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RESEARCH ARTICLE

Physiological parameters dictate bearing pattern in different mango cultivars: Study from sub-tropical India

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Abstract

The bearing habit of mango has long been a subject of interest for pomologists. The difference in bearing pattern among various mango cultivars is attributed to complex physiological interaction. Despite multiple studies on mango bearing, detailed investigations in this area remain limited. This study aims to explore the interrelationship between the bearing patterns and the associated physiological changes in different mango cultivars. The physiological parameters were examined at various growth stages in Baramasi (a perennial bearer), Amrapali (a regular bearer) and Langra and Alphonso (irregular bearer) of mango (*Mangifera indica* L.). Significant variations were observed in chlorophyll content, internal carbon dioxide concentration, photosynthetic rate and flowering intensity. An increase in internal carbon dioxide concentration led to reduced carbon dioxide uptake, which impacted net photosynthesis production. A direct correlation between flowering intensity and photosynthetic rate was identified, while a nonlinear relationship between photosynthetic rate and total carbohydrate content was also noted. The study suggests that variations in the photosynthetic rate and the subsequent source-sink relationship may contribute to the differences in bearing patterns across mango cultivars. While further studies are needed for more conclusive results, this research can be valuable for pomologists, physiologists and breeders working with mango.

Keywords

mango; physiological; flowering intensity; regular; irregular; Baramasi

Introduction

Mango (*Mangifera indica* L.) is one of the most extensively cultivated fruit crops in India and belongs to the family Anacardiaceae. Mango cultivars grown in India exhibit varying bearing patterns, which are crucial for orchard productivity and economic returns. While the bearing habit of mango is largely genetic, there has been limited effort to understand the physiological factors underlying these patterns (1). Several factors, such as climatic conditions, genetic traits and orchard management practices, play a significant role in mango productivity (2-4). A key event that influences a tree's ability to bear fruit is flowering, which is a complex physiological process. A tree's capacity to produce flower buds depends on its floriferousness, or flowering ability (5). Crop yield is closely linked to the amount of assimilates produced through photosynthesis. Consequently, crop production and

carbon dioxide supply can be predicted by the photosynthetic rate of the plant (6-9).

Environmental factors and adaptation to specific habitats play a crucial role in determining the pattern and duration of developmental phases in mango. Mango undergoes various phenological stages, starting with cell division in the apical and lateral meristems (10). Typically, individual stems remain dormant, with growth occurring in distinct phases known as flushes. A flush marks the initiation of shoot growth from a group of stems connected by branching. On individual stems, vegetative growth flushes usually occur one or more times a year. In subtropical regions, these flushes take place when temperatures are around 25 °C or higher. Conversely, flushes that occur at lower temperatures (5-15 °C) often result in flowering (11). The mango inflorescence is a terminal panicle with multiple branches, which can contain anywhere from a few hundred to over 6000 flowers. The fruit of the mango, classified as a drupe, varies significantly in size and shape. The frequency of these growth flushes is influenced by the tree's size, the cultivar and other environmental factors (12).

Considering that floral induction is influenced by factors occurring much earlier at specific phenological stages, it is reasonable to hypothesize that physiological parameters during different phenological stages, particularly in the pre-flowering period, may affect the bearing patterns of mango cultivars. This study aims to enhance our understanding of how chlorophyll content, photosynthetic rate, internal carbon dioxide concentration and total carbohydrate levels play a crucial role in determining the bearing patterns of mango cultivars. The research, therefore, seeks to explore the physiological variations in mango cultivars with different bearing patterns and how these physiological and phenological differences ultimately impact yield outcomes through their influence on bearing patterns.

Materials and Methods

Experimental location and climatic conditions

The experiment was conducted in the experimental garden at Sabour, Bhagalpur, India, a permanent experimental site of Bihar Agricultural University, Sabour, during the years 2012-13 and 2013-14. The experimental location is situated at 25.2376°N latitude and 87.0507°E longitude, with an evaluation of 45.72 m above mean sea level. Sabour has a semi-arid, subtropical characterized by hot, desiccating summer and cold, frost less winters. The average annual rainfall at the site is approximately 1150 mm, with the majority of precipitation occurring between mid-June to mid-October.

Soil of the experimental plot

The soil at the experimental site was relatively level and had a silty loam texture with medium fertility. The soil properties of the experimental plot are detailed in Table 1.

Table 1. Soil properties of the experimental field.

Properties	Units	
	0-15 cm	15-30 cm
pH (1:2:5)	6.84	6.79
Electrical Conductivity	0.093	0.085
Organic Carbon (%)	0.48	0.45
Available Nitrogen (kg/ha)	190.68	182.75
Available Phosphorous (kg/ha)	26.15	24.33
Available Potassium (kg/ha)	276.80	222.79

Plants description

The study involved 4 mango cultivars, representing irregular, regular and Baramasi (all-season) types. The key characteristics of these cultivars are briefly described below:

Baramasi (All season)

This cultivar has a moderately vigorous tree with spreading branches and a dense canopy. Its most distinctive feature is its flowering behaviour, with flowers appearing 4 to 5 times a year. The fruits are medium-sized with a reddish-yellow colour.

Amrapali (Regular bearer)

A hybrid between Dashehari and Neelum, developed by the Indian Agricultural Research Institute, New Delhi, and released for commercial cultivation in 1979. Amrapali is a precocious, regular and prolific bearer with a distinctly dwarf stature, making it ideal for high-density orcharding.

Langra (Irregular bearer)

This cultivar has a moderately vigorous tree with spreading branches and a dense canopy. It exhibits irregular or biennial bearing. During the experimental period, 2012-13 was an "on" year for flowering, while 2013-14 was an "off" year.

Alphonso (Irregular bearer)

The tree is vigorous and exhibits biennial bearing. In this study, 2012-13 was an "off" year, whereas 2013-14 was an "on" year for flowering.

Physiological parameters

Chlorophylls (mg/g)

The chlorophyll content (chlorophyll a, b and total chlorophyll) was estimated following the method of Barnes (13).

Internal CO_2 concentration of leaf (ppm)

The internal CO_2 concentration of leaves at different stages, such as during flowering, post-flowering and pre-flowering was measured using a portable photosynthesis system (LI-COR LI- 6400 XT) with an IRGA (Infra-red gas analyser) chamber. Freshly matured leaves from the experimental plants were placed inside the IRGA chamber and data were recorded. This procedure was repeated 5 times for each tree between 9:00 AM and 12:00 PM.

Photosynthesis rate (μ mol/m^2/sec)

The rate of photosynthesis during the pre-flowering, flowering and post-flowering stages was measured using the same portable photosynthesis system (LI-COR LI-6400 XT)

with the IRGA chamber. Freshly matured leaves were placed inside the chamber and data collection was performed 5 times for each tree between 9:00 AM and 12:00 PM.

Total Carbohydrates (mg/g)

The total carbohydrates content in mango shoots at different stages was determined using the Anthrone method (14).

Flowering intensity (No. of flowers/Foot^2)

Flowering intensity was measured by calculating the total number of flowers per square foot of tree canopy. The total number of panicles in a square foot area and the number of flowers in each panicle were counted to determine flowering intensity using the following formula (15).

Flowering intensity = No. of flowering shoots × 100 /Total no. of shoots.

PPO (Polyphenol oxidase) activity (change in absorbance/min/g)

The polyphenol oxidase activity in mango shoots at different phenophases was measured using a modified version of the standard method (16). For enzyme extract, 2 g fresh tissue from mango shoot was ground in a pre-chilled mortar with 10 mL of ice-cold extraction medium containing 0.2 M phosphate buffer (pH 6.8), PVP and Triton. The extract was then transferred to centrifuge tubes and centrifuged at 11000 rpm for 20 min at 2 °C. The supernatant was used as the enzyme extract for PPO activity.

Substrate mixture

Two cuvettes were prepared, each containing 2.5 mL of 0.1 M phosphate buffer (pH 6.5) and 0.3 mL of 0.01 M catechol solution. The cuvettes were placed in a spectrophotometer and zeroed. The first cuvette was removed and 0.2 mL of enzyme extract was added. The cuvette was placed back in the spectrophotometer and absorbance was recorded at 495 nm over a 5 min period, at 30 sec intervals.

Statistical analysis

The experimental data were statistically analysed using Duncan's Multiple Range Test (DMRT) (17). Four cultivars were selected as treatments and each treatment was replicated 5 times.

Results

Chlorophyll content

During the flowering, pre-flowering and post-flowering stages, the highest levels of total chlorophyll, chlorophyll 'a' and chlorophyll 'b' were observed in the leaves of the Baramasi cultivar, while the lowest levels were recorded in Alphonso (Fig. 1). The range of total chlorophyll, chlorophyll 'a' and chlorophyll 'b' content across all phenological stages was as follows: in Baramasi, 2.17 to 2.75 mg/g, 0.69 to 1.069 mg/g and 2.95 to 4.04 mg/g respectively; in Langra, 1.90 to 2.34 mg/g, 0.58 to 0.72 mg/g and 2.49 to 3.00 mg/g; in Amrapali, 2.05 to 2.59 mg/g, 0.61 to 0.95 mg/g and 2.71 to 3.73 mg/g and in Alphonso, 1.69 to 2.10 mg/g, 0.44 to 0.53 mg/g and 2.08 to 2.48 mg/g, during the years 2012-2013 and 2013-2014 respectively.

Internal carbon dioxide concentration

The maximum internal CO_2 concentration in leaves during both experimental years (2012-2013 and 2013-2014) at the pre-flowering stage was recorded at 250.97 ppm and 208.10 ppm respectively, in the Baramasi cultivar. This was followed by Alphonso with 248.00 ppm and 204.85 ppm respectively and Amrapali with 244.67 ppm and 203.00 ppm respectively. The minimum value was observed in Langra, with concentrations of 222.81 ppm and 195.21 ppm respectively (Table 2). During the flowering stage, a similar pattern emerged, with higher internal CO_2 concentrations found in the Baramasi cultivar at 255.45 ppm and 250.95 ppm in 2012-2013 and 2013-2014 respectively. This was followed by Alphonso at 243.46 ppm and 242.70 ppm and

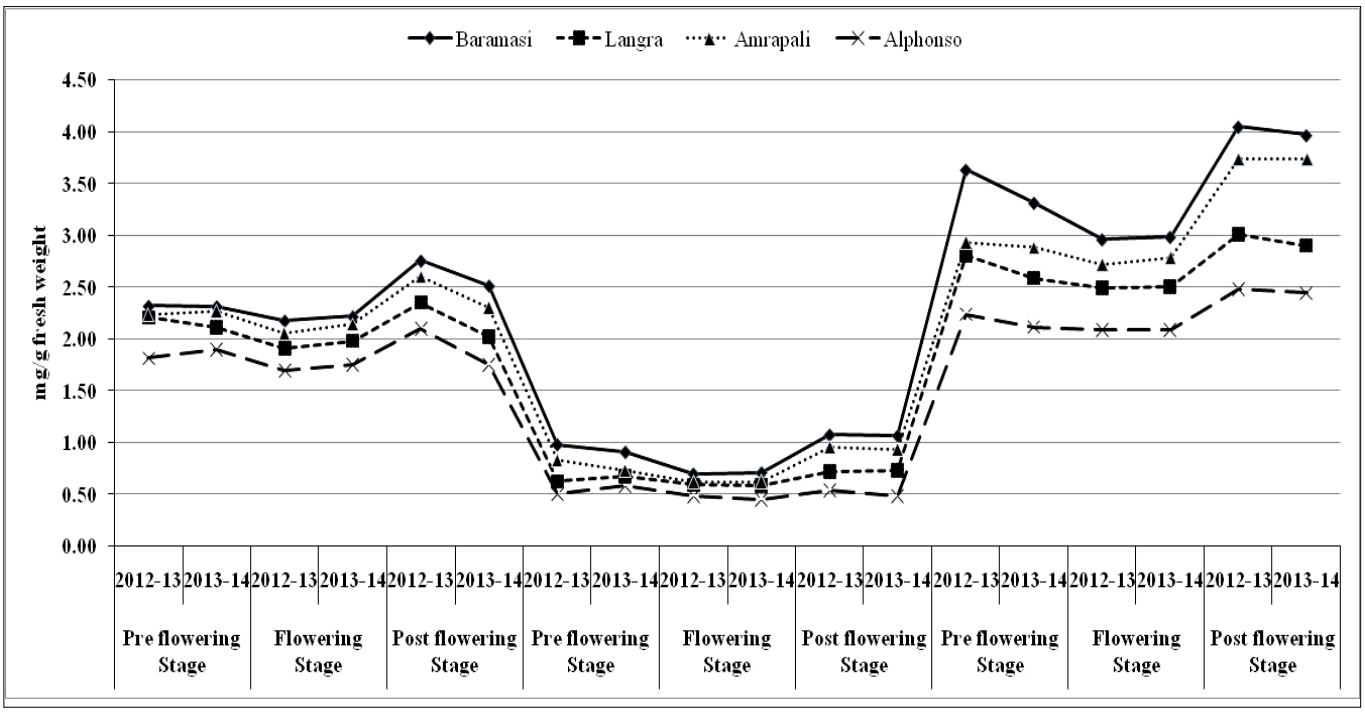

Fig. 1. Cholorophyll-a, b and total chlorophyll during different growth stages of *Baramasi*, regular and irregular bearing mango.

Table 2. Internal CO_2 concentration (ppm) in leaf of *Baramasi*, regular and biennial bearing mango during different stages.

Cultivars	Pre flowering stage		Flowering stage		Post flowering stage	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Baramasi	250.97[a]	208.10[a]	255.46[a]	250.95[a]	244.84[a]	245.50[a]
Langra	222.81[b]	195.21[a]	236.28[b]	235.49[a]	222.76[b]	224.85[b]
Amrapali	244.68[a]	203.00[a]	248.22[ab]	245.59[a]	234.51[ab]	234.51[ab]
Alphonso	248.00[a]	204.86[a]	243.46[ab]	242.70[a]	243.09[a]	240.17[ab]

Amrapali at 248.22 ppm and 245.59 ppm. Lower values were recorded in Langra, with concentrations of 236.28 ppm and 235.49 ppm respectively. After the flowering stage, the internal CO_2 concentration in leaves decreased, with values observed in both experimental years being 244.84 ppm and 245.50 ppm for Baramasi, 240.17 ppm and 243.09 ppm for Alphonso, 234.51 ppm for Amrapali and 222.76 ppm and 224.85 ppm for Langra.

Photosynthetic rate

At the post-flowering stage, the irregular-bearing cultivar Langra exhibited a significantly higher photosynthetic rate of 13.61 µ mol/m^2/sec, followed by the regular-bearing cultivar Amrapali at 10.15 µ mol/m^2/sec and the other irregular-bearing cultivar Alphonso at 8.28 µ mol/m^2/sec. The lowest rate was recorded in Baramasi at 6.55 µ mol/m^2/sec during the first experimental year (2012-2013) (Table 3). In the subsequent experimental year (2013-2014), the rate of photosynthesis decreased slightly compared to the previous year, yet the same pattern was observed. A similar trend was noted at the pre-flowering stage, where the highest photosynthetic rate was recorded in the irregular-bearing cultivar Langra at 13.09 µ mol/m^2/sec, followed by regular-bearing Amrapali at 9.49 µ mol/m^2/sec and Alphonso at 7.41 µ mol/m^2/sec, with Baramasi again showing the lowest rate at 6.47 µ mol/m^2/sec during the first experimental year (2012-2013). This pattern persisted in the following year. At the flowering stage, the irregular-bearing cultivar Langra also had the highest photosynthetic rate of 12.52 µ mol/m^2/sec, followed by regular-bearing Amrapali at 9.21 µ mol/m^2/sec and Alphonso at 7.07 µ mol/m^2/sec, while Baramasi recorded the lowest rate at 6.19 µ mol/m^2/sec during the first experimental year (2012-2013), with a similar trend noted in the subsequent year. The rate of photosynthesis reflects the rate at which the source produces food materials, which are later mobilized to the sink, ultimately influencing the plant's yield capacity.

Total Carbohydrate

The carbohydrate levels at the flowering stage were significantly highest in the Baramasi cultivar, with values of 89.96 mg/g and 88.60 mg/g during 2012-2013 and 2013-2014 respectively. This was followed by the regular-bearing cultivar Amrapali, which recorded 72.87 mg/g and 71.23 mg/g during the same years. In contrast, the biennial -bearing cultivar Alphonso showed the lowest carbohydrate levels at 40.70 mg/g and 43.44 mg/g during 2012-2013 and 2013-2014 respectively, followed by Langra at 58.89 mg/g and 53.87 mg/g during the same periods (Table 4). A similar trend was observed at the pre-flowering stage, where the highest carbohydrate levels were again found in Baramasi, at 89.87 mg/g and 88.64 mg/g for 2012-2013 and 2013-2014 respectively. Amrapali followed with 67.39 mg/g and 67.31 mg/g during the same years, while Alphonso recorded the lowest levels at 38.82 mg/g and 40.99 mg/g, followed by Langra with 56.52 mg/g and 51.82 mg/g for 2012-2013 and 2013-2014 respectively. Likewise, at the post-flowering stage, Baramasi again had the highest carbohydrate levels at 89.83 mg/g and 87.05 mg/g during 2012-2013 and 2013-2014 respectively. Amrapali followed with 65.31 mg/g and 66.78 mg/g in those years. Conversely, Alphonso exhibited the lowest carbohydrate content at 37.60 mg/g and 40.26 mg/g for the same periods, with Langra recording 55.70 mg/g and 51.21 mg/g respectively. Total carbohydrate content is a function of photosynthesis; however, the final yield is determined by how carbohydrates are partitioned toward the sink.

Table 3. Photosynthetic rate (µ mol/m^2/sec) of *Baramasi*, regular and biennial bearing mango during different stages.

Cultivars	Pre flowering stage		Flowering stage		Post flowering stage	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Baramasi	6.47[d]	5.86[d]	6.19[c]	5.78[d]	6.55[d]	5.90[d]
Langra	13.09[a]	10.37[a]	12.52[a]	10.07[a]	13.61[a]	10.61[a]
Amrapali	9.49[b]	8.90[b]	9.21[b]	8.29[b]	10.15[b]	9.10[b]
Alphonso	7.41[c]	7.40[c]	7.07[c]	7.22c	8.28[c]	7.52[c]

Table 4. Total carbohydrate (mg/g) in shoots of *Baramasi*, regular and biennial bearing mango during different stages.

Cultivars	Pre flowering stage		Flowering stage		Post flowering stage	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Baramasi	89.87[a]	88.64[a]	89.96[a]	88.60[a]	89.83[a]	87.05[a]
Langra	56.52[c]	51.82[c]	58.89[c]	53.87[c]	55.70[c]	51.21[c]
Amrapali	67.39[b]	67.31[b]	72.87[b]	71.23[b]	65.31[b]	66.78[b]
Alphonso	38.82[d]	40.99[d]	40.70[d]	43.44[d]	37.60[d]	40.26[d]

Flowering intensity (No. of flowers/Foot²)

A review of the data reveals a significant difference in flowering intensity among all 4 cultivars (Table 5). The highest flowering intensity was observed in Langra, with 4448 flowers/ft² and 4143 flowers/ft² during both experimental years. This was statistically comparable to Amrapali, which recorded 4196 flowers/ft² and 3926 flowers/ft² respectively. In contrast, the lowest flowering intensity was noted in Baramasi, with 2006.4 flowers/ft² and 3235.6 flowers/ft², followed by Alphonso with 2891.4 flowers/ft² and 3621.2 flowers/ft² during the same years. Flowering intensity is a valuable parameter, as it may reflect the fruit-bearing capacity of the plants.

Table 5. Flowering intensity in different mango cultivars.

Cultivars	Flowering intensity (*No. of flowers/Foot²*)	
	2013	2014
Baramasi	2006.40^{c}	3235.60^{b}
Amrapali	4196.00^{a}	3926.60^{a}
Langra	4448.00^{a}	4143.00^{a}
Alphonso	2891.40^{b}	3621.20^{ab}

PPO (Polyphenol oxidase) activity (change in absorbance/min/g)

Higher polyphenol oxidase (PPO) activity was observed during the pre-flowering stage, followed by the flowering stage. Although there was not much difference between the flowering stage and the post-flowering stage, PPO activity was slightly higher during the flowering stage than in the post-flowering stage (Table 6). In the first experimental year, the highest PPO activity was recorded at the pre-flowering stage in the biennial bearing cultivar Langra, with a change in absorbance of 2.10 min/g, followed by another biennial bearer, Alphonso, at 1.49 min/g. The regular bearer Amrapali (1.16 min/g) and Baramasi (1.44 min/g) exhibited the lowest activity. This trend was consistently observed during the flowering stage, post-flowering stage and the second experimental year as well.

Table 6. Polyphenol oxidase (change in absorbance/min/g) activity of *Baramasi*, regular and biennial bearing mango during different stages.

Cultivars	Pre flowering stage		Flowering stage		Post flowering stage	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Baramasi	1.44^{b}	1.44^{b}	1.30^{b}	1.33^{b}	1.29^{b}	1.32^{b}
Langra	2.10^{a}	2.12^{a}	1.96^{a}	2.00^{a}	1.93^{a}	1.95^{a}
Amrapali	1.16^{c}	1.17^{c}	1.01^{c}	1.05^{c}	0.99^{c}	0.99^{d}
Alphonso	1.49^{b}	1.47^{b}	1.34^{b}	1.32^{b}	1.32^{b}	1.30^{b}

Discussion

Chlorophyll content was analyzed at 3 different stages: pre-flowering, flowering and post-flowering. The observations indicated that Baramasi experienced the highest chlorophyll losses, while the other cultivars demonstrated stability in chlorophyll content at various stages. The regular-bearing cultivar exhibited higher chlorophyll content at all stages compared to the alternate-bearing cultivars. Internal carbon dioxide concentration followed the order: Baramasi > Alphonso > Amrapali > Langra, whereas the photosynthesis rate followed the order: Langra > Amrapali > Alphonso > Baramasi. An inverse relationship was observed between internal carbon dioxide concentration and the photosynthesis rate. This inverse relationship arises from the lower entry of carbon dioxide into the leaves in plants with higher internal carbon dioxide concentrations (18, 19). Consequently, this reduced carbon dioxide entry into the leaves resulted in diminished photosynthesis (20). Since carbon dioxide is the initial component in the photosynthetic process, it significantly influences photosynthetic outcomes and overall yield.

The flowering stage exhibited the highest concentration of carbohydrates, followed by the pre-flowering and post-flowering stages in all cultivars, except for Baramasi, where carbohydrate content remained nearly consistent across all stages, differing only slightly. The maximum carbohydrate content was significantly observed in the cultivar Baramasi, followed by the regular-bearing cultivar Amrapali. In contrast, the minimum carbohydrate content was found in the biennial-bearing cultivars Alphonso and Langra during all growth stages. This may be attributed to increased enzyme activity that breaks down carbohydrates as well as the mobilization of metabolites from the leaves to the developing and differentiating sink organs associated with these stages (21, 22). However, total carbohydrate content did not show a clear correlation with the photosynthetic rate. PPO activity was slightly higher during the flowering stage compared to the post-flowering period, although there was not much difference between the 2 phases. The biennial-bearing cultivar Langra exhibited higher polyphenol oxidase activity, while the regular-bearing cultivar Amrapali showed the lowest. In general, regular-bearing cultivars had lower PPO activity than biennial bearers; consequently, the higher enzyme activity in alternate bearers promotes vegetative growth and inhibits flowering during the mango "off" year. Low catecholase and cresolase (PPO) activity in regular bearers may be due to the dilution of polyphenols during the "on" year and vice versa (23). A closer examination of the data suggests a direct relationship between photosynthetic rate and flowering intensity. This observation might explain the lack of a direct relationship between photosynthetic rate and total carbohydrate content, as a significant portion of photosynthate may be utilized for flowering in a plant (24, 25). Ultimately, the yield outcome depends on the source-sink photosynthetic partitioning. The portion of net photosynthetic products diverted toward the sink contributes to the final yield of a particular variety. This process is influenced by various factors, including environmental, physiological and genetic factors.

Conclusion

Mango bearing patterns are crucial parameters that influence orchard productivity and hold significant economic importance. The study of physiological parameters indicates a significant relationship between the rate of photosynthesis and flowering intensity. The photosynthetic rate was affected by chlorophyll content and internal carbon dioxide concentration, with an inverse relationship observed between internal carbon dioxide concentration and the photosynthetic rate. However, an increase in the photosynthetic rate did not correspond to an increase in carbohydrate content, likely due to significant variations in the source-sink relationship, which could have driven the observed differences in flowering intensity among the various cultivars. Given the complexity and interplay of different physiological parameters, further studies are needed to understand plant bearing patterns, particularly in crops like mango, where considerable inter-cultivar variations exist. The research also underscores the necessity for more studies on physiological, phenological and genetic interactions to enhance fruit yield in plants like mango, where the final yield is the result of complex interactions among these factors.

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Authors' contributions

DKT carried out the experiment, generated the data and drafted the manuscript. VBP conceptualized the experiment and edited the manuscript. KB conceptualized the experiment and edited the manuscript. RBV conceptualized the experiment and edited manuscript. SNS participated in the design of the study and performed the statistical analysis. BBM participated in the design of the study and assisted in soil data. AKP edited the manuscript. All authors read and approved the final manuscript and coordination.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None.

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