



ISSN Print: 2664-9926
 ISSN Online: 2664-9934
 NAAS Rating (2025): 4.82
 IJBS 2025; 7(9): 14-17
www.biologyjournal.net
 Received: 09-06-2025
 Accepted: 11-07-2025

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Comparative growth and reproductive phenology of two ethnomedicinal *Curcuma* species from Assam: Implications for conservation and domestication

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DOI: <https://www.doi.org/10.33545/26649926.2025.v7.i9a.471>

Abstract

The family Zingiberaceae comprises numerous ethnomedicinal plants of immense therapeutic value, many of which remain underexplored scientifically. *Curcuma caesia* and *C. amada*, two threatened species of Zingiberaceae, are widely utilized in traditional and Ayurvedic medicinal systems yet face increasing conservation concerns. The present study undertakes a comparative phenological investigation of these species under the prevailing climatic conditions of Jorhat, Assam. Rhizomes collected from local villages were cultivated in the Botanical Garden of Jagannath Barooah University, and phenophases including shoot initiation, leaf development, inflorescence emergence, flowering period, flower longevity, and vegetative growth parameters were recorded over three consecutive years. Results indicate that both species exhibit broadly similar early-stage growth, but significant differences in plant height and leaf size become evident at later stages, with *C. amada* showing slightly greater growth values. Leaf number remained statistically similar across all growth stages, while flowering occurred during June-July in both species, producing short-lived flowers. No fruit set was recorded. The observed phenological variations highlight the ecological strategies of these taxa and provide baseline information critical for their domestication, sustainable harvesting, and conservation. Overall, this study underscores the role of comparative phenological research in safeguarding threatened medicinal resources and ensuring consistent bioactive compound availability.

Keywords: Phenology, Zingiberaceae, *Cucuma*, Growth parameters, Rhizome

Introduction

Family Zingiberaceae consists of the large number of medicinal plants and is well-known for its use in ethnomedicine and play a major role in the Indian System of Medicine, Ayurveda (Kumar *et al.*, 2013) [2]. The Zingiberaceae family constitutes a large number of rhizomatous medicinal and aromatic plants. The family Zingiberaceae is well known for its immense medicinal values and is distributed widely throughout the tropics, particularly in Southeast Asia (Rasool and Maqbool, 2019) [4]. North eastern India is one of the richest sources of Zingiberene with about 19 genera and 90 species. Most of the Zingiberaceae members are found here in wild states, and many of them lack scientific investigation. Traditionally, the rhizomes of the various species under the genus *Curcuma* are used in the treatment of various common ailments, including hemorrhoids, leprosy, asthma, cancer, epilepsy, fever, wounds, vomiting, menstrual disorder, anthelmintic, aphrodisiac, inflammation, gonorrheal discharges, etc. The present work deals with study about a comparative phonological study of two important Zingiberaceae plant *C caesia* and *C. amada*. Phenology is the study of periodic phenomena in organisms and how these are influenced by seasonal and interannual variations in climate, as well as habitat factors. The study of phenological aspects of plants involves the observation, recording, and interpretation of the timing of their life history events (Fenner, 1998) [1]. The study of plant phenology provides knowledge about the pattern of plant growth and development as well as the effects of environment and selective pressures on flowering and fruiting behaviour (Zhang *et al.*, 2006) [7]. The knowledge of the timing of phenological events and their variability can provide valuable data for planning, organizing, and timely execution of certain standard and special agricultural activities that require advanced information on the dates of specific stages of crop development (Rumi and Vulic).

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Plant Phenological study provides valuable information about the pattern of vegetative growth and development of plants, which helps set priorities and conservation strategies for the conservation of rare and endangered plant species. *C. caesia* and *C. amada* are the threatened species of Curcuma from this region. Hence, detailed phenological observations of these widely used ethnomedicinal plants from North-East India are crucial for their conservation, particularly through domestication and cultivation supported by modern breeding techniques.

Materials and Methods

About the study site: Jorhat is a major urban centre of the Upper Brahmaputra valley zone of Assam and lies near 26°45' N, 94°12' E. The Jorhat district covers about 2,851 km². The climate is humid subtropical, with an average annual temperature of 23.7 °C and an annual precipitation of 2,700 mm. Relative humidity is consistently high, peaking above 80-85% during the monsoon months.

Methods of the study: To study the life cycle events of plants under the prevailing climatic conditions of the study area, phenological observations were conducted over three consecutive years by maintaining the plants in the Botanical Garden of Jagannath Barooah University, Jorhat. Planting material, i.e., rhizomes, was collected from villages across the study site, and the observations focused on key phenophases, such as the initiation of shoots from rhizomes, leaf growth and measurements, inflorescence development, the number of flowers, flowering period, and flower longevity. In addition, plant height and leaf number were recorded at 60, 100, 140, and 180 days after planting. The rhizomes were planted during the first week of May, 2022, and subsequent observations were systematically documented.

Results and Discussion

C. caesia is a perennial rhizomatous herb with externally brownish rhizomes that are bluish-black inside. The plant reaches a height of about 84 ± 0.52 cm after 180 days of plantation. Mature leaves measure up to 17 × 45 cm, and are lanceolate, oblong-elliptic, or oblong-lanceolate in shape. The inflorescence arises from the base of the rhizome, bearing pale yellow flowers with reddish margins. Leaves usually appear after the emergence of flowers. The green foliage dries in late autumn, and the rhizomes remain dormant during winter.

C. amada is also a perennial leafy rhizomatous herb, growing up to 86.3 ± 0.21 cm after 180 days. Its rhizomes are stout, finger-like, branched, and with a raw mango flavour. Mature leaves, similar, 16 × 45 cm, and are oblong-lanceolate, tapering at both ends. Inflorescences arise from the rhizome base, producing greenish-white flowering bracts and coma bracts tinged with pink or red. Flowers are unisexual and are pink in color. Like *C. caesia*, the foliage dries in late autumn, and the rhizomes remain dormant in winter.

Growth Parameters

Plant height: Maximum height was recorded at 180 days, 84 ± 0.52 cm in *C. caesia* and 86.3 ± 0.21 cm in *C. amada*. No significant difference was observed at 60 and 100 days ($p > 0.05$). However, plant height differed significantly at

140 and 180 days ($p < 0.05$), indicating divergence in growth during later stages.

Petiole height: Maximum petiole height was recorded after 180 days, 67.8 ± 1.4 cm in *C. caesia* and 68.7 ± 2.9 cm in *C. amada*. No significant difference was found at 140 days ($p > 0.05$), whereas significant variation occurred at 60, 100, and 180 days ($p < 0.05$).

Leaf size: Leaf dimensions increased gradually, reaching maximum size at 180 days. In *C. caesia*, leaf length and breadth measured 44.2 ± 1.1 cm and 16.6 ± 0.27 cm, respectively. In *C. amada*, the corresponding measurements were 45.2 ± 0.46 cm and 17.1 ± 0.78 cm. No significant differences were observed at 60 days, but significant variation was noted at 100, 140, and 180 days ($p < 0.05$).

Leaf number: The number of leaves increased initially but decreased at later growth stages. Statistical analysis revealed no significant difference between the two species at any of the four stages (60, 100, 140, and 180 days), with $p > 0.05$ throughout.

Reproductive Phenology

Inflorescence development: In *C. caesia*, inflorescence appeared 80 - 90 days after sprouting (third year of plantation), whereas in *C. amada* it appeared 78 - 85 days after sprouting (second year).

Floral traits: *C. caesia* produced 9-12 flowers, while *C. amada* produced 10 -16 flowers. Flowering occurred between June and July in both species, with individual flowers lasting only 1-3 days.

Fruit formation: No fruit formation was observed in either species during the study period.

C. caesia and *C. amada* display largely uniform aerial growth characteristics in the initial stages of development; detailed statistical analysis reveals that differences in plant height and leaf size become significant during later growth phases. Specifically, while no significant differences in plant height and leaf dimensions were observed at 60 and 100 days post-planting ($p > 0.05$), both traits showed statistically significant divergence at 140 and 180 days ($p < 0.05$), suggesting that *C. amada* may outpace *C. caesia* in later-stage growth. In contrast, leaf number remained statistically similar between the species throughout all four growth phases (60, 100, 140, and 180 days; $p > 0.05$), indicating comparable foliage density.

Understanding phenological differences between related medicinal species guides sustainable harvesting, ensures consistent bioactive compound yield, and aids in incorporating Indigenous knowledge systems (Kumar *et al.*, 2011) [3]. By comparing phenological traits across species, researchers can identify which ones are more resilient or adaptable to domestication and conservation efforts (Varban *et al.*, 2021). Various studies confirmed that the plant phenological studies can guide us to select which wild plants are suitable for cultivation, help breeders select uniform and adaptable varieties, and ensure successful integration into the agricultural system (Zhang *et al.*, 2005; Varban *et al.*, 2021) [7].

Table 1: Plant height and height of petiole at four growth stages (average of 4-6 plants)

Species	Days after Plantation				Days after Plantation			
	60	100	140	180	60	100	140	180
	Plant height in cm				Petiole Height in cm			
<i>C. caesia</i>	25.8±0.31	51.4±0.32	72.2±2.11	84± 0.52	19±0.3	42.3±0.6	63.2±0.6	67.8± 1.4
<i>C. amada</i>	26.3±0.12	51.9± 1.4	73.6±0.31	86.3± 0.21	20 ±0.31	43.2±2.1	64.1±1.3	68.7± 2.9

Table 2: Size of leaf and leaf number of at four growth stages (average of 4-6 plants)

Species	Days after Plantation				Days after Plantation			
	60	100	140	180	60	100	140	180
	Size of leaf in cm				Leaf Number			
<i>C. caesia</i>	L-14±0.93 B-7±1.2	L-28±2.2 B-12±0.7	L-39.1±0.34 B-15±1.8	L- 44.2 ± 1.1 B-16.6 ± 0.27	1-3	5-9	7-10	8-10
<i>C. amada</i>	L-16.1±2.3 B-7±0.46	L-29.02±1.3 B-12.4±0.21	L-39.6±0.2 B-16.1±0.4	L- 45.2 ± 0.46 B- 17.1 ± 0.78	1-4	5-10	8-10	8-12

Table 3: Statistical comparison of plant height at four growth stages

Days after plantation	Between Species	t-test	P-value	Decision
60	<i>C. caesia</i> and <i>C. amada</i>	1.564	0.156	Not significant
100	<i>C. caesia</i> and <i>C. amada</i>	1.241	0.242	Not significant
140	<i>C. caesia</i> and <i>C. amada</i>	4.321	0.002	Significant
180	<i>C. caesia</i> and <i>C. amada</i>	4.432	0.002	Significant

Table 4: Statistical comparison of height of petiole at four growth stages

Days after plantation	Between Species	t-test	P-value	Decision
60	<i>C. caesia</i> and <i>C. amada</i>	4.121	0.003	Significant
100	<i>C. caesia</i> and <i>C. amada</i>	4.567	0.001	Significant
140	<i>C. caesia</i> and <i>C. amada</i>	1.341	0.220	Not significant
180	<i>C. caesia</i> and <i>C. amada</i>	5.128	0.001	Significant

Table 5: Statistical Comparison of the size of leaf and leaf number at four growth stages

Days after plantation	Between Species	t-test	P-value	Decision
60	<i>C. caesia</i> and <i>C. amada</i>	1.769	0.116	Not Significant
100	<i>C. caesia</i> and <i>C. amada</i>	1.312	0.230	Not Significant
140	<i>C. caesia</i> and <i>C. amada</i>	2.431	0.042	Significant
180	<i>C. caesia</i> and <i>C. amada</i>	0.864	0.416	Not Significant

Table 6: Different phenological characteristics.

Sl. No	Parameters	<i>C. caesia</i>	<i>C. amada</i>
2	Inflorescence development	Observed after two years 2-3 months of plantation (in 3 rd Year)	Observed after 1 years 4 months of plantation (in 2 nd Year)
3	No. of flowers	9-12	10-16
4	Flowering period	June-July	June - July
5	Longevity	1-2 days	1-3 days
6	Fruit formation	No	No

Conclusion

The comparative phenological study of *C. caesia* and *C. amada* reveals that both species exhibit similar early-stage vegetative growth, significant differences in plant height and leaf size emerge during later growth phases, with *C. amada* showing relatively higher values. Leaf number, however, remains comparable throughout all stages, indicating uniform foliage density. Flowering patterns are almost similar, though minor variations exist in timing and the number of flowers. The absence of fruit formation in both species highlights their reliance on vegetative propagation. These findings emphasize the importance of phenological monitoring for sustainable harvesting, conservation, and domestication of threatened ethnomedicinal species of Zingiberaceae, thereby ensuring long-term availability and consistent bioactive yields.

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