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ORIGINAL ARTICLE

Eco-biology of the White Arab Tip Butterfly *Colotis vestalis* in the Eastern Ghats of Andhra Pradesh – India

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ABSTRACT
Colotis vestalis the White Arab tip was a Pieridae species that enhanced Kadapa's ecosystem by laying eggs on Maerua apetala's young foliage year-round. This butterfly had a multivoltine life cycle, producing 7-8 broods annually, with eggs taking 3-4 days to incubate, larvae 15-17 days, pupal 7-9 days, and adult emergence 27-30 days. The Consumption Index (CI) and Growth Rate (GR) diminished with larval age, with average values of 2.33 and 0.31, respectively. The average Approximate Digestibility (AD) scores increase to 82% and decrease in subsequent instars. The Efficiency of Conservation of Digested food (ECD) and Efficiency of Conservation of Ingested food (ECI) improved with larval age, with average values of 18.56% and 23.68%, respectively. Adults commonly visit flowers at a rate of 14 to 35 blossoms per minute, spending between 1.0 and 3.3 seconds on each one. Peak foraging activity predominantly increased between 9-10 a.m. The proboscis successfully collected pollen from most floral species encountered, demonstrating its crucial role in butterfly pollination. The pollinator was deemed a "high-energy" pollinator due to its rapid and powerful flight, which facilitates cross-pollination.
Keywords: *Colotis vestalis, Life cycle, Maerua apetala, Population index, Butterfly pollination.*

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INTRODUCTION

Butterflies provide economic and ecological benefits to humanity through their beauty and crucial role in pollination, which promotes global sustainability. Adults and larvae of these creatures rely on vegetation, engaging in intricate feeding relationships with green plants, requiring various nectar sources, and exhibiting host-specificity (1), (2). Butterfly populations are declining due to habitat destruction, with some on the brink of extinction, highlighting the urgent need for conservation efforts (3). Eco-biological studies have improved temperate butterfly conservation management, but only a few tropical species, like *Ornithoptera,* have seen significant progress, making them costly globally (4). Such knowledge is crucial for formulating effective conservation management strategies (5), (6), (7). For most Indian butterflies, such autecological information is severely lacking (8), (9). Yogi Vemana University is working to improve the knowledge about South Indian butterflies, specifically the White Arab tip *Colotis vestalis*, a species of the Pieridae butterfly. This butterfly is found in various parts of India, Pakistan, Iran, Somalia, Ethiopia, Sudan, Kenya, and Tanzania (10), with documented locations in Baluchistan, Punjab, western India, and Northern Karnataka and Telangana. It is also located in the provinces surrounding the Persian Gulf (11). The larvae of all *Colotis* species specialize in plants belonging to the Capparaceae family. The larval host plants are *Salvadora persica* (Salvadoraceae) (12) and *Maerua apetala*. The *C. vestalis* species, with a wingspan of 85-100 mm, is notable for its pale canary yellow upper wings and light brown or beige ventral surface with yellowish markings. These wings help it conceal against predators and enhance its habitat for its larval host plant, *Maerua apetala*, and roost communally with other *Colotis* species (12).

MATERIAL AND METHODS

The *Colotis vestalis* was found in Andhra Pradesh's Kadapa district and Palakondalu region, ovipositing on *Maerua apetala*. Researchers studied its reproductive behaviour from 2023-2024, focusing on its eggs and their habitat in the Capparaceae family. We transported the eggs to the insect laboratory for incubation, monitored their development, and provided fresh leaves daily, ensuring accurate records of hatching, larval and pupal stages, and adult emergence timings. To determine the population index, we conducted monthly searches to document the various life stages of eggs, larvae, and pupae on ten juvenile *Maerua apetala* plants. We quantified food intake and growth at each stage. We computed food usage indices following Waldbauer's [13] method, preserving five replications for each indicator. The study examined the plant species utilized as nectar sources and their respective flowering periods. The study assessed adult flower visitation patterns on clear weather days by recording hourly visits from 6 a.m. to 6 p.m., measuring foraging speed, and timing nectar foraging durations. We used light microscopy to analyze pollen deposition on body parts, evaluate pollination capability, and assess the diurnal activity pattern of adult flower visitation.

Study area: Palakondalu is located in Puttampalli, Southern Andhra Pradesh. It is approximately 3.12 kilometres from the Kanamalepall train station (Figure 1).

Figure 1: Study area of Palakondalu - Southern Andhra Pradesh

The formulae of Waldbauer [13]:

$$\text{CI (Consumption index)} = \frac{\text{Weight of food consumed}}{\text{Weight of instar x Number of feeding days}}$$

$$\text{GR (Growth rate)} = \frac{\text{Weight gained by the instar}}{\text{Mean weight of instar x Number of feeding days}}$$

$$\text{AD (Approximate digestibility)} = \frac{\text{Wt. of food ingested – Weight of faeces}}{\text{Weight of food ingested}} \text{ x 100}$$

$$\text{ECI (Efficiency of conversion of ingested food)} = \frac{\text{Weight gained by the instar}}{\text{Weight of food ingested}} \text{ x 100}$$

$$\text{ECD (Efficiency of conversion of digested food)} = \frac{\text{Weight gained by the instar}}{\text{Wt. of food consumed – Weight of faeces}} \text{ x 100}$$

RESULTS

Life History Stages: The White Arab tip, *Colotis vestalis*, deposits eggs individually on both sides of the juvenile leaves of *Maerua apetala* (Figure 2). It sequentially deposits 8–12 eggs on various leaves of the host tree. The eggs have longitudinal ridges extending from the apex to the base, characterized by a smooth texture and a light mustard yellow hue, measuring 0.82-0.85 (0.87 ± 0.02) mm in length and 0.32-0.35 (0.36 ± 0.01) mm in width. They incubate for 3–4 days following deposition. The larvae undergo five instars (Figure 2). Instar I lasted for 2-3 days. Its length ranges from 2.91-6.17 (6.57 ± 0.4) mm, and its width ranges from 0.6-0.63 (0.66 ± 0.03) mm. The thoracic area exhibited pilose features. Upon hatching, the body had a cream hue; toward the end of day one, it transitioned to a green coloration. Upon emerging, the larva's head initially turns black before transitioning to green. We measured the diameter of the round head as 0.8-1.0 (1.9 ± 0.9) mm. Instar II endures for 2-3 days. The length ranged from 6.18-9.14 (9.28 ± 0.14) mm, and the width varied from 0.64-1.04 (1.25 ± 0.21) mm. The diameter of its head ranged from 0.65-1.07 (1.12 ± 0.05) mm. The mid-dorsal line becomes visible; the body transitions to a green, hairy, and coarse texture. Instar III endures for 2-3 days. The length ranged from 9.14-14.21 (14.32 ± 0.11) mm, and the width ranged from 1.05-1.28 (1.33 ± 0.05) mm. The diameter of its head ranged from 1.08-1.21 (1.24 ± 0.04) mm. Instar IV endures for 3-4 days. The length ranged from 14.22-18.15 (18.24 ± 0.09) mm, and the width varied from 1.06-1.96 (2.0 ± 0.04) mm. Body segmentation was distinctly evident in the physique. The cylindrical head features a prominent orange patch on the dorsal side, measured as 1.21-1.39 (1.42 ± 0.03) mm in diameter. The dorsal and ventral profiles of the body transition to a dark green hue, with a patch of whitish-yellow evident on the lateral side. Instar V persisted for 3–4 days. Upon reaching full maturity, the larva exhibited a robust green coloration, with its length and width measuring 18.16–20.45 (20.57 ± 0.12) mm and 1.97–2.79 (2.96 ± 0.17) mm, respectively. The diameter of its head ranged from 1.39 - 1.43 (1.45 ± 0.02) mm. No alterations occurred in the other characters. The fifth instar contracts on the same day to transition into the pupal stage. It measured 14.97–15.02 (15.07 ± 0.04) mm in length and 5.49–5.61 (5.64 ± 0.03) mm in width in the broader section. It adheres to the substrate with its entire body (Fig. 2). This phase endures for 7–9 days. It was a light brown hue. The rear end was tapered. The male had a white base color on the dorsal side, complemented by black terminal bars on both the forewings and hind wings. The forewing base exhibited a dense coverage of dusky-grey scales, but the hind wing displayed a more uniform appearance with gray scales at its base. The ventral surface had a greenish-yellow hue adorned with black scales, whereas the hind wing was homogenous, featuring a diminutive circular patch on the discocellulars. The antennae, head, thorax, and abdomen were all black. The female's dorsal side resembled the males, featuring wider, brownish terminal bands, a greenish-yellow basal underside, and a pale ochraceous hind wing surface. The forewing had black dots, while the hind wing displayed an indistinct, macular stripe.

Larval Performance: The larvae initially ingested their vacant egg shell before subsequently feeding on foliar debris. Observing feeding behaviour over 4 hours in the laboratory revealed that the first three instars consumed food in 2-4 episodes, dedicating a total duration of 5-22 minutes, while the subsequent two instars consumed food in 4-6 episodes, allocating a total duration of 20-35 minutes. The initial three instars consumed food at a moderate pace, whereas the subsequent two instars did it swiftly. The weight gain showed a consistent increase from the initial two instars (0.0-1.8 mg) to the subsequent instars (Table 1). Table 1 presents qualitative data about ingested food, excrement, larval weight gain, growth rate, and consumption index. The amount of food ingested escalated from instar to instar. Instar II exhibited a threefold rise compared to instar I. Instar III demonstrated an eighteen-fold increase over instar II, and instar IV showed around a two-fold increase relative to instar III. The relationship between larvae's weight gain and the amount of food they ate each day was linear (Graph 1), with an r-value of 0.99, which was higher than the Table‘t’ value of 0.725 at the 1% significance level. The relative growth and consumption index exhibited a decreasing trend from instar I to V, while instar I recorded a value superior to that of instar II. In instars I to V, the concentrations of AD decreased. The values of both ECD and ECI exhibited the same trend, increasing from Instars I to V, with the peak value observed in the fifth instar.

Hatching, Pupal, and Adult Development Success: We incubated all eggs collected during the year in the laboratory to evaluate the success of the successive stages of larvae, pupae, and adults. Hatching success for the year ranged from 80%, larval development rate from 99%, and pupal development rate from 100% (Table 2; Graph 3).

Population Index: Investigations of 10 juvenile host trees for eggs, larvae, and pupae throughout various months revealed that these developmental stages persist year-round, exhibiting numerical fluctuations among the months. The life stages occurred more frequently from June to January (Table 3; Graph 4).

Adult Nectar Resources: Field investigations revealed the common visitation of 10 distinct plant species for nectar and the recording of their flowering seasons (Table 5). Table 5 and Table 6 document the butterfly's diurnal foraging on several floral species, the number of flowers visited each minute, and the duration (in seconds) spent at each flower. The butterfly frequented 12 to 35 flowers every minute, dedicating 1.0 to 3.4 seconds to nectar extraction from each bloom. The butterfly foraged during daylight, with peak foraging times varying by flower type, predominantly occurring between 9 - 10 am (Table 6). The proboscis length of *C. vestalis* was around 35 mm, whereas the corolla tube length ranged from 3 to 39 mm, with an average height of 12.4 mm. The butterfly, with its flapping wings, interacts with the vital organs of a flower during nectaring, with the specific interaction depending on the flower's architecture. Among the 10 plants examined, pollen from nine plants adhered to the proboscis: 4 to the head, 2 to the wings, 2 to the legs, and 1 to the antennae. The frequency of contact between different body parts and the stigma varied. Consequently, the proboscis primarily established contact with vital organs in numerous floral species and facilitated pollination.

Table 1: Food Consumption and Utilization Efficiencies of *Colotis vestalis* larvae on *Maerua apetala*

Instar No	Wt. of the food ingested (mg)	Wt. of the feces (mg)	Wt. gain by the larvae (mg)	GR	CI	AD %	ECI%	ECD %
I	3.6±0.25	0.1±0.1	0.19±0.03	0.37	6.31	97.2	5.4	5.2
II	8.8±0.6	1.35±0.1	1.8±0.11	0.35	1.62	84.6	24.1	20.4
III	28.2±0.8	5.5±0.32	6.0±0.3	0.33	1.56	80.4	26.4	21.2
IV	87.79±1.5	21.9±0.6	20.06±0.6	0.26	1.09	76.0	30.4	22.8
V	285.9±2.09	79.2±1.2	66.4±1.12	0.25	1.07	72.2	32.1	23.2

Table 2: Hatching rate, Pupal, and adult development success of *C. vestalis* in laboratory conditions

Life cycles stage	J	F	M	A	M	J	J	A	S	O	N	D
Eggs incubated	12	9	6	4	2	25	30	24	21	20	17	15
Larvae hatched	9	7	3	2	0	22	26	20	17	15	14	13
Pupae formed	9	7	3	1	0	21	26	20	17	15	14	13
Adult emerged	9	7	3	1	0	21	26	20	17	15	14	13

Table 3: Population index of *Colotis vestalis* on *Maerua apetala* at Palakondalu, Kadapa

Life cycles stage	J	F	M	A	M	J	J	A	S	O	N	D
Eggs	10	8	5	2	1	24	26	23	20	19	15	13
Larvae	6	4	2	0	0	20	21	18	14	13	11	9
Pupae	2	1	0	0	0	8	10	6	4	4	3	2

Table 4: Nectar plants of *Colotis vestalis*

Floral species	Common name	Flowering period
Lantana camara	Lantana	May to October
Tithonia diversifolia	Mexican Sunflower	August to October
Hibiscus rosa-sinensis	Hibiscus	March to November
Cassia fistula	Golden Shower Tree	May to June
Moringa oleifera	Drumstick Tree	May to August
Bougainvillea spectabilis	Bougainvillea	April to June and September to November
Clerodendrum blomfieldianum	Clerodendrum	June to October
Zinnia elegans	Zinnia	May to October
Aloevera	Aloe	May to June
Marigold	Tagetes spp.	March to November

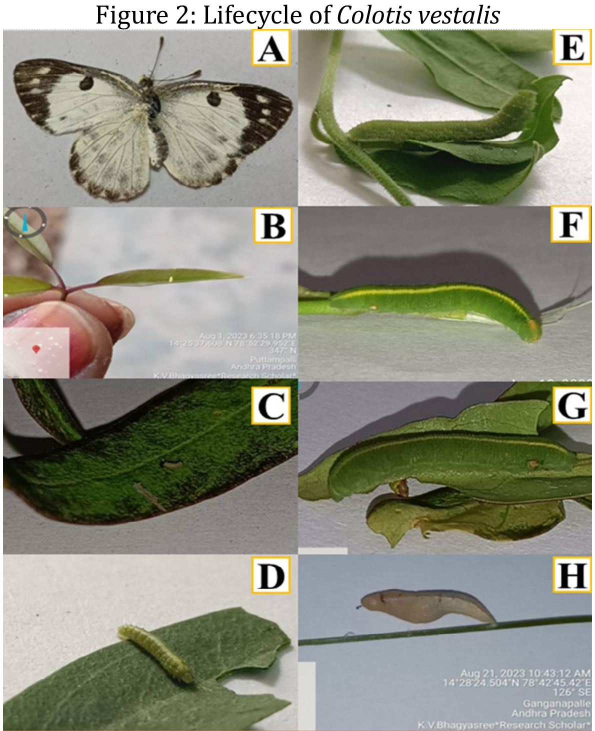
Table 5: Diurnal activity pattern of *C. vestalis* on different floral species (Data for each hour is given as a percentage of total daily activity)

Floral species	Time of day in hours										
	6-7 a.m.	7-8 a.m.	8-9 a.m.	9-10 a.m.	10-11 a.m.	11-12 a.m.	1-2 p.m.	2-3 p.m.	3-4 p.m.	4-5 p.m.	5-6 p.m.
Lantana camara	0	1-5	15-20	20-25	10-15	20-25	10-15	5-10	1-5	1-5	0
Tithonia diversifolia	1-5	0	25-30	40-45	30-35	25-30	25-30	15-20	5-10	5-10	1-5
Hibiscus rosa-sinensis	0	1-5	10-15	25-30	20-25	15-20	1-5	5-10	1-5	1-5	0
Cassia fistula	0	5-10	5-10	1-5	0	1-5	0	1-5	0	0	0
Moringa oleifera	0	0	5-10	10-15	5-10	5-10	5-10	0	1-5	0	0
Bougainvillea spectabilis	0	1-6	1-5	5-10	10-15	10-15	1-5	5-10	0	0	0
Clerodendrum blomfieldianum	0	1-5	5-10	15-20	15-20	15-20	0	1-5	0	0	0
Zinnia elegans	0	0	10-15	20-25	15-20	20-25	10-15	5-10	1-5	1-5	1-5
Aloe vera	0	1-7	5-10	10-15	10-15	10-15	1-5	0	0	0	0
Marigold	0	1-5	10-15	25-30	5-10	0	1-5	1-5	0	0	0

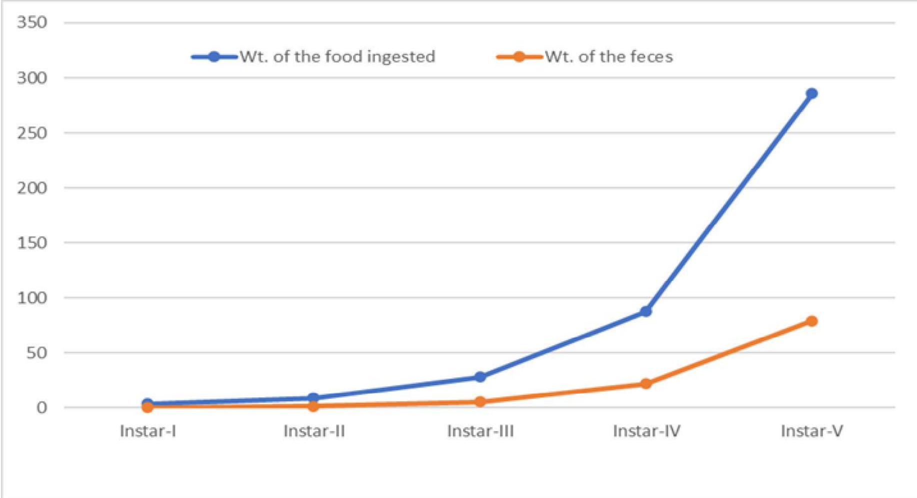
Table 6: Floral and foraging speed of *C. vestalis*

Floral species	Time spent on each flower (Sec.)	Number of flowers visited per 1 minute
Lantana camara	2.5	24
Tithonia diversifolia	3.3	18
Hibiscus rosa-sinensis	2.4	25
Cassia fistula	2.3	19
Moringa oleifera	2.0	26
Bougainvillea spectabilis	2.3	18
Clerodendrum blomfieldianum	2.5	23
Zinnia elegans	3.2	35
Aloevera	2.1	14
Marigold	1.5	16

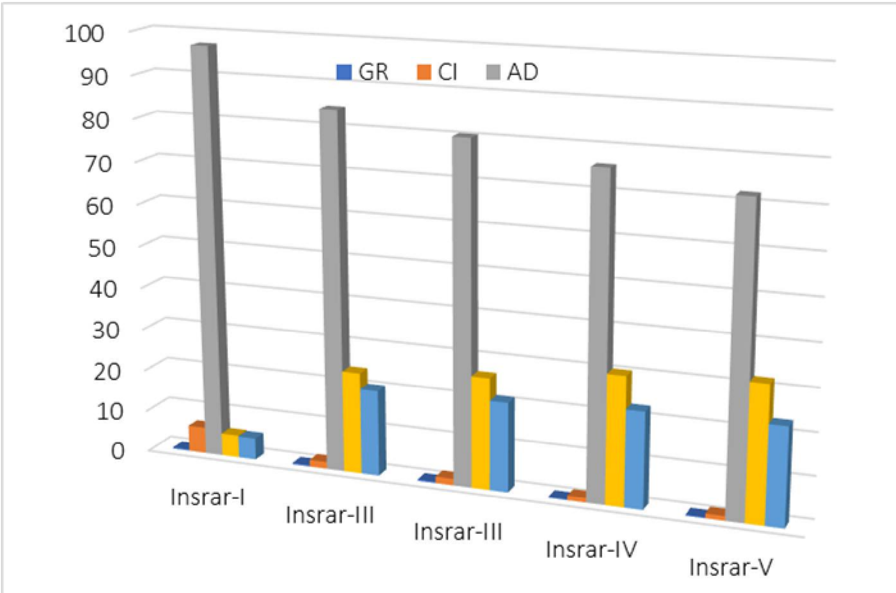
Figure 2: Lifecycle of *Colotis vestalis*



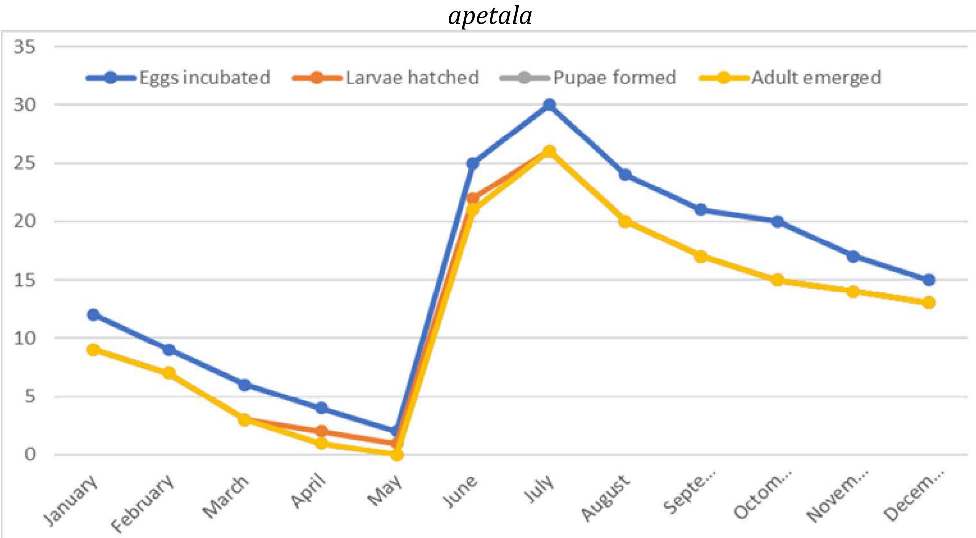
A. Adult; B. Egg; C. Instar-I; D. Instar-II; E. Instar-III; F. Instar-IV; G. Instar-V; H. Pupa



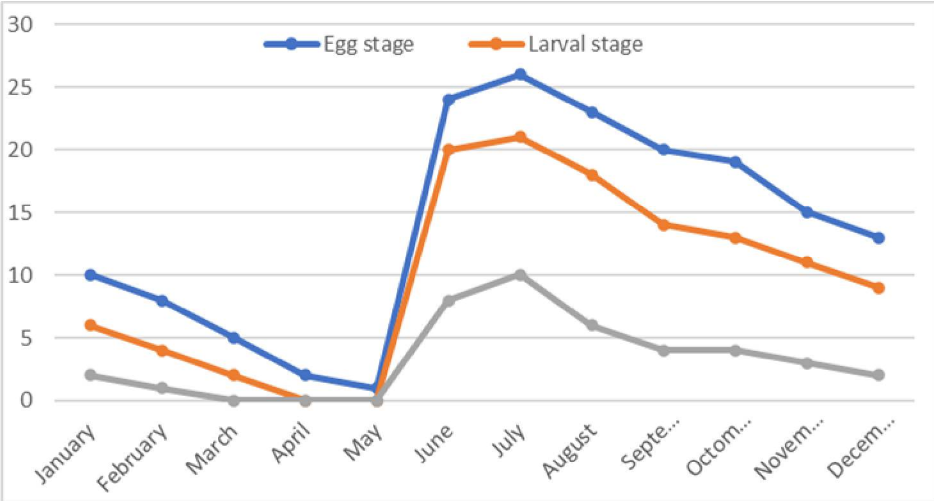
Graph 1: Relationship between food consumption and growth in *Colotis vestalis* larvae on *Maerua apetala*



Graph 2: Food consumption, growth, and food utilization efficiency of *Colotis vestalis* larvae on *Maerua apetala*



Graph 3: Growth success of different life stages of *Colotis vestalis* in the laboratory



Graph 4: Population index of different life stages of *Colotis vestalis* in *Maerua apetala*

DISCUSSION

Most butterflies deposit their eggs individually (14), and the White Arab tip *Colotis vestalis* was one such species. The host plant's quantity of nourishment serves as a primary constraint on oviposition behaviour (15). Therefore, we anticipate that butterflies exhibiting solitary oviposition behaviours will use diminutive fauna as their hosts. However, *Maerua apetala* and other *Colotis vestalis* host plants have a tree-like form, characterized by dense foliage, which reduces larvae's exposure to heat and desiccation, benefiting the butterfly species (16). The eggs required 3-4 days to incubate. The five larval stages need 15-17 days to progress to the pre-pupal stage. The final instar required 12-24 hours for pre-pupation before entering the pupal stage. The pupa necessitated 7-9 days for metamorphosis into the adult form. The overall duration from the egg stage to adult emergence was estimated to be between 27 and 30 days. The brief life cycle duration, population metrics, and laboratory data on egg, larval, and pupal developmental success indicate that the White Arab tip was multivoltine. Based on an adult lifespan of 7-12 days (17), the potential number of broods per year was at least 4-5. Butterflies exhibiting this short generation period, seen in areas of diminishing latitudes, were anticipated to produce multiple broods (17). Consequently, *Colotis vestalis* found in southern India between latitudes 8° 10' N and 22° 24' N may produce multiple broods. Throughout its growth, a larva, on average, ingested over 82.86 mg of foliar material. Consumption grew with each instar, with the final two instars accounting for nearly 90% of the overall food intake. Lepidopteran larvae generally show a propensity for increased consumption during the final two instars (13), (18), (19), (20), (21), (22), (23), which offsets the energy expenditure associated with the non-feeding pupal stage (24). The consumption index (CI) and growth rate (GR) inversely correlate with the rising food consumption at subsequent instars. Both CI and GR diminished with larval age, with CI declining from a maximum of 6.31 to a minimum of 1.07 and GR decreasing from a maximum of 0.37 to a minimum of 0.25 (Table 1; Graph 2). The mean values of these two indices were CI = 2.33, with only the first instar surpassing this average, and GR = 0.312, where the first three instars had readings exceeding the average. The CI values fall within the range of 0.31 - 6.60, as predicted for tree foliage chewers (25). The rate of food consumption was contingent upon the conversion efficiency of ingested food to biomass (ECI); as conversion efficiency diminishes, the rate increases, and vice versa (25). Poor conversion efficiency likely caused the high CI value (6.31) of instar I, as evidenced by its lower ECI than later instars. Growth rates were greater at the penultimate instar compared to the last instar (26). The growth rates of the penultimate and final instars of *Colotis vestalis* align with the declining tendency. From instar I to instar V, the approximate digestibility (AD) values decreased, peaking at 97% in instar I when the larval food intake made up 0.86% of the total consumption, and falling to 72% in instar V when the food intake was 69% (Table 1; Graph 2). These results were analogous to the AD values (19-81%) for lepidopteran larvae (24) and *Pericallia ricini* (28.7-84.6%). The mean AD% exceeds 82, and this elevated AD corroborates the assertion of Slansky F. & Scriber J. M. (25) that leaf chewers frequently achieve high AD values. We anticipate elevated AD values when dietary items are abundant in nitrogen and moisture (24). Researchers observed similar results with *Pieris brasicae* (27) and *Euploea core* (28). The values of both ECI and ECD escalated as the larvae matured (Table 1; Graph 2). The escalation was significant from the first instar to the second instar. Notwithstanding the much-elevated CI of the first instar, its conversion efficiency was quite modest. The conversion efficiency significantly increased across all instars, peaking at the fifth instar larvae. This higher efficiency followed the fact that Instar V. *Phaeoba infunata* and *Pachliopta hector* gained more weight and steadily increased ECI and ECD (29). The ECI values varied from 5.4% to 32.1% (average 23.68%), whereas the ECD values ranged from 5.2% to 23.2% (average 18.56%). These values are equivalent to those reported for foliage chewers in general (25). The obtained ECDs were low in comparison to the ADs, and such diminished values were not uncommon (13). This signifies the low efficiency of converting digested food into bodily tissues. People frequently attribute the inadequate use of food to either a lack of certain important nutrients (30) or factors that elevate metabolic energy consumption (31). The trend of ECI values closely mirrored the trend of ECD. The values (5.4–32.1%) found were equivalent to the expected range for foliage chewers (2–31%) (25). Despite expectations that the ECI pattern would resemble the AD pattern (13), the two indices for *Colotis vestalis* do not correlate. Instead, there was a clear upward trend in ECI values, supporting the idea that ECI values have increased since Slansky F. & Scriber J. M. (25). Floral nectar is a crucial nutritional resource for butterflies (32). *Colotis vestalis* butterflies frequently visit flowers to consume nectar; this improves their longevity and egg production. It primarily collects pollen on its proboscis, similar to how butterflies collect pollen on their heads (33). *Colotis vestalis*, a powerful pollinator known for its rapid flight and ability to extract nectar, frequently visits numerous flowers within a given time frame. Such "high-energy" pollinators may traverse distances and facilitate cross-pollination (34), (35).

CONCLUSION

The study on the *Colotis vestalis* butterfly in the Eastern Ghats of Andhra Pradesh provided valuable insights into its ecology, behaviour, and habitat preferences, emphasizing the importance of understanding the environmental factors affecting its life cycle. The study reveals that *C. vestalis* thrives in diverse environments, demonstrating adaptation to various ecological situations. It emphasizes the importance of different vegetation types in sustaining its population, emphasizing the need for conservation initiatives to protect these ecosystems, which are crucial for the overall biodiversity of the region. The study recommends continuous monitoring and habitat restoration for the long-term sustainability of *C. vestalis* populations in the Eastern Ghats due to habitat degradation and climate change concerns. Future research should quantify the effects of environmental variability and human-induced stresses on this species, guiding conservation measures and ensuring the biological equilibrium of the region.

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