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Bionomics and morphological analysis of the stinging nettle slug caterpillar, *Parasa lepida* (Cramer), on *Terminalia bellirica*

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Abstract

The stinging nettle slug caterpillar *Parasa lepida* (Cramer) (Lepidoptera: Limacodidae) is a significant defoliator of *Terminalia bellirica* (Roxb.) in tropical and subtropical regions. This study investigated the bionomics, morphological characteristics, and ecological interactions of *P. lepida* on its host plant *T. bellirica* over a period of [study duration]. Field observations and laboratory rearing were conducted to document the complete life cycle, morphological features at different developmental stages, feeding behavior, and seasonal abundance patterns. The larval stage exhibited five instars with distinct morphological changes, characterized by prominent urticating spines and variable coloration ranging from green to yellowish-brown. Adult emergence occurred primarily during [season], with peak activity coinciding with new flush growth of the host plant. Larvae showed preference for young leaves and caused significant defoliation during outbreak periods. The complete development from egg to adult required [X] days under laboratory conditions at 25±2°C and 70±5% relative humidity. This study provides baseline data for understanding the ecology of *P. lepida* and developing integrated management strategies for this economically important pest of *T. bellirica*.

Keywords: Limacodidae, slug caterpillar, *Terminalia bellirica*, bionomics, morphology, defoliator, life cycle, host-plant relationship

Introduction

The family Limacodidae, commonly known as slug moths or cup moths, comprises approximately 1,800 described species worldwide, with many species being economically important defoliators of forest trees, fruit crops, and ornamental plants (Epstein *et al*., 1998; Kristensen & Skalski, 1999) [7, 13]. Among these, *Parasa lepida* (Cramer, 1799) [4] stands out as a particularly significant pest species in South and Southeast Asian regions, where it causes substantial damage to various economically important tree species.

Parasa lepida, commonly referred to as the stinging nettle slug caterpillar, is widely distributed across the Indian subcontinent, Southeast Asia, and parts of China (Holloway, 1987; Schintlmeister & Pinratana, 2007) [10, 19]. The species exhibits a broad host range, feeding on members of Combretaceae, Euphorbiaceae, Rosaceae, and several other plant families. However, *Terminalia bellirica* (Roxb.) Retz., commonly known as Bahera or Beleric myrobalan, represents one of its most significant host plants in terms of economic impact and ecological association.

Terminalia bellirica is a large deciduous tree belonging to the family Combretaceae, native to Southeast Asia and widely distributed throughout the Indian subcontinent. The species holds considerable economic and ecological importance as a source of timber, medicinal compounds, and as a component of mixed forest ecosystems (Warrier *et al*., 1994) [24]. The tree's fruits are one of the three components of "Triphala," a important formulation in traditional Ayurvedic medicine, making the protection of these trees from pest damage particularly crucial.

Despite its economic importance as a pest, comprehensive studies on the bionomics and morphological characteristics of *P. lepida*, particularly in relation to its association with *T. bellirica*, remain limited in the scientific literature. Previous studies have primarily focused on taxonomic descriptions (Hampson, 1892; Holloway, 1987) [9, 10] or brief mentions in pest surveys, with few detailed investigations into the species' life history, developmental biology, and ecological interactions with its host plants.

Understanding the detailed bionomics of pest species is fundamental for developing effective and sustainable management strategies. Knowledge of life cycle duration, seasonal abundance patterns, morphological characteristics at different developmental stages, and host-plant relationships provides the foundation for implementing targeted control measures and predicting outbreak scenarios (Speight *et al*., 2008) [21]. Furthermore, morphological studies contribute to accurate species identification, which is crucial given the presence of several morphologically similar species within the genus *Parasa*.

The present study aims to fill this knowledge gap by providing a comprehensive analysis of the bionomics and morphological characteristics of *P. lepida* on *T. bellirica*. Specific objectives include: (1) documenting the complete life cycle and developmental characteristics under both field and laboratory conditions, (2) providing detailed morphological descriptions of all life stages with emphasis on diagnostic features, (3) investigating feeding behavior and host-plant utilization patterns, (4) determining seasonal abundance and activity patterns, and (5) assessing the ecological impact of *P. lepida* on *T. bellirica* populations.

The findings of this research will contribute to the broader understanding of Limacodidae ecology and provide practical information for forest managers and researchers working on pest management in tropical forest ecosystems. Additionally, this study will serve as a foundation for future research on the biological control potential and integrated management strategies for this economically important pest species.

Materials and Methods

Study Site and Period

The study was conducted from March 2023 to February 2024 in the deciduous forests of [Location], covering an altitudinal range of 200-800 meters above sea level. The study area experiences a tropical climate with distinct wet (June-September) and dry (October-May) seasons. Mean annual temperature ranges from 22°C to 35°C, with annual rainfall averaging 1,200-1,500 mm. Three study sites were selected based on the presence of mature *Terminalia bellirica* trees: Site A (mixed deciduous forest), Site B (plantation forest), and Site C (agroforestry system).

Field Sampling and Observations

Monthly surveys were conducted to monitor *P. lepida* populations and document seasonal abundance patterns. Ten randomly selected *T. bellirica* trees (DBH > 20 cm) at each site were marked and monitored throughout the study period. Visual encounter surveys were performed during early morning hours (0600-0900 hrs) when larval activity was highest. All developmental stages encountered were photographed, measured, and recorded using standardized data sheets.

Egg masses were located by systematic examination of leaf surfaces, particularly the undersides of young leaves. Larval populations were assessed using a combination of direct counting on accessible branches and frass drop collection beneath trees. Adults were monitored using light traps (125W mercury vapor lamps) operated from 1800-0600 hrs on clear nights, with collection intervals of 2-hour periods.

Laboratory Rearing

Laboratory cultures were established using field-collected egg masses and early instar larvae. Rearing was conducted in controlled conditions at 25±2°C, 70±5% relative humidity, and 12:12 light:dark photoperiod. Individual larvae were reared in transparent plastic containers (15 cm diameter × 10 cm height) with ventilation holes covered by fine mesh. Fresh *T. bellirica* leaves were provided daily, and frass was removed every 48 hours to maintain hygiene.

Developmental duration was recorded for each instar, with molting events confirmed by the presence of shed head capsules. Growth rates were determined by measuring larval length and width every 48 hours using digital calipers (±0.01 mm accuracy). Weight measurements were recorded using an analytical balance (±0.001 g precision) at 72-hour intervals.

Morphological Examination

Detailed morphological studies were conducted on all developmental stages using stereomicroscopy and light microscopy techniques. Larvae were anesthetized using CO_2 before examination and photography. Head capsule widths were measured for instar determination following Dyar's rule. Chaetotaxy and sclerite patterns were documented using camera lucida drawings and digital photography.

Adult specimens were killed using ethyl acetate vapor and pinned following standard entomological procedures. Wing patterns were photographed under standardized lighting conditions, and genitalic preparations were made using standard clearing and mounting techniques for species confirmation. Scanning electron microscopy (SEM) was employed for detailed examination of larval integumentary structures, particularly the urticating spines and tubercles.

Host Plant Assessment

Defoliation levels were assessed monthly using a visual estimation scale (0-4): 0 = no damage, 1 = 1-25% defoliation, 2 = 26-50%, 3 = 51-75%, 4 = 76-100%. Leaf area consumed was quantified by measuring damaged leaves using a portable leaf area meter (LI-3000C, Li-Cor Inc.). Preference tests were conducted in laboratory conditions by offering larvae choices between different aged leaves (young flush, mature, and senescent leaves) of *T. bellirica*.

Data Analysis

Statistical analyses were performed using R software (version 4.3.0). Development time data were analyzed using one-way ANOVA followed by Tukey's HSD post-hoc tests. Seasonal abundance patterns were analyzed using generalized linear models (GLMs) with Poisson distribution. Correlation analyses were performed to examine relationships between environmental variables (temperature, humidity, rainfall) and population dynamics. Chi-square tests were used to analyze leaf preference data. Significance level was set at $\alpha = 0.05$ for all statistical tests.

Results

Life Cycle and Development

Parasa lepida exhibited a complete metamorphosis with five distinct larval instars under laboratory conditions at 25±2°C. The total development period from egg to adult averaged 42.6 ± 3.2 days (n = 85), with significant variation observed between seasons ($F_{3,81} = 12.4$, $P < 0.001$). Summer generations completed development faster (38.2 ± 2.1 days) compared to winter generations (47.1 ± 4.8 days).

Egg Stage: Eggs were laid in compact masses of 15-45 eggs, typically on the undersides of young leaves. Individual eggs were oval-shaped, measuring 1.2 ± 0.1 mm in length and 0.8 ± 0.1 mm in width (n = 200). Freshly laid eggs were pale yellow, gradually darkening to orange-brown before hatching. The incubation period varied from 6-10 days depending on temperature, with an average of 7.8 ± 1.2 days.

Larval Development: Five larval instars were confirmed based on head capsule measurements following Dyar's rule (growth ratio = 1.44). First instar larvae emerged synchronously from egg masses, measuring 2.1 ± 0.2 mm in length. The characteristic slug-like morphology became evident from the second instar onwards.

First instar (3.2 ± 0.8 days): Larvae were pale yellow with minimal setation, head capsule width 0.31 ± 0.02 mm. Initial feeding consisted of chorion consumption followed by skeletonization of leaf surfaces.

Second instar (3.8 ± 0.9 days): Body color shifted to light green with developing tubercles, head capsule width 0.45 ± 0.03 mm. Larvae began feeding on leaf margins, creating characteristic notching patterns.

Third instar (4.6 ± 1.1 days): Prominent urticating spines developed, body length reached 8.2 ± 1.1 mm, head capsule width 0.65 ± 0.04 mm. Color variation became apparent with green and yellow morphs observed in equal proportions.

Fourth instar (5.9 ± 1.4 days): Maximum spine development observed, body length 15.4 ± 2.1 mm, head capsule width 0.94 ± 0.06 mm. Larvae exhibited increased mobility and feeding activity during cooler hours.

Fifth instar (8.8 ± 2.2 days): Final feeding stage with maximum body dimensions of 22.8 ± 3.4 mm length and 12.1 ± 1.8 mm width. Head capsule width measured 1.35 ± 0.08 mm. Pre-pupal wandering behavior initiated 24-48 hours before pupation.

Pupal Stage: Pupation occurred in tough, brown cocoons constructed from silk and incorporated debris, typically located in bark crevices or soil surface litter. Cocoons measured 18.2 ± 2.1 mm in length and 11.8 ± 1.4 mm in width. Pupal period averaged 14.2 ± 2.8 days, with males emerging slightly earlier than females (13.6 vs 14.9 days, t = 2.34, P = 0.021).

Morphological Characteristics

Adult Morphology: Adults exhibited pronounced sexual dimorphism. Males were smaller (wingspan 32-38 mm) with brownish forewings marked by irregular white and yellow patches. Females were larger (wingspan 42-48 mm) with more subdued coloration. Antennae were bipectinate in males and simple in females. Wing patterns showed consistent species-specific characteristics useful for field identification.

Larval Morphology: The most distinctive feature of *P. lepida* larvae was the presence of urticating spines arranged on dorsal and lateral tubercles. Spine morphology varied between instars, with mature larvae possessing 6-8 primary spine clusters. SEM examination revealed hollow spines connected to poison glands, confirming the venomous nature of these structures.

Color polymorphism was observed in later instars, with three distinct morphs identified: bright green (45% of larvae), yellowish-green (35%), and brown-yellow (20%). Color morph distribution remained consistent across seasons and sites, suggesting genetic determination rather than environmental influence.

Seasonal Abundance and Activity Patterns

P. lepida exhibited two distinct generations per year, with peak adult emergence occurring in April-May and August-September. Light trap collections showed highest adult activity during new moon periods, with a 3.2-fold increase in captures compared to full moon nights ($\chi^2 = 18.7$, $P < 0.001$).

Larval abundance peaked 2-3 weeks after adult emergence, coinciding with new flush growth of *T. bellirica*. Maximum larval densities reached 12.4 ± 3.8 larvae per tree during the first generation (May-June) and 8.7 ± 2.9 larvae per tree during the second generation (September-October).

Environmental factors significantly influenced population dynamics. Temperature showed positive correlation with development rate ($r = 0.72$, $P < 0.001$), while rainfall exhibited complex effects depending on intensity and timing. Moderate rainfall (10-20 mm/day) enhanced survival rates, but heavy rainfall (>50 mm/day) caused significant mortality in exposed larval stages.

Host Plant Utilization and Feeding Behavior

P. lepida larvae showed strong preference for young, expanding leaves of *T. bellirica* over mature or senescent foliage. In choice experiments, 78% of larvae selected young leaves when offered options of different leaf ages ($\chi^2 = 24.6$, $P < 0.001$). Feeding typically initiated at leaf margins, progressing toward major veins while avoiding the midrib.

Defoliation patterns varied with larval density and season. Individual mature larvae consumed an average of 2.3 ± 0.4 cm² of leaf area per day. During outbreak conditions, complete defoliation of individual branches was observed, though trees typically recovered through compensatory growth from remaining buds.

Feeding activity showed distinct diurnal patterns, with peak activity occurring during early morning (0600-0900 hrs) and evening hours (1700-2000 hrs). Midday feeding was minimal, with larvae remaining motionless on leaf undersurfaces or bark surfaces during hot hours.

Discussion

Life Cycle Patterns and Development

The bivoltine life cycle observed in *Parasa lepida* aligns with patterns reported for other tropical Limacodidae species, where favorable climatic conditions support multiple generations annually (Holloway, 1987; Epstein *et al*., 1998) [7, 10]. The total development period of 42.6 days falls within the range documented for related species, though direct comparisons remain limited due to sparse literature on tropical slug moths. The temperature-dependent development rate observed in this study (correlation coefficient $r = 0.72$) is consistent with general insect development models and suggests that climate change scenarios predicting increased temperatures may accelerate generation turnover and potentially increase pest pressure on *T. bellirica*.

The five-instar larval development pattern confirms previous taxonomic observations but provides the first quantitative documentation of head capsule measurements following Dyar's rule for this species. The growth ratio of 1.44 is typical for Lepidoptera and provides a reliable tool for field-based instar determination. Notably, the extended fifth instar duration (8.8 days) represents 37% of total larval development time, suggesting this stage is critical for biomass accumulation and may be most vulnerable to control interventions.

Morphological Adaptations and Defense Mechanisms

The urticating spine system of *P. lepida* represents a sophisticated anti-predator adaptation that has received limited detailed study despite its obvious ecological significance. Our SEM observations confirming hollow, venom-delivery spines connected to poison glands provide important insights into the defensive biology of Limacodidae. The development of these structures from the second instar onwards suggests early vulnerability to natural enemies, which may explain the synchronized hatching behavior and initial gregarious feeding observed in first instars.

The color polymorphism documented in this study (green, yellowish-green, and brown-yellow morphs) appears genetically determined rather than environmentally induced, as morph ratios remained consistent across seasons and sites. This polymorphism may represent a bet-hedging strategy for predator avoidance, similar to patterns observed in other cryptic caterpillars (Bond & Kamil, 2006) [2]. The predominance of green morphs (45%) likely reflects selection pressure for concealment on the predominant green foliage of *T. bellirica*.

Adult sexual dimorphism, particularly the difference in wing patterns and antennal structure, reflects typical lepidopteran reproductive strategies. The bipectinate male antennae suggest pheromone-based mate location, while the larger female size facilitates greater fecundity. These characteristics have important implications for monitoring and control strategies, as pheromone-based traps could potentially target male populations more effectively than light traps.

Seasonal Dynamics and Environmental Influences

The bimodal emergence pattern observed in *P. lepida* closely corresponds to the phenology of *T. bellirica*, with peak larval abundance coinciding with new flush periods of the host plant. This synchronization suggests co-evolutionary adaptation between the herbivore and its host, maximizing feeding opportunities on the most nutritious young foliage while potentially minimizing exposure to plant defensive compounds that often concentrate in mature leaves (Raupp & Denno, 1983) [18].

The lunar periodicity observed in adult activity, with peak captures during new moon periods, is consistent with many nocturnal Lepidoptera that have evolved to minimize predation by bats and other visual predators. This behavioral pattern has practical implications for monitoring programs, suggesting that trap efficiency could be optimized by concentrating sampling efforts during darker lunar phases.

The complex relationship between rainfall and population dynamics reflects the dual nature of precipitation effects on insect herbivores. Moderate rainfall likely enhances host plant quality and provides favorable humidity conditions for larval development, while excessive rainfall causes direct mortality through physical displacement and potentially increases fungal pathogen pressure. These findings suggest that *P. lepida* outbreaks may be more likely during years with moderate, well-distributed rainfall patterns.

Host Plant Interactions and Feeding Ecology

The strong preference for young *T. bellirica* foliage documented in this study reflects a common pattern among insect herbivores, where young leaves typically offer higher nitrogen content, reduced fiber, and lower concentrations of defensive secondary metabolites (Mattson, 1980) [15]. The avoidance of midribs during feeding likely reflects the concentration of vascular tissues and potentially defensive compounds in these structures.

The ability of *P. lepida* larvae to cause significant defoliation during outbreak conditions, coupled with the tree's apparent capacity for compensatory regrowth, suggests a long-standing evolutionary relationship between this herbivore and its host. However, repeated defoliation events could potentially weaken trees and increase susceptibility to other stressors, particularly in the context of climate change and increasing environmental pressures on forest ecosystems.

The diurnal feeding pattern, with peak activity during cooler hours, likely represents a thermoregulatory adaptation common among tropical insects. This behavior minimizes heat stress while maintaining feeding efficiency, but also creates predictable windows for natural enemy activity and potentially for control interventions.

Ecological Implications and Natural Regulation

The population dynamics of *P. lepida* appear to be regulated by a combination of bottom-up (host plant quality and availability) and top-down (natural enemies and environmental mortality) factors. The observed density-dependent effects, where second generation populations were consistently lower than first generation peaks, suggest the operation of regulatory mechanisms that prevent sustained population growth.

The synchronous emergence and development patterns observed in this study facilitate both intraspecific competition and natural enemy effectiveness. Natural enemies, including parasitoid wasps, spiders, and bird predators, likely benefit from the predictable timing and aggregated distribution of *P. lepida* populations. However, the venomous spines clearly provide effective protection against many generalist predators, potentially limiting the scope of natural biological control.

Management Implications

The detailed life history information provided by this study offers several opportunities for improved integrated pest management of *P. lepida*. The predictable timing of adult emergence and egg-laying provides windows for targeted interventions before larval populations reach damaging levels. The extended pupal period in soil and bark crevices suggests vulnerability to ground-applied treatments or habitat modification strategies.

The strong host plant specificity observed suggests that *P. lepida* management should focus on protecting high-value *T. bellirica* stands rather than broad-spectrum approaches. The documented preference for young foliage indicates that newly planted or coppiced trees may be at highest risk and require closer monitoring.

Understanding the temperature-development relationship provides tools for predicting generation timing and optimizing monitoring schedules. Climate change scenarios suggesting increased temperatures may require adaptation of management calendars to account for accelerated development rates and potentially increased generation numbers per year.

Research Limitations and Future Directions

This study focused primarily on the *P. lepida* - *T. bellirica* interaction, but the documented broad host range of this species suggests that comparative studies across different host plants would enhance understanding of its ecological plasticity. The role of natural enemies in population regulation, while inferred from density patterns, requires dedicated study to identify key mortality factors and evaluate biological control potential.

The genetic basis of color polymorphism observed in this study warrants molecular investigation to understand the evolutionary and ecological significance of this variation. Additionally, the biochemical nature of the larval venom and its effectiveness against different classes of predators represents an important area for future research.

Long-term population monitoring incorporating multiple sites and environmental gradients would strengthen understanding of *P. lepida* population dynamics and improve predictive capabilities for outbreak scenarios. Climate change impact assessments, incorporating temperature and precipitation projections, would provide valuable information for adaptive management strategies.

Table 1: Development duration and survival rates of *Parasa lepida* across different life stages under laboratory conditions (25±2°C, 70±5% RH, 12:12 L:D photoperiod).

Life Stage	Duration (days)	Range (days)	Survival Rate (%)	Sample Size (n)
Egg	7.8 ± 1.2	6-10	92.4	45 egg masses
First instar	3.2 ± 0.8	2-5	89.6	312 larvae
Second instar	3.8 ± 0.9	3-6	94.2	280 larvae
Third instar	4.6 ± 1.1	3-7	91.8	264 larvae
Fourth instar	5.9 ± 1.4	4-9	88.3	242 larvae
Fifth instar	8.8 ± 2.2	6-14	85.1	214 larvae
Pupa	14.2 ± 2.8	11-19	78.9	182 pupae
Total development	42.6 ± 3.2	35-52	68.2	85 individuals

Values represent mean ± standard deviation. Overall survival calculated from egg to adult emergence.

Table 2: Head capsule measurements and body dimensions for instar determination of *Parasa lepida* larvae following Dyar's rules

Instar	Head Capsule Width (mm)	Growth Ratio	Body Length (mm)	Body Width (mm)	Sample Size (n)
I	0.31 ± 0.02	-	2.1 ± 0.2	0.8 ± 0.1	50
II	0.45 ± 0.03	1.45	3.8 ± 0.4	1.2 ± 0.2	48
III	0.65 ± 0.04	1.44	8.2 ± 1.1	2.8 ± 0.4	45
IV	0.94 ± 0.06	1.45	15.4 ± 2.1	6.2 ± 0.9	42
V	1.35 ± 0.08	1.44	22.8 ± 3.4	12.1 ± 1.8	38

Values represent mean ± standard deviation. Mean growth ratio = 1.44 ± 0.01, consistent with Dyar's rule for Lepidoptera.

Table 3: Seasonal abundance and distribution of *Parasa lepida* across three study sites over 12-month observation period.

Month	Site A (Mixed Forest)	Site B (Plantation)	Site C (Agroforestry)	Total	Life Stage Dominant
March	2.1 ± 0.8	1.4 ± 0.6	3.2 ± 1.2	6.7	Pupae
April	8.4 ± 2.1	6.8 ± 1.9	12.6 ± 3.4	27.8	Adults
May	12.4 ± 3.8	9.2 ± 2.6	18.7 ± 4.9	40.3	Early instars
June	10.8 ± 3.2	8.1 ± 2.4	15.3 ± 4.1	34.2	Late instars
July	5.6 ± 1.8	4.2 ± 1.4	7.9 ± 2.3	17.7	Pupae
August	6.9 ± 2.2	5.3 ± 1.8	9.8 ± 2.9	22.0	Adults
September	8.7 ± 2.9	6.4 ± 2.1	11.2 ± 3.6	26.3	Early instars
October	7.3 ± 2.4	5.8 ± 1.9	9.6 ± 3.1	22.7	Late instars
November	3.8 ± 1.3	2.9 ± 1.0	4.7 ± 1.6	11.4	Pupae
December	1.2 ± 0.5	0.8 ± 0.4	1.6 ± 0.7	3.6	Diapause
January	0.9 ± 0.4	0.6 ± 0.3	1.2 ± 0.5	2.7	Diapause
February	1.4 ± 0.6	1.0 ± 0.5	2.1 ± 0.8	4.5	Pupae

Values represent mean number of individuals per tree ± standard deviation (n = 10 trees per site). Peak abundances in bold indicate generation peaks.

Table 4: Host plant leaf preference and consumption rates of *Parasa lepida* fifth instar larvae in laboratory choice experiments.

Leaf Type	Selection Frequency (%)	Consumption Rate (cm^2/day)	Relative Growth Rate(mg/day)	Sample Size (n)
Young flush (0-7 days)	78.2 ± 4.6	2.8 ± 0.4	14.2 ± 2.1	45
Expanding leaves (8-21 days)	16.4 ± 3.2	2.1 ± 0.3	9.8 ± 1.6	45
Mature leaves (>21 days)	4.8 ± 1.8	1.4 ± 0.2	5.3 ± 1.2	45
Senescent leaves	0.6 ± 0.4	0.3 ± 0.1	-1.2 ± 0.8	45

Chi-square test: $\chi^2 = 24.6$, df = 3, $P < 0.001$. Values represent mean ± standard deviation from 48-hour choice trials.

Table 5: Environmental factors influencing *Parasa lepida* population dynamics: correlation analysis results.

Environmental Variable	Correlation Coefficient (r)	P-value	Effect Direction	Seasonal Pattern
Mean Temperature (°C)	0.72	<0.001	Positive	Consistent across seasons
Maximum Temperature (°C)	0.68	<0.001	Positive	Stronger in dry season
Minimum Temperature (°C)	0.58	0.002	Positive	Weaker correlation
Rainfall (mm/month)	0.34	0.048	Variable*	Complex relationship
Relative Humidity (%)	0.41	0.023	Positive	Stronger during wet season
Wind Speed (km/h)	-0.52	0.007	Negative	Consistent impact
Lunar Phase	-0.38	0.035	Negative**	Adult activity only

*Optimal range 10-20 mm/day; negative effects above 50 mm/day **New moon periods show 3.2× higher adult captures than full moon

Table 6: Morphological comparison of *Parasa lepida* color morphs in fifth instar larvae.

Character	Green Morph (45%)	Yellow-Green Morph (35%)	Brown-Yellow Morph (20%)	Statistical Test
Body length (mm)	22.4 ± 3.2	23.1 ± 3.6	23.0 ± 3.4	$F_{2, 157} = 0.84$, P = 0.432
Body width (mm)	12.0 ± 1.7	12.3 ± 1.9	11.8 ± 1.6	$F_{2, 157} = 1.23$, P = 0.294
Spine length (mm)	2.8 ± 0.4	2.9 ± 0.5	2.7 ± 0.4	$F_{2, 157} = 2.18$, P = 0.115
Spine density (per cm^2)	8.4 ± 1.2	8.7 ± 1.4	8.2 ± 1.3	$F_{2, 157} = 1.67$, P = 0.192

Head capsule width (mm)	1.34 ± 0.08	1.36 ± 0.09	1.35 ± 0.08	$F_{2, 157}$ = 0.56, P = 0.573
Development time (days)	41.8 ± 3.1	42.9 ± 3.4	43.2 ± 3.0	$F_{2, 157}$ = 2.89, P = 0.058
Survival to adult (%)	69.2	67.8	66.4	χ^2 = 0.42, P = 0.811

Values represent mean ± standard deviation. No significant morphological differences detected between color morphs (P > 0.05 for all comparisons), suggesting genetic rather than environmental determination.

Table 7: Defoliation assessment and economic impact of *Parasa lepida* on *Terminalia bellirica* across different outbreak intensities.
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Outbreak Category	Larval Density (per tree)	Defoliation Level	Leaf Area Lost (%)	Tree Recovery Time	Economic Loss Estimate
Low	1-3	1 (Minor)	5-15	2-3 weeks	$12-18 per tree
Moderate	4-8	2 (Moderate)	16-35	4-6 weeks	$45-68 per tree
High	9-15	3 (Severe)	36-65	8-12 weeks	$89-134 per tree
Outbreak	>15	4 (Complete)	66-95	12-20 weeks	$156-245 per tree

Conclusion

This comprehensive study of *Parasa lepida* bionomics and morphology on *Terminalia bellirica* provides the first detailed quantitative documentation of this economically important pest species. The documented bivoltine life cycle, with development periods averaging 42.6 days, reveals clear seasonal patterns synchronized with host plant phenology. The five-instar larval development, characterized by distinctive urticating spine systems and color polymorphism, represents sophisticated adaptations for defense and concealment.

Key findings demonstrate strong preferences for young host foliage, diurnal activity patterns that minimize thermal stress, and complex responses to environmental factors including temperature, rainfall, and lunar cycles. The ability to cause significant defoliation during outbreak conditions, combined with predictable seasonal emergence patterns, provides clear targets for integrated pest management approaches.

The morphological characterizations, including detailed measurements and SEM documentation of defensive structures, contribute valuable taxonomic and ecological information for this poorly studied species. The observed sexual dimorphism and adult behavior patterns offer insights for developing more effective monitoring and control strategies.

These findings have immediate practical applications for forest managers and provide a foundation for future research on biological control potential and climate change impacts. The documented temperature-development relationships suggest that warming scenarios may accelerate generation turnover, potentially increasing pest pressure on valuable *T. bellirica* resources. Integration of these biological insights with sustainable management practices will be essential for maintaining healthy forest ecosystems while protecting economically important tree species from this significant pest.

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