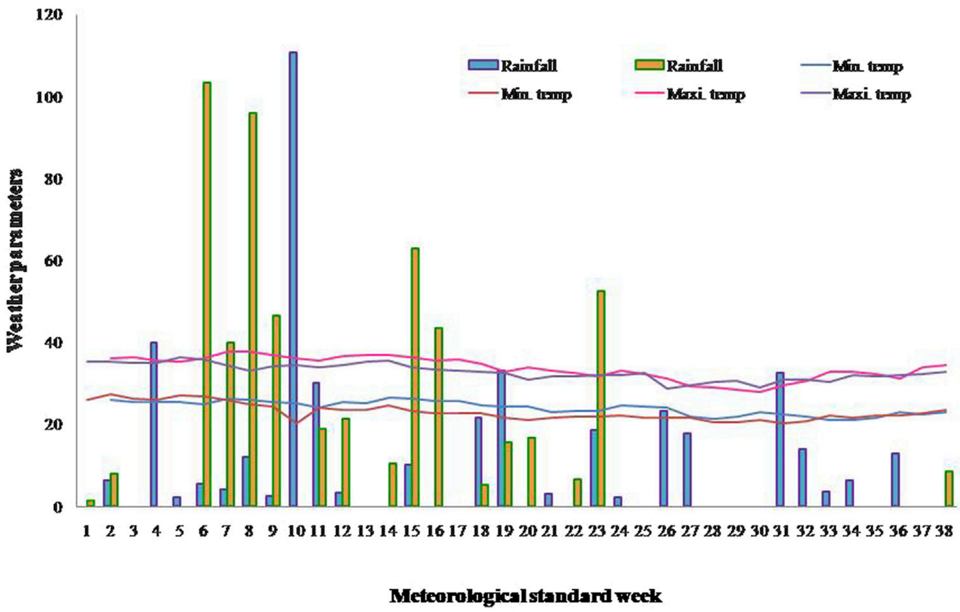

FIGURE 1
Meteorological parameters observed during the experimental period for both years.

higher mean grain yield of 958 kg ha^{-1}. Even though CO 6 (V_1) obtained a higher yield due to its long duration nature, it matured in 187 days, whereas VBN (Rg) 3 (V_3) matured within 129 days. According to the experimental results, the redgram cultivar CO6 produced the highest yield during the second fortnight of June, while the short-duration redgram cultivarVBN (Rg) 3 demonstrated the highest yield during 15 to 30thof September. The results revealed that redgram seed yield was significantly affected by the combination of sowing time and cultivar. Redgram CO 6, sown during 15 to 30thof June (V_1S_6), yielded the highest grain yield of 1,161 kg ha^{-1} among the six sowing dates and three redgram cultivars. Close behind was CO 6 sown in 15 to 30thof September (V_1S_4), which produced a grain yield of 1,105 kg ha^{-1}.

3.4 Weed density (no/m^2) and weed drymatter production (g/m^2)

The weed population in the experimental field was varied and included broadleaved, sedge, and grass weeds. *Dactyloctenium aegyptium* and *Chloris barbata* were the most common grass-related weed species, while *Cyperus rotundus* was the most common sedge-related weed. The broadleaved weeds included *Flaveria australica*, *Cleome gynandra*, *Eclipta alba*, *Convolvulus arvensis*, *Digera arvensis*, *Vicia* spp., and *Celosia argentea*. The result revealed that, among the six different dates of sowing, crops sown at15-30th of September (S_4) registered significantly lower weed density and weed dry matter production of 7.82 nos m^{-2} and 10.52 g m^{-2} respectively, followed by the 1–14thof September (S_3)

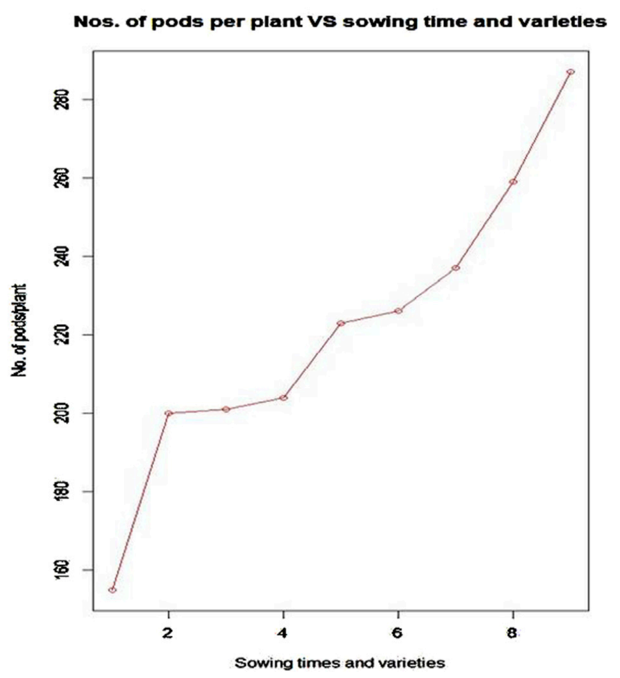

FIGURE 2
Effect of sowing times and varieties on the number of redgram pods per plant at harvest.

(Table 3; Figure 4). The highest weed density and weed dry matter production of 8.29 nos m^{-2} and 11.84 g m^2 respectively, registered the crop sown on August 1 to 14th. Among the three redgram cultivars, CO 6 (V1) exhibited significantly the lowest weed density and weed dry matter production, with values of 7.80 nos. m^{-2} and 10.49 g m^{-2}, respectively, followed by VBN (Rg) 3 (V_3). The weed density and weed dry matter production was significantly influenced by interaction between redgram cultivars and sowing time. Among the six sowing dates and three redgram cultivars. CO 6, sown during the 15 to 30th the 2nd fortnight of June (V_1S_4), yielded the highest grain yield of 7.51 No. m^{-2} and Weed dry matter 9.61 g m^{-2}) on 30 DAS. It was followed by redgram CO 6 sown in the 1 to 14th of September (V_1S_3).

3.5 Economics

Sowing of redgram during the 15 to 30th of June (S_6) recorded the highest gross and net income of ₹. 83,433 and 51,433 ha^{-1}, respectively, and a B: C ratio of 2.61, followed by the September 15 to 30th (S_4) 2.45 (Table 4). Among the three redgram cultivars, CO 6 (V_1) recorded higher gross and net income of ₹. 76,252 and 44,252 ha^{-1} respectively, and a B: C ratio of 1: 2.38, followed by VBN (Rg) 3 (V_3) at 2.24.

4 Discussion

4.1 Influence of time of sowing

The sowing of long-duration redgram during the second week of July notably enhanced plant height and the number of branches per plant in both study years. Unlike other planting dates, seeds sown early in the second week of July resulted in significantly larger plants. One plausible explanation for this observation could be that the crop had sufficient time to mature and capitalize on favourable environmental conditions for vegetative growth and development, leading to increased accumulation of photosynthates during the early stages of crop growth. Similar results were found in studies by Sandeep et al. (2022) and Dahariyaet al. (2018) about the largest plant height. Flowering time dictates how long the vegetative phase lasts, marks the beginning of the reproductive phase, and thus influences the climatic conditions affecting crop growth thereafter. As the season progresses, photoperiod ceases to be a limiting factor, with temperature and soil moisture becoming the primary climatic variables affecting the rate of progress from flowering to physiological maturity. Later sowings in the first fortnight of October accelerated the time to reach physiological maturity and shortened the duration of vegetative, flowering, and podding growth phases compared to the second fortnight of September as earlier sowing dates. These findings are consistent with prior research indicating the substantial impact of temperature on (Soybean by Kundu et al., 2016 and in Chickpea by Richards et al., 2020; 2022) development and the length of growth stages.

The phenology of redgram crop aligns with the resources available in the production environment, including water, nutrients, light, and space, as well as with the genetic variability among redgram cultivars reported by Patel et al. (2000). When crops were sown early, their leaf area index was higher than when they were sown later. Planting a high-yielding cultivar at the optimal time can effectively utilize all production inputs which leads to better plant growth, leaf area index and maximize yield was reported by Kittur and Guggari (2017). Positive weather conditions such as light, temperature, and precipitation may have aided in greater development, and the genetic composition of the cultivar may have provided higher growth parameters and yield-related qualities like the number of pods per plant. It may be the result of the maximum transfer of photosynthates into seed growth in crops sown early (Sandeep et al., 2022). The lowest weed density and dry matter were observed in the sowing of redgram CO6 during the second week of September. The reasons might be the crop's accelerated vegetative and reproductive growth may have resulted from a combination of favourable weather conditions, including higher soil moisture content from adequate rainfall from third week of July to the second week of September in both the years of study (Subbulakshmi,2021).

4.2 Influence of redgram genotypes

The extended duration redgram cultivar CO6 required 43 days more for flowering to maturity compared to VBN(Rg)3, which took 17 days less. CO6, the prolonged-duration cultivar, stood 27 cm taller and produced 12.3 percent more than the early maturing cultivar CO(Rg)7, while VBN(Rg)3 exhibited a 7.0 percent increase among the early maturing cultivars, in contrast to CO(Rg)7. These differences in blooming time, maturity time, plant height, and seed yield were attributed to variations in the genetic composition and characteristics of the plants. Consistent with findings from Kithan et al. (2020), cultivars characteristics in redgram production

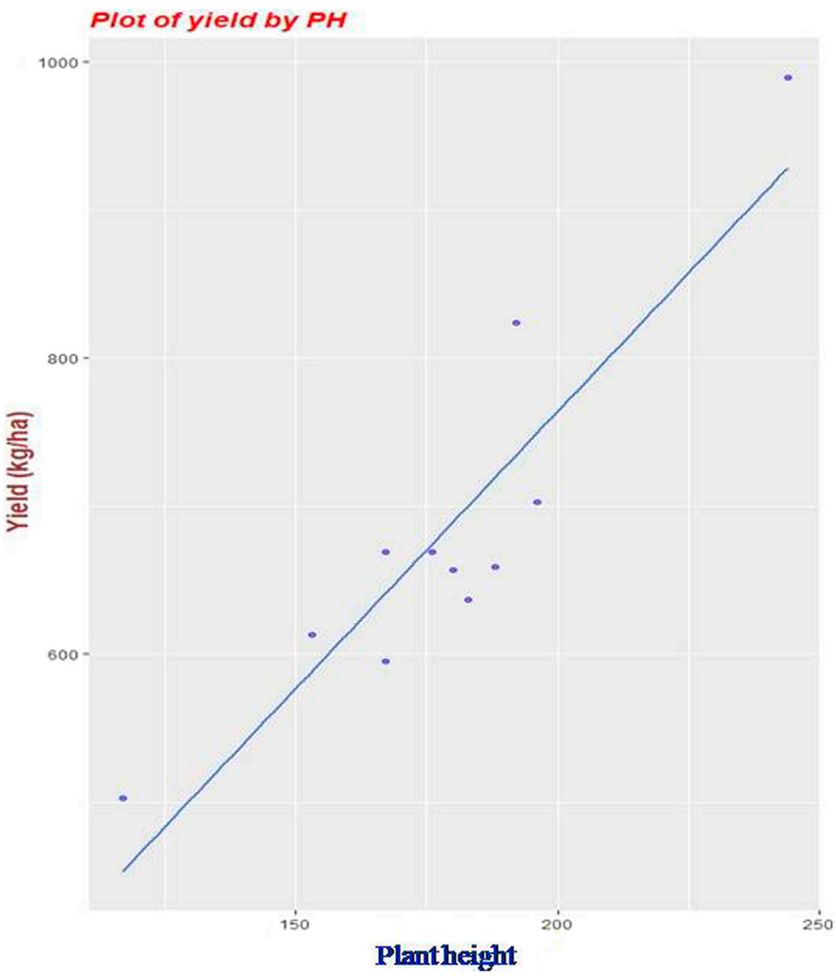

FIGURE 3
Scatter plot of sowing times and varieties on the plant height and grain yield of redgram.

influenced differences in flowering and ripening days, plant height, and seed yield. For instance, they noted that the yield of cultivar UPAS 120 was higher (969 kg ha^{-1}) among the three categories tested. Similarly, Kuri et al. (2018), Chawhan et al. (2019), and Rani and Reddy (2010) observed varietal differences contributing to yield variance in redgram in their investigations. Singh (2000) also highlighted the influence of environmental factors on the source-sink relationship and its impact on redgram seed yield.

Early-maturing or short-duration cultivars tend to be small in stature due to their short vegetative growth period, while late-maturing or long-duration cultivars are typically taller owing to their extended vegetative phase, as noted by Anil et al. (2023). In both years of the study, primary branches/plants were greater in extended-duration redgram cultivars (Reddy, 1990). The interaction between grain yield and plant height was found to be significant in both research years, consistent with reports by several researchers (Mligo and Craufurd, 2005; Reddy et al., 2006; Singh, 2006; Egbe and Vange, 2008) indicating genetic variation in growth and yield.

Among the various factors influencing redgram production, sowing time is considered a crucial non-monetary input. Cultivar choice and planting time are the two most critical elements in redgram production. Sowing a high-yielding cultivar at the proper time is a key strategy for optimizing production input consumption and achieving the best yield. Based on our research, it was concluded that the best time to sow redgram cultivar CO6 is 15 to 30thof June for a long-duration crop and in 15 to 30thof September for the short-duration cultivar VBN (Rg) 3. Although CO6 achieved a higher yield, VBN (Rg) 3 (V_3) matured 58 days earlier than CO6. Hence, the sowing of redgram cultivar VBN (Rg) 3 during 15 to 30thof September is suitable for the southern zone of Tamil Nadu.

4.3 Weed growth

The slow initial growth of redgram encourages rapid weed growth, resulting in intense competition that ultimately reduces crop yield (Channappagoudar and Birdar, 2007). Early sown led to stronger crop growth and canopy, which controlled weeds better than late planting. This early sowing also boosted crop vitality and faced less weed competition, resulting in higher productivity (Malik and Yadav, 2014). Lateral expansion of the canopy resulted in reduced weed density and dry weight, consequently boosting chickpea grain yield (Dhiman, 2007). Leaves shaded deeper within the canopy receive diminished levels of photosynthetically

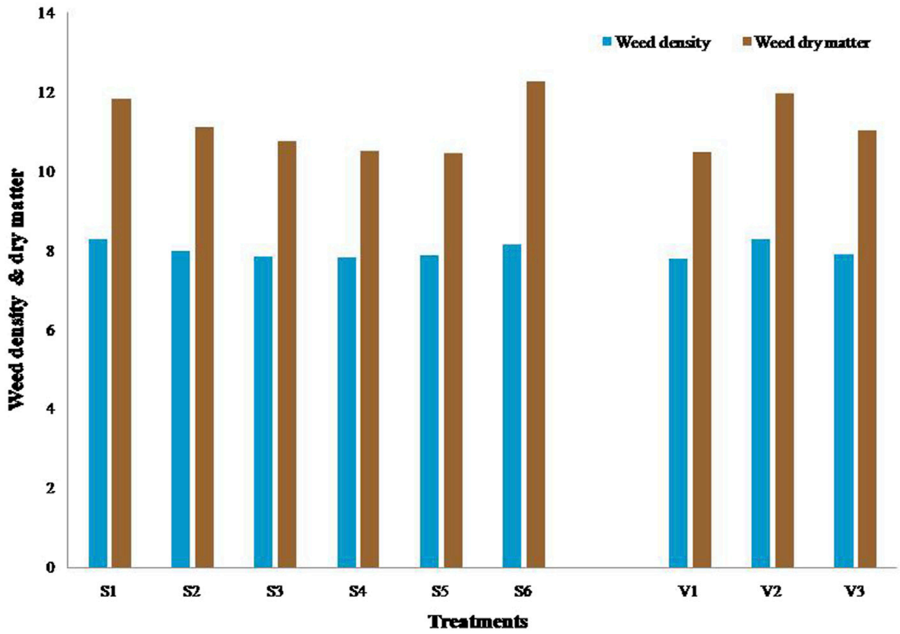

FIGURE 4
Effect of sowing times and redgram varieties on weed density and weed dry matter on 30 DAS.

active radiation and a lower ratio of red to far-red light leads to poor weed growth (Olabode et al., 2007; Rajesh and PaulPandi, 2015). The growth and yield of pulse crops are directly influenced by the sowing date. Sowing at the wrong time in the season can have several negative effects. If sowing occurs either too early or too late, it can result in reduced seed germination and poor growth. Additionally, there may be fewer branches and a smaller crop canopy, allowing more light to penetrate the ground. This increased light can lead to higher weed seed germination, further reducing crop yield. Early sowing may expose young seedlings to frost damage, whereas late sowing could expose plants to heat stress during important growth phases, both of which can significantly impact overall crop productivity. Earlier sowing resulted in significantly lower weed populations and reduced weed dry weight compared to delayed sowing. This is likely due to more favourable environmental and weather conditions that promoted optimal germination and early establishment of plants, leading to a denser canopy that effectively suppressed weeds. This enhanced weed control allowed crops to utilize natural resources more efficiently, with reduced light transmission at the surface inhibiting weed seed germination and growth (Chaudhary et al., 2023). The timing of pea sowing significantly impacts their growth, flowering, and fruiting, ultimately affecting yield per hectare. Optimal sowing dates vary based on local climatic conditions and the specific pea cultivar (Kaur et al., 2024). Pulses sown earlier may undergo a longer vegetative phase, allowing for more branch development. Conversely, late sowing may result in shorter vegetative phases, limiting branch formation (Doraiswamy and Singh, 2001). This is probably because plants sown early benefit from an extended growing season and more favourable temperature and light conditions, which promote pod development. Conversely, late sowing may expose plants to higher temperatures and during critical pod development stages, resulting in shorter pods (Al-Asadi and Kopytko, 2019).

4.4 Yield

The key to maximizing redgram production lies in selecting the right cultivar and sowing it at the optimal time. By choosing a high-yielding cultivar and planting it at the correct time, farmers can effectively utilize production inputs and achieve the highest possible yield (Anil et al., 2023). The combination of sowing time and cultivar significantly influenced redgram seed yield. Commencing from the second half of July, a combination of favourable growth conditions and yield traits contributed to an increase in seed production. Early sowing establishes conditions conducive to robust growth and development, facilitating the formation of larger leaf areas and increased biomass accumulation, ultimately leading to higher seed yield. These outcomes could be attributed to variations in precipitation and temperature over the 2-year period. (Figure 1). The sowing dates and cultivar selections in modern farming reflect the gradual adaptation and fine-tuning of cropping systems to suit local conditions and respond to incremental changes in climate (Minoli et al., 2022).

The decrease in grain yield observed when sowing *kharif* mungbean later, from July 5 to August 5, as reported by Singh et al. (2010), may be attributed to various factors including the genetic makeup of the cultivar, favourable meteorological conditions, and physiological processes could be the highest translocation of photosynthates toward seed development in redgram. The earlier sowing allowed for optimal growth parameters and yield-enhancing characteristics such as increased pod count, facilitated by ideal meteorological conditions including temperature, light, and precipitation, which promoted better growth.

(Sandeep et al., 2022). Moreover, early sowing provides the crop with sufficient time and favourable weather conditions—adequate light, warmth, and developmental cues—for optimal growth, development, and maturation stages. These findings are consistent with those of Fukugawa and Zhenga (1999), who observed significant increases in blooms following vegetative growth in early-planted crops.

In contrast, late sowing of redgram can impact seed germination and yield due to decreased temperatures during the reproductive and maturity periods, along with increased soil moisture (Dhanoji and Patil, 2011; Kumar et al., 2008). Similarly, when redgram is sown later, it often results in shorter plants, longer flowering and maturity periods, and lower yields compared to earlier sowing conditions (Kuri et al., 2018; Kittur and Guggari, 2017; Chawhan et al., 2019). The study findings align with previous research by Kithan et al. (2020) and Kumar et al. (2008), which demonstrated superior production and growth characteristics with the 15 to 30th of September sowing.

The reduction in yield associated with later sowing dates can be attributed to shortened timeframes for flowering, maturity, and dry matter production, as evidenced by Arunkumar and Meena (2018). Interactions between environmental factors and morphological or physiological characteristics throughout the pre- and post-flowering phases contribute to variations in grain legume production. Notably, crops sown in the second and third weeks of July exhibited increased main and subsidiary branches, resulting in higher pod production per plant and overall seed yield. Conversely, delayed seeding led to earlier flowering, reduced vegetative growth, and premature maturity, all of which negatively impacted seed production. These observations align with the findings of Nene and Sheila (1990) and Reddy et al. (2015), indicating that delays in redgram sowing result in reduced branching per plant and lower dry weight at harvest compared to timely sowing (Kumar et al., 2023).

5 Conclusion

The inherent challenges faced in pulse production, particularly the impact of climate variability resulting from shifting rainfall patterns, necessitates adaptive techniques to ensure sustainable productivity. With this background, field experiments were conducted at the National Pulses Research Centre, Vamban, Pudukkottai, Tamil Nadu, South India, during the *kharif* seasons of 2017–18 and 2018–19, focused on optimizing sowing times and identifying suitable redgram cultivars, especially in the face of delayed monsoons in Tamil Nadu. The exploration of six distinct sowing dates alongside three redgram cultivars resulted in a clear correlation between varied sowing times and redgram's growth characteristics and yield. Results showed that the crop sown in 15 to 30th of June showcased remarkable success, with higher plant growth and yield attributes and also a profitable B:C ratio. This sowing period exhibited comparable success to later sowing dates, highlighting its viability even amidst challenging conditions. Among the redgram cultivars, CO 6 emerged as the most productive among the redgram cultivars, attributed to its prolonged phenological phases and extended days to reach critical growth stages, leading to amplified yields compared to other cultivars. However, the shorter duration redgram cultivar, VBN (Rg) 3, despite its lower yield compared to CO 6, matured significantly faster, within 129 days, offering an advantage for crop sequencing and enhancing overall cropping intensity of the farm and also sustain the profitability in harsh climate situations such as drought and erratic rainfall. The research outcome suggests the need for strategic crop cultivar selection and timely sowing practices to mitigate the impact of adverse environmental conditions in changing climatic scenario, ultimately ensuring sustained redgram productivity in rainfed agricultural systems.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

SMM: Conceptualization, Formal Analysis, Investigation, Methodology, Supervision, Resources, Validation, Visualization, Writing–review and editing, Writing–original draft. VB: Funding acquisition, Resources, Writing–review and editing. AD: Investigation, Validation, Visualization, Conceptualization, Formal Analysis, Methodology, Supervision, Writing–review and editing. SM: Funding acquisition, Visualization, Resources, Writing–review and editing. US: Funding acquisition, Visualization, Conceptualization, Formal Analysis, Investigation, Methodology, Supervision, Resources, Writing–review and editing, Writing–original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Al-Asadi, M. S., and Kopytko, P. (2019). Effect of row spacing and planting density on yield and yield components of pea (*Pisum sativum* L.). *J. Environ. Biol.* 40 (4), 821–826.

Anil, P., Sarita, M., and Dangi, S. R. (2023). Effect of sowing date and variety on pigeonpea production in Nepal. *Asian J. Res. Crop Sci.* 8 (3), 173–178. doi:10.9734/ajrcs/2023/v8i3177

Aruna, E., and Sunil Kumar, K. (2023). Influence of sowing time on varied duration redgram genotypes in YSR kadapa district. *Int. J. Plant Soil Sci.* 35 (18), 1983–1988. doi:10.9734/ijpss/2023/v35i183483

Arunkumar, M. M., Dhanoji., and Meena, M. K. (2018). Phenology and productive performance of pigeon pea as influenced by date of sowing. *J. Pharmacogn. Phytochemistry* 7 (5), 266–268.

Channabasavanna, A. S., Kitturmath, M. S., and Rajakumar, H. (2015). Standardization of sowing date and genotypes of pigeonpea [*Cajanus cajan* (L.) Mill sp.] under erratic rainfall conditions in northern dry zone of Karnataka. *Karnataka J. Agric. Sci.* 28 (4), 604–605.

Channappagoudar, B. B., and Birdar, N. R. (2007). Physiological approaches in weed management in soybean and redgram (4:2 rp) intercropping system. *Karnataka J. Agric. Sci.* 20, 241–244.

Chaudhary, A., Venkatramanan, V., Kumar Mishra, A., and Sharma, S. (2023). Agronomic and environmental determinants of direct seeded rice in South Asia. *Circ. Econ. Sustain.* 3, 253–290. doi:10.1007/s43615-022-00173-x

Chawhan, R. G., Chahande, R. V., and Deshmukh, H. S. (2019). Effect of sowing date on seed quality of pigeonpea [*Cajanus cajan*(L.) Mill sp.]. *Pharma Innovation J.* 8 (7), 784–789.

Dahariya, L., Chandrakar, D. K., and Chandrakar, M. (2018). Effect of dates of planting on the growth characters and seed yield of transplanted pigeonpea (*Cajanus cajan*L. Mill Sp.). *Int. J. Chem. Stud.* 6 (1), 2154–2157.

Dhanoji, M. M., and Patil, J. R. (2011). Effect of date of sowing on potential source and sink realization in pigeon pea. *Environ. Ecol.* 29 (3), 1003–1005.

Dhiman, M. (2007). Techniques of weed management in chickpea. *Agric. Rev.* 28 (1), 34–41.

Doraiswamy, P. C., and Singh, N. P. (2001). Effects of sowing dates on growth, yield and quality of early maturing cultivars of pea (*Pisum sativum* L.) under semi-arid conditions. *Indian J. Agrl. Sci.* 71 (3), 210–212.

Egbe, O. M., and Vange, T. (2008). Yield and agronomic characteristics of 30 pigeonpea genotypes at Otobi in Southern Guinea Savanna of Nigeria. *Life Sci. J.* 5, 70–80.

Fischer, T., Byerlee, D., and Edmeades, G. (2014). Crop yields and global food security. *ACIAR Canberra*, 8–11.

Fukugawa, Y., and Zhenga, S. U. H. (1999). Growth response to sowing dates of pigeonpea in northern kyusha of Japan. *Jpn. J. Crop Sci.* 68, 33–38.

Gaikwad, S. V., Mahude, S. V., and Jadhav, S. S. (2023). Effect of dates of sowing on Pigeon pea varieties under varied weather conditions. *Pharma Innovation J.* 12 (12), 320–322.

Grigorieva, E., Livenets, A., and Stelmakh, E. (2023). Adaptation of agriculture to climate change: a scoping review. *Climate* 11, 202. doi:10.3390/cli11100202

Islam, S., Nanda, M. K., and Mukherjee, A. K. (2008). Effect of date of sowing and spacing on growth and yield of *rabi* pigeon pea (*Cajanus cajan*(L.) Millsp.). *J. Crop Weed* 4 (1), 7–9.

Kaur, R., Kondal, P., Singh, N., Maurya, V., Sharma., A., and Kumar, R. (2024). Effect of spacing and sowing dates on growth, yield and quality of pea (*Pisum sativum* L.). *Int. J. Res. Agron.* 7 (2), 238–251. doi:10.33545/2618060X.2024.v7.i2d.312

Kithan, L., Sharma, M. B., and Longchar, A. (2020). Efrformance of promising pigeonpea genotypes under NEHZ. *Int. J. Econ. Plants* 7, 6–8.

Kittur, C. N., and Guggari, A. K. (2017). Effect of sowing time and planting geometry on the growth and yield of pigeonpea in Northeren Dry Zone (Zone 3) of Karnataka. *J. Farm Sci.*, 334–337.

Krsti, ´C. M., Mladenov, V., Banjac, B., Babec, B., Dunđerski, D., C´ uk, N., et al. (2023). Can modification of sowing date and genotype selection reduce the impact of climate change on sunflower seed production? *Agriculture* 13, 2149. doi:10.3390/agriculture13112149

Kumar, N., Gopinath, K. A., Srivastva, A. K., and Mahajan, V. (2008). Performance of pigeonpea (*Cajanus cajan*L. Millsp.) at different sowing dates in the mid-hills of Indian Himalaya. *Archives Agron. Soil Sci.* 54, 507–514. doi:10.1080/03650340802287018

Kumar, R., Niwas, R., Khichar, M. L., and Leharwan, M. (2023). Assessment of sowing time and cultivars on growth, development and yield parameters of pigeonpea. *Legume Res.* 46 (5), 604–608. doi:10.18805/LR-4380

Kundu, P. K., Roy, T. S., Khan, S. H., Parvin, K. ., and Mazed, H. E. M. K. (2016). Effect of sowing date on yield and seed quality of soybean. *J.Agric. Ecol. Res. Int.* 9, 1–7. doi:10.9734/jaeri/2016/29301

Kuri, S., Shivaramu, H. S., Thimmegowda, M. N., Yogananda, S. B., Prakash, S. S., and Murukannappa, S. M. (2018). Effect of row spacing, varieties and sowing dates on growth and yield of pigeonpea. *Int. J. Cur. Microbio. App. Sci.* 7 (8), 1125–1128. doi:10.20546/ijcmas.2018.708.127

Malik, R. S., and Yadav, A. (2014). Effect of sowing time and weed management on performance of pigeonpea. *Indian J. Weed Sci.* 46 (2), 132–134.

Mallikarjuna, B. O., and Devaraja, T. N. (2023). Frontline demonstration A tool to study drought tolerant and high yielding red gram variety for davanagere district, India. *Int. J. Curr. Microbiol. App. Sci.* 12 (08), 100–105. doi:10.20546/ijcmas.2023.1208.012

Minoli, S., Jägermeyr, J., Asseng, S., Urfels, A., and Müller, C. (2022). Global crop yields can be lifted by timely adaptation of growing periods to climate change. *Nat. Commun.* 13, 7079. doi:10.1038/s41467-022-34411-5

Mligo, J. K., and Craufurd, P. Q. (2005). Adaptation and yield of pigeonpea in different environments in Tanzania. *Field Crops Res.* 94, 43–53. doi:10.1016/j.fcr.2004.11.009

Nene, Y. L., and Sheila, V. K. (1990). "Pigeonpea: geography and importance," in *The pigeonpea*. Editors Y. L. Nene, S. H. Hall, and V. K. Sheila (Wellingford, U.K: CAB International), 1–14.

Olabode, O. S., Ogunyemi, S., and Adesina, G. O. (2007). Response of okra (*Abelmoschus esculentus* (L.)Moench.) to weed control by mulching. *Food Agric. Environ.* 5 (3-4), 324–326.

Padhi, A. K. (1995). Effect of sowing date and planting geometry on yield of redgram (*Cajanus cajan*) genotypes. *Indian J. Agron.* 40 (1), 72–76.

Patel, H. P., Gurjar, R., Patel, K. V., and Patel, N. K. (2019). Impact of sowing periods on incidence of insect pest complex in Pigeon pea. *J. Entomology Zoology Stud.* 7 (2), 1363–1370.

Patel, N. R., Mehta, A. N., and Shekh, A. M. (2000). Radiation absorption, growth and yield of pigeon pea cultivars as influenced by sowing dates. *Exp. Agric.* 36, 291–301. doi:10.1017/s001447970000301x

Pawar, G. R., Gokhale, D. N., and Mirza, I. A. B. (2020). Performance of different sowing dates and cropping systems on yield attributes and yield of pigeonpea (*Cajanus cajan*L.) under rainfed condition. *Int. J. Curr. Microbiol. App. Sci.* 11, 63–73.

Rajesh, N., PaulPandi, V. K., and Duraisingh, R. (2015). Enhancing the growth and yield of pigeon pea through growth promoters and organic mulching- A review. *Afr. J. Agric. Res.* 10 (12), 1359–1366. doi:10.5897/ajar2014.8736

Ram, H., Singh, G., Sekhon, H. S., and Khanna, V. (2011). Effect of sowing time on the performance of pigeonpea genotypes. *J. Food Legumes* 24, 207–210.

Rani, B. P., and Reddy, R. D. (2010). Performance of pigeonpea in sole and intercropping system in vertisols of Krishna - godavari zone in Andhra Pradesh. *Indian J. Agric. Res.* 44 (3), 225–228.

Ravi, D., Patil, B. L., Manjunatha, B. L., and Patil, S. L. (2022). Climate change mitigation and adaptation strategies in drylands of Northern Karnataka. *Indian J. Agric. Sci.* 92 (1), 80–84. January 2022/Article. doi:10.56093/ijas.v92i1.120844

Reddy, G. K., Reddy, P. M., Kumari, P. L., and Krishna, T. G. (2015). Response of Pigeonpea varieties to time of sowing during rabi season. *J. Agric. Veterinary Sci.* 8 (2), 12–15.

Reddy, L. J. (1990). "Pigeonpea: morphology," in *The pigeonpea*. Editors Y. L. Nene, S. D. Hall, and V. K. Sheila (Wallingford,UK: CAB International), 47–86.

Reddy, M. M., Padmaja, B., and Malathi, S. (2012). Evaluation of pigeonpea genotypes for delayed Sowing in Telangana region of Andhra Pradesh under rainfed conditions. *Indian J. Dry land Agrl. Res. Dev.* 27 (2), 59–62.

Reddy, M. M., Padmaja, B., and Rao, L. J. (2006). Agronomic management for improving productivity of pigeonpea-based intercropping system under rainfed conditions in vertisols. *Indian J. Pulses Res.* 19, 219–221.

Reed, W., Lateef, S. S., Sithananthan, S., and Pawar, C. S. (1989). *Pigeonpea and chickpea insect identification handbook international crops research institute for the semi-AridTropics (ICRISAT), patancheru, Andhra Pradesh*. India, 120.

Richards, M. F., Maphosa, L., and andPreston, A. L. (2022). Impact of sowing time on chickpea (*Cicer arietinum* L.) biomass accumulation and yield. *Agronomy* 12, 160. doi:10.3390/agronomy12010160

Richards, M. F., Preston, A. L., Napier, T., Jenkins, L., and Maphosa, L. (2020). Sowing date affects the timing and duration of key Chickpea (*Cicer arietinum* L.) growth phases. *Plants* 9, 1257. doi:10.3390/plants9101257

Sandeep, G., Vijaya Bhaskar Reddy, U., Ramesh Babu, P. V., Kavitha, P., and Srinivasa Reddy, M. (2022). Cultivar and sowing date effect on growth attributes and yield of redgram (*Cajanus cajan*L.). *Pharma Innovation J.* 11 (7), 2476–2479.

Sasane, S. (2017). "Impact of south west monsoon on crop yield: a statistical analysis," in *International interdisciplinary seminar on geographical and historical perspective of global problems, 1-10, 2017*. Kolhapur, India: Department of Geography, D.P. Bhosle College.

Sharifi, R. S., Sedghi, M., and Gholipouri, A. (2009). Effect of plant population density and yield attributes of maize hybrids. *Res. J. Biol. Sci.* 4 (4), 375–379.

Singh, G., Sekhon, H. S., Ram, H., Gill, K. K., and Sharma, P. (2010). Effect of date of sowing on nodulation, growth, thermal requirement and grain yield of kharif mungbean genotypes. *J. Food Legumes* 23, 132–134.

Singh, I. (2000). Flowering and podding behavior in determinate and indeterminate pigeonpea genotypes. *Indian J. Agrl. Res.* 34 (1), 67–70.

Singh, R. S. (2006). Performance of late duration pigeonpea varieties under delayed planting. *Indian J. Pulses Res.* 19, 255–256.

Subbulakshmi, S. (2021). Effect of sowing dates and weed control treatments on weed management and grain yield of greengram under rainfed condition. *Indian J. Weed Sci.* 53 (2), 191–194. doi:10.5958/0974-8164.2021.00036.8

Sunil Kumar, D. U., Rao, M., Pratibha, T., and Kale, P. (2020). Small and marginal farmers of Indian agriculture: prospects and extension strategies. *Indian Res. J. Ext. edu.* 20 (1).

Surendran, U., Raja, P. M. J., Rama Subramoniam, S., and Subramoniam, S. R. (2021). Use of efficient water saving techniques for production of rice in India under climate change scenario: a critical review. *J. Clean. Prod.* 309, 127272. doi:10.1016/j.jclepro.2021.127272