



RESEARCH ARTICLE

Seasonal nutrition dynamics of eri silkworm: A comparative study of eco-races on different host plants

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Abstract

Nutritional efficiency plays a crucial role in determining the growth and productivity of eri silkworms (*Samia ricini* Donovan). The performance of different eco-races largely depends on host plant quality and seasonal conditions, which influence feeding behaviour and nutrient utilisation. The present study was conducted during 2018–19 at the Department of Sericulture, Assam Agricultural University, Jorhat, to evaluate the nutritional parameters of two commercial eco-races, Borduar and Kokrajhar, reared on castor (*Ricinus communis* L.) and borpat (*Ailanthus grandis* Prain) during the spring and autumn seasons. The results showed that castor leaves supported better nutritional efficiency than borpat during both seasons. The Kokrajhar eco-race recorded significantly higher food intake, with mean ingesta values of 7.48 g on castor and 10.66 g on borpat. However, Borduar eco-race exhibited superior digestion and nutrient conversion efficacy, recording higher values of growth rate for both the seasons (1.33 per day on castor), approximate digestibility (35.83 % on castor and 38.58 % on borpat), efficiency of conversion of ingested food (ECI) (23.43 % on castor and 23.18 % on borpat) and efficiency of conversion of digested food (ECD) (40.89 % on castor and 40.26 % on borpat). Seasonal variation significantly affected larval performance, with spring-reared larvae exhibiting higher ingestion (8.84 g on castor and 13.61 g on borpat) and digesta (4.65 g on castor and 6.32 g on borpat) than larvae reared during autumn. The study indicates that castor is a superior host plant for eri silkworm rearing and that the Borduar eco-race demonstrates better feed conversion efficiency. Spring rearing provides favourable conditions for improved nutritional performance and growth of eri silkworm larvae.

Keywords: Borduar; foliar quality; host plant suitability; Kokrajhar; nutritional parameters; *Samia ricini*

Introduction

Eri silk is one of the most important non-mulberry silks produced in India and holds considerable economic and cultural importance in the north-eastern region, particularly in Assam. The silk is primarily produced by the eri silkworm, *Samia ricini* Donovan, which is widely cultivated by rural households because of its low input requirements and relatively simple rearing practices. According to recent statistics, India produced approximately 38913 metric tonnes (MT) of raw silk during 2023–24, of which eri silk contributed about 7183 MT (1). In recent years, eri culture has gained increasing popularity among farmers because of the silkworm's adaptability to diverse climatic conditions and its comparatively higher resistance to diseases than other silkworm species.

In Assam, extreme climatic fluctuations affect seed cocoon quality and consistency, while in Tamil Nadu, seasonal variations have minimal impact on seed cocoon production. Records of higher average cocoon yield in Tamil Nadu (61.36 kg/100 disease free layings) and Gujarat (74.23 kg/100 DFLs) compared to Assam (42.73 kg/100 DFLs) suggest that ericulture has strong potential for expansion into non-traditional agroclimatic zones, highlighting its adaptability and scope for increased eri production across wider regions (1).

The eri silkworm is multivoltine in nature, producing five to six generations annually and can tolerate a wide range of temperature range from 20 °C to 40 °C (2). These characteristics make the eri culture a sustainable and viable livelihood activity in different agroclimatic regions. The eri silkworm is polyphagous and feeds on a wide variety of host plants. Among these, castor (*Ricinus communis* L.) is considered the most suitable and preferred food plant for commercial rearing (1). However, during periods of castor leaf scarcity, several alternative host plants are utilised, including kesseru (*Heteropanax fragrans* Seem.), tapioca (*Manihot utilissima* Pohl.), gulanch (*Plumeria acutifolia* Poir.), borkesseru (*Ailanthus excelsa* Roxb.) and borpat (*Ailanthus grandis* Prain.). These plants help sustain eri silkworm rearing in different seasons and regions where castor availability may fluctuate (3). The ability of eri silkworms to utilise multiple host plants contributes significantly to the stability and resilience of eri culture systems.

In addition to host plant diversity, genetic variability among eri silkworm populations also plays an important role in determining their adaptability and performance. Based on morphological characteristics, 26 eco-races of *S. ricini* have been identified and are presently maintained at the Central Muga Eri Research and Training Institute (CMER & TI), Lahdoigarh, Jorhat, Assam (3). Among these, ten accessions (001, 002, 003, 004, 005,

006, 011, 015, 018 and 025) have been identified as promising in terms of overall rearing performance and commercial traits (4). Such genetic diversity provides opportunities for selecting eco-races with improved feeding efficiency, adaptability to different host plants and higher silk productivity.

Nutritional physiology is a key factor influencing the growth, development and productivity of silkworms. Differences in feeding behaviour, food consumption, nutrient assimilation and conversion efficiency are commonly observed among different silkworm races and strains (5, 6). The nutrient composition of host plant leaves plays a crucial role in determining larval development, survival and cocoon quality (7–9). Adequate availability of essential nutrients such as proteins, lipids, carbohydrates, vitamins and minerals is necessary for proper metabolic activity and silk synthesis. Conversely, deficiency or imbalance of nutrients in the diet can adversely affect larval digestion, growth rate and silk production (10, 11).

Among the commonly used host plants, castor leaves are generally considered nutritionally superior because of their relatively higher crude protein and lipid content, which are essential for larval development and silk synthesis (12). Several studies have demonstrated that eri silkworms fed on castor leaves exhibit superior larval weight, cocoon weight and shell percentage, indicating better nutrient availability and utilisation (13, 14). Although borpat leaves can also sustain the growth of eri silkworms, larvae feeding on this plant may sometimes show a longer larval duration and relatively lower cocoon parameters compared with those reared on castor (15, 16). Such variations may arise from differences in nutrient composition or the presence of certain anti-nutritional factors. Furthermore, the nutritional composition of host plants can vary with season, plant accession and environmental conditions, which in turn influence larval feeding behaviour and nutrient utilisation efficiency (17, 18).

Despite the availability of studies on growth performance, economic traits and grainage characteristics of eri silkworm eco-races, information on their nutritional efficiency when reared on different host plants under varying seasonal conditions remains limited. Understanding the interaction among eco-race, host plant and seasonal environment is essential for identifying suitable combinations that can improve feeding efficiency, larval growth and overall silk productivity.

Therefore, the present study was undertaken to evaluate the nutritional efficiency of two eco-races of *S. ricini* when reared on castor and borpat (*A. grandis*) leaves during different rearing seasons. It was hypothesised that variations in host plant quality, eco-race characteristics and seasonal conditions significantly influence larval feeding behaviour, digestion efficiency and nutrient conversion, ultimately affecting the growth performance of eri silkworms.

Materials and Methods

Experimental design

The experiment was conducted in the rearing laboratory of the Department of Sericulture, Assam Agricultural University, Jorhat, Assam, India, during the spring and autumn seasons of 2018–2019.

Rearing conditions

Two commercially reared eri silkworm (*S. ricini* Donovan) eco-races, Kokrajhar and Borduar, were collected from Kokrajhar and Kamrup districts of Assam. The larvae were reared on two host plants, castor and borpat.

The experiment was laid out in a factorial completely randomised design (FCRD) with two factors: eri silkworm eco-race (Kokrajhar and Borduar) and host plant (castor and borpat). Each treatment combination was replicated four times with 100 larvae per replication. The four treatment combinations were Kokrajhar × castor, Kokrajhar × borpat, Borduar × castor and Borduar × borpat.

Larvae were reared under standard indoor conditions following recommended eri silkworm rearing practices. During the experimental period, the rearing room temperature was maintained at $25 \pm 2^\circ\text{C}$ with a relative humidity of 70–80 % under a natural photoperiod. Equal quantities of fresh leaves based on fresh weight from the respective host plants were supplied to each replication at every feeding.

Nutritional indices

For nutritional studies, a batch of 100 larvae was maintained for each eco-race–host plant combination. The initial weight of the larvae in each replication was recorded prior to feeding and subsequently at 24 hr intervals during the feeding period to determine larval growth.

Determination of food consumption

After 24 hr of feeding, the leftover leaves and faecal matter from each replication were collected separately and weighed. To estimate moisture loss from the leaves, an equal quantity of leaves from each host plant was kept in a separate tray as a blank under identical environmental conditions. The reduction in leaf weight in the blank tray represented evaporation loss.

The corrected weight of uneaten food was obtained by adding the evaporation loss to the measured leftover food weight.

Ingesta describes the mechanism by which food enters the alimentary canal. Digesta describes how complex nutrients (materials) are broken down into simpler compounds that can then be integrated into simpler compounds and metabolism. The rate of feeding (intake) in relation to the silkworm's mean weight during a specific period of time is known as the consumption index. Approximate digestibility (AD) reflects the efficiency with which silkworms assimilate nutrients from leaves and is influenced by the rate at which food passes through the gut. Growth rate represents the increase in larval biomass and reflects the efficiency with which nutrients are converted into body mass in silkworm larvae. Efficiency of conversion of ingesta (ECI) is a measure of the overall ability of the insect to utilise consumed food for growth. It depends on the digestibility of the food, its nutritional quality and the amount of nutrients ingested. The efficiency of conversion of digesta (ECD) represents the efficiency with which digested food is transformed into body tissues or biomass.

The nutritional indices were calculated by using the following formulae:

Ingesta (g)

$$I = \text{Fresh weight of leaf offered} - \text{fresh weight of leftover leaf}$$

Digesta (g)

$$D = \text{Fresh weight of leaf ingested} - \text{fresh weight of excreta}$$

Consumption index (CI)

$$CI = \frac{F}{TA}$$

Where, F = Fresh weight of food eaten (g)

T = Duration of feeding (days)

A = Mean fresh weight of larva during feeding period (g)

Growth rate (GR)

$$GR = \frac{G}{TA}$$

Where, G = Fresh weight gain of larva during feeding period (g)

T = Duration of feeding (days)

A = Mean fresh weight of larva during feeding period (g)

Approximate digestibility (AD)

$$AD = \frac{WF_1 - WF}{WF_1} \times 100$$

Where, WF_1 = Weight of food ingested (g)

WF = Weight of faeces (g)

Efficiency of conversion of ingested food to body biomass (ECI %)

$$ECI = \frac{WG}{WF_1} \times 100$$

Where, WG = Weight gain of larvae (g)

WF_1 = Weight of food ingested (g)

Efficiency of conversion of digested food to body biomass (ECD)

$$ECD = \frac{WG}{WF_1 - WF} \times 100$$

Where, WG = Weight gain of larvae (g)

WF = Weight of faeces (g)

WF_1 = Weight of food ingested (g)

Reference ratio (RR)

$$RR = \frac{\text{Weight of food eaten (fresh) (g)}}{\text{Weight of faeces (fresh) (g)}}$$

Statistical analysis

The experimental data were analysed using analysis of variance (ANOVA) appropriate for an FCRD. The statistical model used was:

$$Y_{ijk} = \mu + R_i + H_j + (RH)_{ij} + \varepsilon_{ijk}$$

where:

Y_{ijk} = observation in the k^{th} replication of the i^{th} eco-race and j^{th} host plant

μ = overall mean

R_i = effect of the i^{th} eco-race

H_j = effect of the j^{th} host plant

$(RH)_{ij}$ = interaction effect between eco-race and host plant

ε_{ijk} = random error, assumed to be independent and normally distributed with a mean of zero and constant variance

Before analysis, the assumptions of normality and homogeneity of variance were verified using Shapiro-Wilk and Levene's tests respectively (19). The significance of treatment effects was assessed using the F-test.

When ANOVA indicated significant differences, treatment means were separated using Tukey's honestly significant difference (HSD) test at the 5 % significance level ($p \leq 0.05$) (20). For significant interaction effects, simple effects were examined by comparing individual treatment combinations.

All statistical analyses were performed using R statistical software (version 4.3.1). The results are presented as mean $\pm$ standard error (SE).

Results and Discussion

Ingesta and digesta

The feeding behaviour of *S. ricini* larvae varied significantly with season, host plant and eco-race. Larvae reared during spring showed higher ingesta values compared with those reared in autumn on both host plants (Table 1). Spring-reared larvae consumed an average of 8.84 g of castor and 13.61 g of borpat leaves. Among the eco-races of both the host plants, Kokrajhar recorded significantly higher mean ingesta values (7.48 g on castor and 10.66 g on borpat) than Borduar. A significant interaction between season and race ($p < 0.05$) was observed. The highest ingestion was recorded in Kokrajhar larvae during spring (9.35 g on castor and 13.63 g on borpat), whereas the lowest values occurred in autumn in Kokrajhar on castor (5.64 g) and Borduar on borpat (7.52 g).

Higher food consumption during spring may be attributed to favourable climatic conditions and better foliar quality during the pre-monsoon growth period. Fresh leaves typically contain higher moisture and nutrient content, which stimulates feeding activity in silkworm larvae (21). The higher ingestion observed in the Kokrajhar eco-race may reflect its greater nutritional requirement to sustain growth, a phenomenon often associated with strains showing lower feed conversion efficiency (22).

Digesta values also followed a similar seasonal trend, with higher mean values in spring (4.65 g on castor and 6.32 g on borpat) compared with autumn. However, Borduar eco-race recorded significantly higher digesta values (3.98 g on castor and 5.61 g on borpat) than Kokrajhar. The interaction between season and race was significant ($p < 0.05$). The highest digesta on castor was observed in Kokrajhar during spring (4.74 g), while the lowest occurred in autumn (2.91 g). On borpat, Borduar larvae recorded the highest (7.35 g) and lowest (3.87 g) digesta during spring and autumn respectively.

The higher digestion efficiency observed in the Borduar race in the spring season suggests superior physiological capacity for nutrient assimilation of the race and better leaf quality due to pre-monsoon flush. Variations in digestive enzyme activity and gut physiology among silkworm races may contribute to such differences in food utilisation (6, 23, 24).

Consumption index and growth rate

Consumption index values were higher in spring (3.88 on castor and 4.74 on borpat) than in autumn. The Kokrajhar eco-race recorded significantly higher CI value (4.34), than Borduar when combined with the Spring season. The lowest CI value (2.15) occurred in Borduar during autumn.

Higher CI values indicate greater food consumption relative to body weight. The elevated CI observed in Kokrajhar larvae suggests a compensatory feeding behaviour, where larvae consume more food to meet their nutritional requirements (25). Such behaviour is often associated with relatively lower feed conversion efficiency.

Table 1. Effect of season × race interaction on ingesta (g), digesta (g), consumption index (CI) and growth rate (GR) of *S. ricini* reared on castor and borpat leaves

Food plant	Ingesta (g)			Digesta (g)			Consumption Index (CI)						Growth rate (GR)			
	Spring		Autumn	Spring		Autumn	Spring		Autumn	Spring		Autumn	Spring		Autumn	
	Borduar	Kokrajhar	Borduar	Kokrajhar	Borduar	Kokrajhar	Borduar	Kokrajhar	Borduar	Kokrajhar	Borduar	Kokrajhar	Borduar	Kokrajhar	Kokrajhar	
Castor	8.37	9.35	6.02	5.64	4.56	4.74	3.41	2.91	3.43	4.34	2.15	2.38	1.36	1.31	0.96	0.93
Season		0.02				0.01					0.01				0.01	
Race		0.02				0.01					0.01				0.01	
S.Ed(±)			0.02			0.02					0.01				0.02	
Season × Race		0.03				0.03					0.01				0.03	
Season			0.03								0.02				0.03	
Race			0.03			0.03					0.02				0.03	
CD																
Season × Race		0.05				0.04					0.03				NS	
Borpat	13.58	13.63	7.58	7.69	7.35	5.29	3.87	4.22	4.75	4.72	3.06	3.22	1.18	1.28	1.09	1.02
Season		0.01									0.01				0.01	
Race		0.01				0.01					0.01				0.01	
S.Ed (±)			0.01			0.02					0.02				0.01	
Season × Race																
Season		0.02				0.03					0.02				0.02	
Race		0.02				0.03					0.02				NS	
CD																
Season × Race		0.03				0.04					0.03				NS	

ECl: Efficiency of conversion of ingested food

ECD: Efficiency of conversion of digested food

S.Ed: Standard error of difference

CD: Critical difference (at 5 % significance level)

NS: Not significant

Borduar: Eco-race native to Nagaon district, Assam

Kokrajhar: Eco-race native to Kokrajhar district, Bodoland Territorial region, Western Assam.

Growth rate values were also influenced by season and host plant. Spring-reared larvae recorded higher GR values (1.36 on castor and 1.28 on borpat). Both Borduar and Kokrajhar larvae performed better on castor in spring. However, the interaction effect between season and race was non-significant both on castor and borpat.

Improved growth during spring may be linked to favourable environmental conditions and enhanced nutrient availability in fresh foliage. Earlier studies have also reported that optimal temperature and humidity conditions during spring favour silkworm metabolism and larval growth (26).

Approximate digestibility

Approximate digestibility values were significantly higher in the Borduar race during spring (40.19 % on castor and 44.99 % on borpat) than during autumn, while the Kokrajhar race recorded slightly lower AD values (37.88 % on castor and 37.36 % on borpat) in spring (Table 2). The interaction between season and race significantly affected AD values. The lowest values occurred during autumn in Kokrajhar when fed on castor (29.82 %).

Higher digestibility during spring is likely associated with improved biochemical composition of host plant leaves during active vegetative growth. Leaves at this stage generally contain higher levels of digestible proteins and soluble nutrients, which enhance larval digestion and nutrient assimilation (12).

Efficiency of conversion of ingested food (ECI)

The efficiency of conversion of ingested food (ECI) was significantly influenced by season and eco-race ($p = 0.05$). Spring-reared larvae recorded higher ECI values (23.43 % on castor and 23.18 % on borpat) than autumn-reared larvae. The Borduar eco-race consistently showed higher ECI values than Kokrajhar, irrespective of host plant. The highest ECI was recorded in Borduar larvae during spring (26.28 % on castor and 23.37 % on borpat), whereas the lowest values were observed in Kokrajhar larvae during autumn (18.84 % on castor and 17.82 % on borpat).

Higher ECI values indicate that larvae convert ingested food more efficiently into body biomass. The superior ECI observed in Borduar suggests better metabolic efficiency and physiological adaptation. The nutritional efficiency of the silkworm has been observed to be directly dependent on the physiological state and the environmental factors, such as temperature and humidity, at the time of rearing. Similar observations have been reported in silkworm strains capable of achieving higher growth with comparatively lower food intake (27–29).

Efficiency of conversion of digested food

Mean ECD values were higher in spring (41.53 % on castor by Borduar and 43.98 % on borpat by Kokrajhar race) than autumn-reared larvae. In contrast, Kokrajhar larvae reared during autumn recorded the lowest ECD values (28.03 %). In the case of castor-fed larvae, the mean ECD value was significantly higher in the Borduar eco-race whereas in borpat-fed larvae the mean ECD value was significantly higher in the Kokrajhar eco-race. The interaction effect of season $\times$ race had a significant effect ($p \leq 0.05$) on both the food plants.

The efficiency of conversion of digested food indicates how effectively digested nutrients are converted into larval biomass. The higher ECD observed during spring indicates that favourable environmental conditions and improved host plant quality enhance

metabolic processes and nutrient utilisation efficiency (27).

Reference ratio

Reference ratio (RR) was also significantly influenced by season and eco-race ($p < 0.05$). However, their interaction effect was insignificant. Spring-reared larvae recorded higher RR values (2.67 on castor by Kokrajhar eco race and 2.89 on borpat by Borduar race) than autumn-reared larvae. The Borduar eco-race showed significantly higher RR values compared with Kokrajhar (28).

Higher RR values during spring indicate improved larval growth under favourable environmental conditions. Seasonal variations in temperature, humidity and leaf nutritional composition are known to influence silkworm feeding behaviour, digestion and metabolic efficiency (27–29).

The higher food consumption and comparatively lower growth efficiency observed in larvae fed on borpat may be attributed to differences in nutritional quality and the presence of anti-nutritional compounds. Castor is considered nutritionally superior due to higher protein content, better digestibility and balanced nutrients, which promote efficient larval growth and cocoon production. In contrast, borpat (*A. grandis*) leaves contain comparatively lower soluble protein and higher structural components. A dietary adaptation study reported total protein content of 20.2 ± 1.61 mg g⁻¹ in castor leaves compared with 18.3 ± 0.33 mg g⁻¹ in *Ailanthus* leaves, indicating lower protein density in *Ailanthus* hosts. Reduced protein availability requires greater consumption to meet nitrogen demand, resulting in higher ingestion but lower conversion efficiency. The silkworms from the same genetic stock responded differently when fed on the leaves of different nutritional quality, which is an indicator of efficient utilisation and conversion of food into silk substance. Variation of the ingesta and digesta values among the different breeds and the same breed in different seasons has been reported previously (30, 31).

Additionally, *Ailanthus* species contain quassinoids, phenolics and other bitter secondary metabolites that may reduce palatability, inhibit digestive enzymes and increase metabolic cost for detoxification, thereby lowering the efficiency of conversion of ingested and digested food. Studies have shown altered midgut protease activity in eri silkworms shifted from castor to *Ailanthus* hosts, indicating physiological stress and reduced nutrient utilisation (27, 28). Furthermore, *Ailanthus* leaves are generally thicker and higher in fibre and lignin, which reduces digestibility and assimilation efficiency. Host plants with higher fibre and toxic metabolites typically result in increased ingestion but reduced growth and cocoon traits, whereas higher protein content improves performance (29, 30). These findings support the present results that borpat may possess lower nutritional density and anti-nutritional factors compared with castor, leading to higher consumption but reduced growth and conversion efficiency.

The present findings highlight the combined influence of host plant species, eco-race characteristics and seasonal environmental conditions on the nutritional efficiency of *S. ricini*. Although borpat leaves were consumed in greater quantities, castor leaves supported better growth and feed conversion efficiency, indicating their superior nutritional quality. Among the eco-races, Borduar demonstrated higher digestion efficiency and nutrient conversion capacity compared with Kokrajhar. Seasonal differences further revealed that spring is the most favourable rearing period due to improved host plant quality and conducive climatic conditions.

These results emphasise the importance of selecting

Table 2. Effect of season × race interaction on nutritional indices (AD, ECI, ECD and RR) of eri silkworm reared on different host plants

Food plant	Approximate digestibility (AD %)						ECI (%)				ECD (%)				Reference ratio (RR)			
	Spring		Autumn				Spring		Autumn		Spring		Autumn		Spring		Autumn	
	Borduar	Kokrajhar	Borduar	Kokrajhar			Borduar	Kokrajhar	Borduar	Kokrajhar	Borduar	Kokrajhar	Borduar	Kokrajhar	Borduar	Kokrajhar		
Castor	40.19	37.88	31.47	29.82	26.28	20.58	23.19	18.84	41.53	40.27	36.99	30.65	2.56	2.67	2.08	1.77		
	Season	0.01				0.01				0.01				0.01				
	Race	0.01				0.01				0.01				0.01				
	S.Ed(±)																	
CD	Season × Race	0.02				0.02				0.02				0.02				
	Season	0.03				0.03				0.03				0.03				
	Race	0.03				0.03				0.03				0.03				
	Season × Race	0.04				0.03				0.04				NS				
Borpat	44.99	37.36	32.16	34.35	23.37	22.98	19.59	17.82	36.53	43.98	34.47	28.03	2.89	2.13	1.69	2.00		
	Season	0.02				0.01				0.02				0.01				
	Race	0.02				0.01				0.02				0.01				
	S.Ed (±)																	
CD	Season × Race	0.02				0.01				0.02				0.01				
	Season	0.03				0.02				0.04				0.02				
	Race	0.03				0.02				0.03				NS				
	Season × Race	0.05				0.03				0.05				NS				

ECI: Efficiency of conversion of ingested food
ECD: Efficiency of conversion of digested food
NS: Not-significant
S.Ed: Standard error of difference
CD: Critical difference (at 5 % significance level).

suitable host plants, eco-races and rearing seasons to enhance eri silkworm productivity and improve silk yield under regional agroclimatic conditions.

Conclusion

The study revealed that important nutritional parameters such as ingesta, digesta, consumption index (CI), growth rate (GR), approximate digestibility (AD), efficiency of conversion of ingested food (ECI) and efficiency of conversion of digested food (ECD) increased progressively with advancing larval instars. This indicates that metabolic and digestive activities become more active during the later stages of larval development. In contrast, the relative consumption rate gradually declined as the larvae matured, possibly because larger larvae require less food relative to their body weight. Among the host plants tested, castor (*R. communis*) proved to be the most suitable for rearing *S. ricini* in this agroclimatic region, as it resulted in better nutritional utilisation and improved cocoon traits. Between the two eco-races studied, Borduar performed better than Kokrajhar, showing higher values for most nutritional indices. Seasonal variation was also evident, with spring rearing producing better results than autumn, likely due to improved leaf quality during the pre-monsoon growth period.

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Authors' contributions

MS conceived and designed the study, developed the methodology, provided resources and participated in the investigation. SDB conducted the formal analysis, contributed to the investigation and prepared the original draft together with PRN, who also contributed to software-related work. SDB and PRN provided software support. MS and MB supervised and validated the study. BK, RRS and SS contributed to the review and editing of the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used QuillBot for paraphrasing purposes. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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