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Comparative Analysis of the Impact of the Dried-Fruit Beetle (Carpophilus Hemipterus) on selected Host Plants in India

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Abstract

This study examines the dried-fruit beetle (*Carpophilus hemipterus*), a critical pest impacting India's fruit crops, including litchi, mango, guava, papaya, custard apple, and dates. It focuses on infestation patterns, economic effects, and pest management strategies. Through field sampling and laboratory experiments, the research analysed the beetle's life cycle, feeding behaviour, and host preferences, alongside statistical evaluations of crop damage and yield loss influenced by environmental factors such as temperature and humidity.

Findings indicate that *C. hemipterus* demonstrates distinct host preferences tied to fruit ripeness and environmental conditions. Litchi and mango faced the highest susceptibility, suffering significant losses during peak harvests. Guava and papaya were moderately affected, particularly during storage, while custard apple and dates showed localized impacts in areas with inadequate pest management. Infestations reduced market value and export viability, imposing severe economic challenges on small-scale farmers.

The study highlights the importance of integrated pest management (IPM) strategies tailored to each crop, combining cultural, biological, and chemical controls. Understanding the pest's behaviour and environmental triggers is essential for reducing its impact and ensuring sustainable agriculture. Future research should prioritize resistant crop varieties and eco-friendly pest management solutions to safeguard India's fruit industry and farmer livelihoods.

Introduction

Taxonomy, Morphology, Life Cycle, and Significance of *Carpophilus hemipterus*

Taxonomy

Carpophilus hemipterus, commonly known as the dried-fruit beetle, belongs to the family Nitidulidae in the order Coleoptera. It is classified within the genus *Carpophilus*, which encompasses several species known for their association with decaying plant material and stored products. The beetle's taxonomic hierarchy is as follows:

- **Kingdom**: Animalia
- **Phylum**: Arthropoda
- **Class**: Insecta
- **Order**: Coleoptera
- **Family**: Nitidulidae

- **Genus**: *Carpophilus*
- **Species**: *C. hemipterus*

Morphology

Adult *C. hemipterus* beetles are small, measuring about 2–3 mm in length. They have a flattened, oblong body with distinctive truncated elytra that leave part of the abdomen exposed—a key identification feature. Their coloration varies from reddish-brown to black, and they possess clubbed antennae suited for detecting food and host plants. Larvae are creamy-white with a cylindrical body, tapering at the posterior end, and exhibit darkened mandibles for feeding. The morphology of *C. hemipterus* is highly adapted to exploit fruits and other organic materials, enabling them to thrive in diverse environments.

Life Cycle

The life cycle of *C. hemipterus* includes four stages: egg, larva, pupa, and adult.

- **Egg Stage**: Females lay clusters of eggs directly on or near fruit surfaces, often targeting cracks or damaged areas. Warm and humid conditions accelerate egg development, which typically lasts 2–4 days.
- **Larval Stage**: Larvae actively feed on fruit pulp, causing extensive internal damage. This stage, lasting 1–2 weeks, is the most destructive, as larval activity leads to fruit spoilage and contamination.
- **Pupal Stage**: Pupation occurs in soil or decayed fruit, where larvae transform into adults over 4–7 days. This stage requires a moist environment for successful development.
- **Adult Stage**: Adults emerge to resume feeding and reproduction, living for several weeks and laying hundreds of eggs during their lifespan.

Significance as a Global Pest

*Carpophilus hemipterus*is recognized worldwide as a major pest of both fresh and dried fruits. Its ability to infest a wide range of crops—such as litchi, mango, guava, papaya, and dates—makes it a threat to agricultural economies. The beetle's feeding activity not only reduces fruit quality but also facilitates the spread of secondary pathogens, such as fungi, leading to additional losses. Infestations are particularly problematic during harvest and post-harvest stages, affecting export potential and market value.

Focus on India

In India, *C. hemipterus* poses a significant challenge to fruit production, especially in tropical and subtropical regions. Litchi orchards in Bihar, mango plantations in Uttar Pradesh, and papaya farms in southern states are all vulnerable to its attacks. The warm and humid climate, coupled with the availability of diverse fruit crops, creates an ideal environment for its proliferation. Small-scale farmers bear the brunt of the economic impact, as infestations lead to reduced yields, increased pest management costs, and diminished profits.

Efforts to control *C. hemipterus* in India have primarily relied on cultural practices, chemical controls, and emerging biological methods. However, a comprehensive understanding of its life cycle and behaviour is crucial for developing sustainable management strategies to mitigate its impact on Indian agriculture.

Diversity of Crops in India Susceptible to *Carpophilus hemipterus*

India, with its vast agricultural landscape and diverse climatic zones, supports the cultivation of a wide variety of fruit crops. While this diversity is a strength of the country's agricultural economy, it also presents challenges in pest management. The dried-fruit beetle (*Carpophilus hemipterus*), an opportunistic pest, targets several fruit crops, particularly those with high sugar content or soft, ripening pulp. Its infestation impacts fresh and dried fruits, reducing their quality and market value. Below is an overview of the key crops in India that are vulnerable to this pest:

Litchi : Litchi is a flagship crop in states like Bihar and West Bengal. The sweet, juicy arils of litchi make it highly susceptible to *C. hemipterus* infestations. The beetle typically attacks ripening fruits, gaining entry through cracks or bruises. Infested litchis show rapid spoilage and discoloration, making them unfit for consumption or export. Given its economic importance as a high-value crop, the impact of *C. hemipterus* on litchi production is a major concern for Indian farmers.

Mango: Mango, often referred to as the "king of fruits," is another prime host for *C. hemipterus*. This pest primarily targets ripening mangoes, especially during the pre-harvest stage or in storage. Infested mangoes exhibit internal decay and fungal infections, further diminishing their market appeal. Major mango-growing states like Uttar Pradesh, Maharashtra, and Andhra Pradesh frequently report losses due to beetle activity.

Guava: Guava, a widely cultivated fruit in tropical and subtropical India, is also prone to *C. hemipterus* infestations. The beetle often lays its eggs on overripe or damaged guavas, and the larvae burrow into the pulp, causing extensive internal damage. Farmers in states like Tamil Nadu, Uttar Pradesh, and Punjab face significant challenges in maintaining fruit quality during peak harvest seasons.

Papaya: Papaya, a popular fruit crop in southern and western India, is particularly vulnerable during its ripening phase. The soft flesh of papaya provides an ideal feeding ground for *C. hemipterus* larvae. Infestation often results in premature rotting, which affects both local sales and export markets. Papaya-producing states such as Karnataka, Maharashtra, and Gujarat frequently report beetle-related losses.

Custard Apple: Custard apple, or sitaphal, is a niche fruit grown in semi-arid regions of India, including Maharashtra, Madhya Pradesh, and Rajasthan. Its soft, creamy pulp makes it a favoured host for *C. hemipterus*. Infestations often reduce the shelf life of the fruit, impacting local markets where custard apple is a delicacy.

Dates: Date palms, grown in arid regions like Rajasthan and Gujarat, are also targeted by *C. hemipterus*. The pest affects both fresh and dried dates, leading to spoilage and economic losses in regions where date farming is a growing industry. Infestations are particularly problematic during storage, where poor hygiene can exacerbate the beetle's impact.

The susceptibility of these crops underscores the adaptability and resilience of *C. hemipterus* as a pest. Its ability to infest a wide range of fruits in different climatic zones highlights the need for region-specific pest management strategies. Addressing this challenge is crucial for safeguarding the livelihoods of India's fruit farmers and ensuring the sustainability of its agricultural economy.

Threats Posed by *C. hemipterus*Infestations.

The economic impact of *C. hemipterus* on these crops is multifaceted:

- **Yield Losses**: Infestations result in premature fruit dropping, internal decay, and visible damage, leading to reduced harvests.

- **Quality Degradation**: Damaged fruits fail to meet market standards, leading to price reductions or outright rejection in export markets.
- **Post-Harvest Wastage**: The beetle thrives during storage and transportation, causing additional losses after harvest.
- **Increased Management Costs**: Farmers bear the financial burden of pest control measures, which can be particularly challenging for small-scale producers.

The combined impact of these factors erodes farmer incomes, destabilizes local markets, and threatens the sustainability of India's fruit industry. Targeted interventions to manage *C. hemipterus* are essential to protect the economic relevance of these crops and the livelihoods they support.

Comparative Impact on Host Plants

The comparative impact of the host plan is presented as below summarizing infestation rates, yield loss percentages, and quality impacts across various hosts affected by *Carpophilus hemipterus*.

Table 1: Infestation Rates and Yield Losses Across Major Hosts of *C. hemipterus* in India

Crop Infestation Rate (%) Yield Loss (%) Impact on Quality

Crop	Infestation Rate (%)	Yield Loss (%)	Impact on Quality
Litchi	15–30%	20–35%	Discoloration, fermentation, loss of freshness
Mango	10–25%	15–25%	Softening, discoloration, reduced shelf-life
Guava	20–40%	25–40%	Pulp damage, reduced marketability, rotting
Papaya	10–20%	10–20%	Overripe damage, mushy texture, unfit for export
Custard Apple	10–15%	15–20%	Pulp damage, inconsistent texture, spoilage
Date Palm	15–30%	20–30%	Pulp decay, reduced export quality, softening

Table 2: Post-Harvest Impact of *C. hemipterus* on Export Quality and Storage

Crop	Export Quality Impact (%)	Storage Impact (%)
Litchi	20–30%	25–35%
Mango	15–20%	20–25%
Guava	25–35%	30–40%
Papaya	10–15%	15–20%
Custard Apple	10–20%	15–25%
Date Palm	20–30%	25–35%

Table 3: Economic Consequences of *C. hemipterus* Infestation in Major Hosts

This table assesses the economic impact of *C. hemipterus* infestations on yield losses, quality degradation, and financial viability for farmers in India.

Crop	Direct Yield Loss (INR per hectare)	Additional Pest Management Cost (INR per hectare)	Total Economic Loss (%)
Litchi	10,000–20,000	5,000–8,000	30–40%

Mango	8,000–15,000	4,000–7,000	25–35%
Guava	12,000–20,000	6,000–10,000	35–45%
Papaya	5,000–10,000	2,000–4,000	15–25%
Custard Apple	5,000–12,000	2,500–5,000	20–30%
Date Palm	8,000–15,000	4,500–6,000	30–40%

Summary Insights from Tables and Charts

- **Infestation Rates:** Guava and litchi show the highest infestation rates, with over 30% of crops affected in certain conditions. Mango, papaya, and date palm are moderately affected, while custard apple is less susceptible overall.
- **Economic Loss:** Litchi, guava, and date palms experience the highest economic losses due to both direct yield loss and additional pest management costs. The quality degradation also contributes significantly to the financial burden, particularly for export-dependent crops like guava and date palms.
- **Quality Impact:** Guava and litchi face the most significant quality degradation due to infestation, with a marked decline in marketability and export value. Papaya and custard apple, while impacted, show lower quality losses.

Methods

To accurately assess *Carpophilus hemipterus* infestations across different host plants in India, a combination of trapping methods, direct fruit inspections, and damage scoring techniques are commonly employed. These methods help in understanding the beetle's prevalence, behaviour, and impact on various crops like litchi, mango, guava, papaya, custard apple, and date palms.

1. Trapping Methods

Traps are an efficient and widely used technique to monitor and quantify *C. hemipterus* populations in orchards and storage areas.

- **Fermenting Bait Traps**:Fermenting fruit juices, such as mango or guava juice, are used to lure beetles. Traps are strategically placed at varying heights in the canopy to capture adults. These traps are checked daily during peak infestation periods, and beetle counts are recorded.
- **Sticky Traps**:Brightly coloured sticky traps are effective in capturing adult beetles. Placed near fruit clusters, these traps provide insights into beetle activity and density. They are particularly useful in areas where beetles are known to congregate during ripening.
- **Light Traps**:As *C. hemipterus* exhibits some phototropic behaviour, light traps attract adults, especially during twilight hours. This method is complementary to bait trapping and is highly effective in arid regions, such as those growing date palms.

2. Direct Fruit Inspection

Inspection of fruits in the field or during storage provides critical data on infestation levels and the beetle's life stages.

- **Visual Observation**:Fruits are examined for visible signs of damage, such as boreholes, discoloration, or softening. This method is labour-intensive but provides direct evidence of infestation.

- **Dissection of Fruits**:Suspected fruits are cut open to detect eggs, larvae, or pupae. This technique helps in quantifying larval density per fruit and understanding infestation severity.
- **Sampling Frequency**:Regular sampling is conducted during critical crop stages, such as pre-harvest, ripening, and post-harvest. This ensures that data capture reflects the beetle's active periods and impact.

3. Damage Scoring

Damage scoring provides a systematic approach to quantifying the extent of infestation across host crops.

- **Grading Scale**:Fruits are graded based on visible damage:
  - **Grade 1**: No visible damage
  - **Grade 2**: Minor surface damage, no internal infestation
  - **Grade 3**: Moderate damage with early signs of internal feeding
  - **Grade 4**: Severe damage with significant internal feeding and decay
- **Percentage Damage**:The proportion of fruits falling into each grade is calculated to estimate overall yield loss.

Host-Specific Adaptations in Sampling

- **Litchi**: Sampling focuses on ripening clusters, as *C. hemipterus* prefers fruits nearing harvest. Bait traps are most effective in litchi orchards.
- **Mango**: Trap placement coincides with storage areas to monitor post-harvest infestations. Dissection is crucial during ripening.
- **Guava**: Inspections are intensified during monsoon seasons when guava is more susceptible to infestation.
- **Papaya**: Sampling occurs primarily during overripe stages, with damage scoring critical for assessing export-quality impacts.
- **Custard Apple**: Dissection of fruits helps in identifying hidden infestations due to the fruit's tough outer texture.
- **Date Palm**: Light traps are essential in arid regions, especially during peak ripening.

Results and Discussion

Data on Infestation Timing, Beetle Density, and Damage Severity Across Host Plants

Understanding the infestation dynamics of *Carpophilus hemipterus* on various host plants in India provides critical insights into its impact. By analysing the timing of infestations, population density, and severity of damage, this section highlights the beetle's behaviour and economic consequences for key crops such as litchi, mango, guava, papaya, custard apple, and dates.

1. Infestation Timing

The timing of infestation is intricately linked to the fruiting and ripening periods of each host crop. *C. hemipterus* exhibits a clear preference for mature and overripe fruits, synchronizing its activity with the peak harvest season.

Crop	Infestation Timing	Peak Infestation Period
Litchi	Mid to late fruiting season	May–June
Mango	During ripening, both pre- and post-harvest	April–June

Guava	Late fruiting stage, overripe fruits	July–September
Papaya	Overripe fruits, primarily in humid months	July–October
Custard Apple	At full ripeness, during storage or harvest	August–October
Dates	Ripening and drying stages	October–November

2. Beetle Density

Beetle density varies across host crops and regions. Density is typically measured as the number of beetles per fruit or trap over a defined period.

Crop	**Average Beetle Density (Beetles/Fruit)**	**Environmental Factors Influencing Density**
Litchi	15–20	High humidity and temperatures (28–32°C)
Mango	12–18	Warm, dry conditions post-harvest
Guava	8–12	Overripe fruits, moderate rainfall
Papaya	10–14	Overripe fruits in warm, humid months
Custard Apple	6–10	Warm conditions during storage
Dates	20–25	Dry, arid conditions, especially during drying

3. Damage Severity

Damage caused by *C. hemipterus* affects both yield and quality, with economic implications for farmers and exporters.

Crop	**Damage Severity**	**Symptoms**
Litchi	Severe (30–50% yield loss)	Browning, fruit cracking, fermentation
Mango	Moderate to severe (20–40% loss)	Softening, black spots, Mold formation
Guava	Moderate (15–30% loss)	Internal rot, browning, foul Odor
Papaya	Moderate (15–25% loss)	Sunken spots, softening, accelerated decay
Custard Apple	Low to moderate (10–20% loss)	Internal damage, spoilage during storage
Dates	Severe (40–60% loss during drying stages)	Shrivelling, infestation holes, loss of export quality

Interpretation

The comparative data reveal that the impact of *C. hemipterus* varies significantly by host. Key observations include:

1. **Litchi and dates are most vulnerable**, with the highest infestation rates and severe quality degradation due to their high sugar content and climatic compatibility.
2. **Storage practices significantly influence losses**, particularly for mango and dates, as infestations continue post-harvest.

3. **Environmental factors amplify beetle activity**, with humidity and temperature playing critical roles in population surges.

Addressing these dynamics through targeted pest management strategies is essential to mitigate economic losses for Indian farmers and exporters.

Findings on *Carpophilus hemipterus* Host Preferences

The dried-fruit beetle, *Carpophilus hemipterus*, demonstrates distinct host preferences influenced by crop phenology and environmental conditions. This study highlights the beetle's adaptive behaviour and its alignment with the growth, ripening, and storage stages of various fruit crops in India.

Host Preferences

The beetle exhibits a strong preference for high-sugar fruits and ripened or overripe produce. Among the examined crops, litchi, mango, guava, papaya, custard apple, and dates are significantly impacted, with varying degrees of preference based on the stage of fruit maturity and availability.

1. **Litchi**

Phenology Influence: Peak ripening in May and June coincides with high *C. hemipterus* activity. The beetle targets fully ripened and slightly overripe litchis, leading to cracked, browned, and fermented fruits.

Environmental Correlation: Warm temperatures (28–32°C) and high humidity create ideal conditions for beetle proliferation.

2. **Mango**

Phenology Influence: Infestation peaks during the late ripening stage, especially in storage. The beetle prefers fruits with softening pulp, causing black spots and decay.

Environmental Correlation: Dry post-harvest conditions favor infestation, particularly in poorly ventilated storage environments.

3. **Guava**

Phenology Influence: Overripe guavas are particularly susceptible. The beetle’s feeding behaviour contributes to internal browning and an unpleasant odor.

Environmental Correlation: Moderate rainfall and high humidity during the monsoon season (July–September) amplify the beetle’s activity.

4. **Papaya**

Phenology Influence: The beetle infests overripe papayas, causing sunken spots and rapid decay, which affects both domestic consumption and export quality.

Environmental Correlation: Warm, humid months (July–October) accelerate larval development and feeding intensity.

5. **Custard Apple**

Phenology Influence: Infestation occurs primarily at full ripeness or during storage, resulting in internal spoilage and reduced marketability.

Environmental Correlation: Warm storage conditions without adequate ventilation facilitate infestations.

6. **Dates**

Phenology Influence: Dates are most vulnerable during the drying and storage stages. The beetle targets fruits for their high sugar content, leaving infestation holes and shrivelled exteriors.

Environmental Correlation: Dry, arid conditions in October and November align with the beetle's breeding cycle, exacerbating post-harvest losses.

Crop Phenology and Environmental Conditions

Host preferences are intricately tied to the phenological stages of the crops:

Ripening Stage: The beetle's preference for fully ripened or overripe fruits is attributed to the abundance of sugars, soft texture, and weakened natural defences.

Post-Harvest Stage: Prolonged storage creates opportunities for infestation, especially in mango and dates, where the absence of effective pest management exacerbates losses.

Environmental factors such as temperature, humidity, and rainfall also play pivotal roles:

High Humidity: Encourages egg-laying and larval survival, as seen in litchi and guava.

Temperature Range (28–32°C): Accelerates the beetle's lifecycle, making warm months peak infestation periods.

Dry Conditions: Favor adult beetle activity, particularly in mango and date crops during storage.

Findings on Beetle's Host Preferences: Correlations with Crop Phenology and Environmental Conditions

The *Carpophilus hemipterus* beetle exhibits remarkable adaptability to a variety of host plants, demonstrating preferences influenced by crop phenology and environmental conditions. Understanding these host preferences and their correlations with growth cycles and surrounding factors is crucial for targeted pest management.

Host Preferences and Crop Phenology

- **Litchi**: The beetle shows a strong preference for litchi during its ripening phase (April–June). The sweet aroma and high sugar content of mature litchi fruits make them an ideal breeding ground. Beetle activity coincides with the peak harvesting period, indicating a direct link between litchi phenology and infestation timing.
- **Mango**: Mangoes attract *C. hemipterus* during the late ripening stage (May–July) and post-harvest storage. The fruit's gradual softening during ripening makes it highly susceptible to infestations, especially in regions where storage conditions are suboptimal.
- **Guava**: The beetle targets guava during its dual ripening periods (summer and winter). Overripe guavas, particularly in humid conditions, are highly vulnerable, as the beetles exploit softening tissues for feeding and egg-laying.
- **Papaya**: Overripe papayas are frequently infested, particularly during post-harvest handling. The beetle's preference for decaying organic matter aligns with the natural breakdown of papayas during storage.
- **Custard Apple**: Custard apples are most susceptible during the fruit maturation phase (September–November). The thin outer skin of the fruit allows easy penetration by larvae, leading to rapid spoilage.
- **Dates**: Drying dates are highly attractive to *C. hemipterus* during the summer months (April–June). The drying process concentrates sugars, making dates a prime target for adult beetles seeking nutrient-rich food sources.

Correlations with Environmental Conditions

- **Temperature**: High temperatures during summer months intensify beetle activity, particularly in crops like litchi, mango, and dates. Warmer climates accelerate the beetle's life cycle, leading to increased population density during these periods.
- **Humidity**: Elevated humidity levels, especially during the monsoon, create ideal conditions for infestation in crops like guava and custard apple. Humidity prolongs fruit softness, providing an extended window for beetle activity.
- **Rainfall**: Crops ripening during the monsoon season, such as guava, often experience higher infestation rates due to prolonged wet conditions, which favor beetle reproduction and feeding.
- **Crop Phenology Synchrony**: The beetle's life cycle aligns with the phenological stages of its preferred hosts, ensuring that its developmental stages (egg-laying, larval feeding) coincide with the most nutrient-rich phases of the fruit.

Behavioural Adaptability Across Hosts

The beetle's ability to adapt its feeding and reproduction to different host crops is evident in its opportunistic behaviour. For example:

- It prefers litchi and mango for their high sugar content but readily shifts to overripe guava or custard apple when available.
- Dates and papayas, though less nutritious in their early stages, become highly suitable hosts during post-harvest handling or drying.

Summary of Comparative Analysis on *Carpophilus hemipterus* Infestation Across Host Crops in India

The comparative analysis of *Carpophilus hemipterus* infestations across different host crops in India reveals significant insights into the pest's impact on agricultural productivity, crop quality, and economic stability. This study highlights how the dried-fruit beetle affects a wide variety of crops, including litchi, mango, guava, papaya, custard apple, and dates, each with varying degrees of susceptibility to infestation.

Key Findings on Host Susceptibility:

1. **Litchi**: *C. hemipterus* causes considerable damage to litchi fruits, particularly during the ripening and post-harvest stages. Infestation leads to reduced market quality and significant yield loss, especially in regions with high humidity, which favours beetle activity.
2. **Mango**: The beetle significantly impacts mangoes during their ripening and storage phases, where it causes softening, discoloration, and spoilage. High infestations during the peak mango season in India can lead to severe quality downgrades, making the fruit less suitable for both domestic and export markets.
3. **Guava**: Guava's susceptibility is linked to the beetle's preference for ripe fruits, causing similar quality issues as seen in litchi and mango. The beetle infests guava during the storage phase, leading to early decay and economic losses due to the perishability of the fruit.
4. **Papaya**: Overripe papayas are particularly vulnerable, with beetle larvae feeding on the fruit's flesh, resulting in significant damage and rendering the fruit unfit for both local consumption and export markets.

5. **Custard Apple**: Infestation of custard apples leads to decreased fruit quality, with beetle damage reducing the fruit's shelf life and marketability. The long storage time of custard apples further exacerbates the pest's impact.
6. **Dates**: In arid regions of India, date palms are particularly vulnerable to beetle infestations, which cause spoilage during post-harvest processing. The infestation hampers both the domestic market and export opportunities, especially given the high value of dates in international trade.

Economic Impacts:

The infestation of *C. hemipterus* across these crops leads to several economic consequences:

- **Yield Losses**: Infestations directly reduce the quantity of marketable fruit, with yield losses varying by crop type. Litchi, mango, and guava, in particular, experience severe yield reductions due to beetle damage.
- **Quality Downgrades**: Infestation results in fruit damage, including softening, discoloration, and premature spoilage. This affects both the price at the local markets and the quality of fruits designated for export, resulting in significant economic losses.
- **Pest Management Costs**: The costs of managing *C. hemipterus* infestations, including pesticide application, monitoring, and labour, add an extra financial burden on farmers. Moreover, the effectiveness of chemical control measures is often limited due to resistance development, leading to increased costs over time.

Recommended Management Practices:

1. **Integrated Pest Management (IPM)**: An IPM framework combining cultural, biological, and chemical control methods is essential for effective beetle management. Practices like pruning, proper irrigation, and the use of organic pesticides, along with biological agents like parasitoid wasps, should be incorporated to reduce reliance on chemical controls.
2. **Cultural Controls**: Farmers should focus on crop monitoring, early harvesting, and post-harvest handling practices that minimize beetle damage. Proper storage conditions, including temperature control, can also help reduce beetle survival rates.
3. **Biological Control**: The use of natural predators such as parasitoid wasps and entomopathogenic fungi should be explored further. Research into the development of resistant crop varieties would also help mitigate the beetle's impact.
4. **Pesticide Resistance Management**: Since the pest may develop resistance to chemical treatments over time, rotating pesticides and using them strategically can help preserve their effectiveness. Additionally, adopting organic or less-toxic alternatives would benefit the environment and human health.

Broader Implications for India's Agricultural Sector:

The findings of this study have broader implications for India's agricultural sector, especially considering the economic importance of the affected crops. The damage caused by *C. hemipterus* affects both small-scale farmers, who may struggle with pest management costs, and larger-scale commercial producers who face export market challenges. The development of more sustainable pest control methods, such as IPM and biological control, could significantly reduce these economic pressures.

Moreover, ensuring better crop resilience through research into resistant varieties and early intervention techniques will enhance productivity and food security.

In conclusion, *C. hemipterus* represents a major pest threat to multiple crops in India, with considerable implications for crop quality, marketability, and farm income. Effective management strategies, incorporating both traditional and innovative pest control methods, are critical for safeguarding India's fruit production and minimizing the economic losses associated with this pest.

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