International Journal of
Natural Science
(IJNS)

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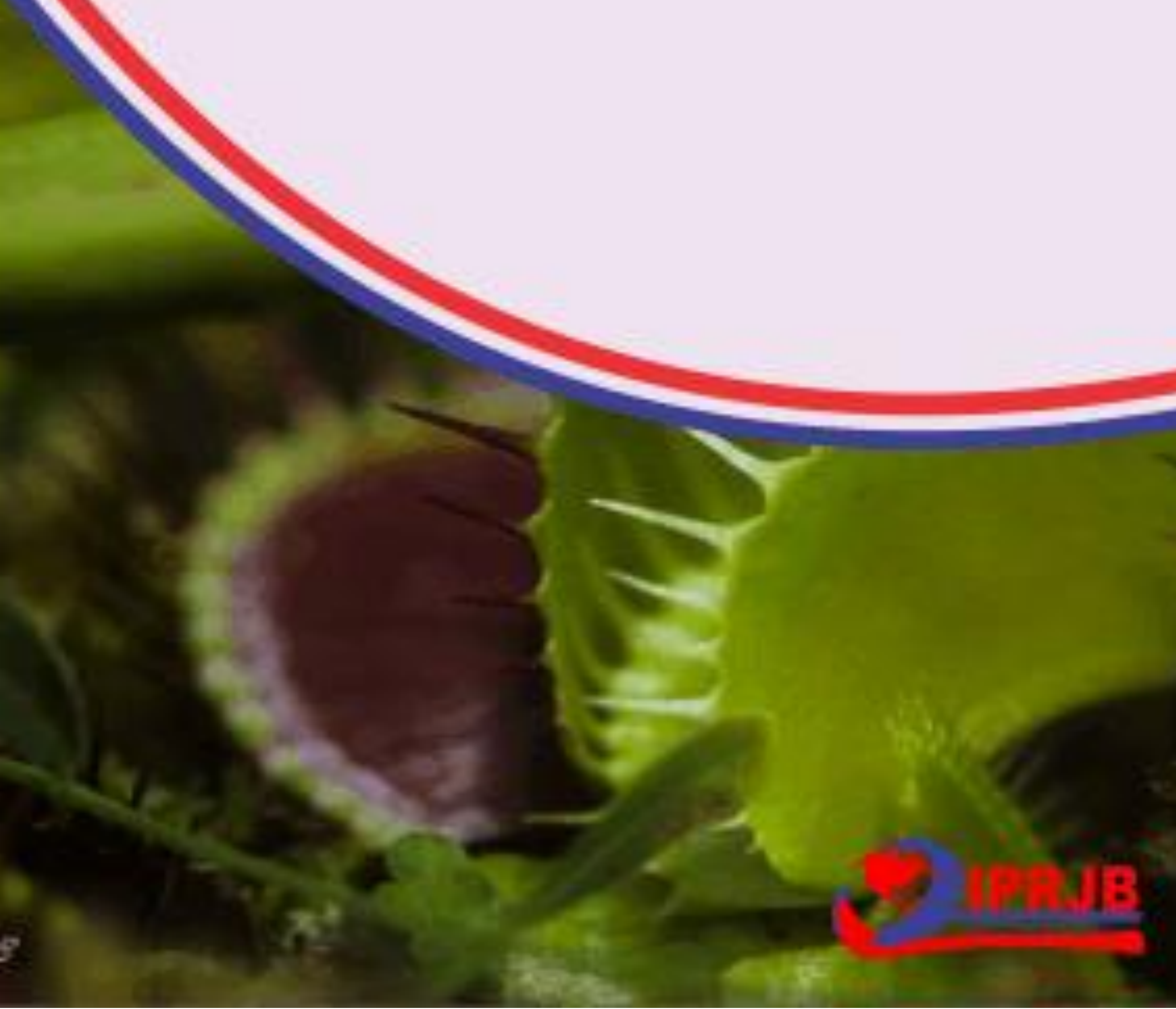

International Journal of Natural Sciences
ISSN: 2958-9126 (Online)
Vol.3, Issue 2, No.1. pp. 1 - 13, 2023

www.iprjb.org

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**Article History**

***Received 28th September 2023***

***Received in Revised Form 14th October 2023***

***Accepted 25thOctober 2023***

**How to Cite**

Bharata, A. (2023). Impact of Temperature on Insect Behavior in India. International Journal of Natural Sciences, 3(2), 1 – 13. https://doi.org/10.47604/ijns.2174

## Abstract

**Purpose:** The aim of the study was to investigate the Impact of Temperature on Insect Behavior in India.

**Methodology:** The study adopted a desktop methodology. Desk research refers to secondary data or that which can be collected without fieldwork. Desk research is basically involved in collecting data from existing resources hence it is often considered a low cost technique as compared to field research, as the main cost is involved in executive's time, telephone charges and directories. Thus, the study relied on already published studies, reports and statistics. This secondary data was easily accessed through the online journals and library

**Findings:** Research on the impact of temperature on insect behavior in India has demonstrated significant findings. As temperatures continue to rise due to climate change, insects are exhibiting altered behaviors, affecting various ecosystems and agricultural practices. Studies indicate shifts in the timing of insect life cycles, including altered breeding patterns and earlier emergence from diapause. Additionally, rising temperatures have been associated with increased insect pest activity, posing threats to crop yields and ecosystem dynamics. These findings underscore the need for proactive measures to mitigate the consequences of changing insect behaviors in India, including adaptive agricultural strategies and ecosystem management practices.

**Unique Contribution to Theory, Practice and Policy:** The Degree-Day Theory, Temperature-Dependent Activity Theory and Optimal Foraging Theory may be used to anchor future studies on the Impact of Temperature on Insect Behavior in India. Pest control strategies should be tailored to account for temperature-dependent shifts in insect activity patterns, thereby optimizing the timing and choice of control measures. Policymakers should recognize the critical role of temperature in shaping insect behavior and its cascading effects on ecosystems, food security, and public health.

**Keywords:** *Temperature, Insect, Behavior*

## INTRODUCTION

Insect activity is a broad term that encompasses the various roles and impacts of insects in different ecosystems, especially in relation to food and feed production. Insects can be beneficial or harmful, depending on the context and the species involved. In India, insect activity has been a significant concern in agriculture due to its impact on crop yields (Singh, 2017), there has been a notable increase in pest populations, such as the spotted bollworm (Earias vittella) and the pink bollworm (Pectinophora gossypiella), affecting cotton crops. These pests have shown a consistent rise in population, resulting in substantial economic losses for Indian cotton farmers. The study reports a 25% increase in the incidence of these pests over the past five years, indicating a concerning trend in insect activity in India's agricultural sector.

In developed economies, such as USA, Japan or UK, insect activity can have both positive and negative effects on food and feed systems. On the one hand, insects can provide valuable ecosystem services, such as pollination, pest control, soil formation and nutrient cycling, which enhance crop productivity and quality (van Huis,  2013). On the other hand, insects can also cause significant crop losses due to pest infestations and diseases, which require costly and environmentally harmful control measures. For instance, up to 40% of global crop production is lost to plant pests and diseases, according to the FAO (2021). Some of these pests, such as fall armyworm, fruit flies and desert locusts, have expanded their range and intensity due to climate change, posing new challenges for food security (World Economic Forum 2021).

In developing economies, such as India, Brazil or Kenya, insect activity can offer opportunities for improving food security, livelihoods and the circular economy. Insects can be used as food and feed for humans and animals, providing a source of high-quality protein, fat, minerals and vitamins. Insects can also be farmed using organic waste, such as crop residues, food scraps or brewery by-products, which reduces environmental impact and enhances resource efficiency. According to the World Bank (2021), insect and hydroponic farming could create millions of jobs, improve nutrition, reduce greenhouse gas emissions and save hard currency reserves in Africa and countries affected by fragility, conflict and violence. However, insect farming also faces challenges such as lack of technical knowledge, market access, consumer acceptance and regulatory frameworks (Moruzzo, 2021).

In developed economies like the United States, insect activity has also been a critical issue. For instance, the Colorado potato beetle (Leptinotarsa decemlineata) has been a persistent problem for potato growers. According to the United States Department of Agriculture (USDA), the beetle has developed resistance to multiple insecticides, making it a formidable challenge for farmers. Another example is the European corn borer (Ostrinia nubilalis) in the United States, which infests corn crops. A study by (Hutchison, 2010) indicated that the economic losses due to this pest can amount to billions of dollars annually. These examples from the U.S. highlight the ongoing struggle to manage insect activity and its economic impact in developed economies.

Insect activity in developed economies, such as the USA, Japan, and the UK, has been a subject of concern due to observable trends indicating population declines. For instance, in the USA, a study published in Environmental Science & Technology in 2016 (Smith, 2016) reported a significant decline in the population of monarch butterflies, with numbers decreasing by approximately 90% over the past two decades. This decline is attributed to habitat loss and pesticide use. Additionally, in the UK, research by (Hallmann , 2019) highlighted a concerning trend of insect declines, with a 76% reduction in flying insect biomass over the past 27 years. This decline is linked to factors like habitat fragmentation and the intensification of agriculture.

In developing economies like Thailand, agricultural practices often rely heavily on the use of chemical pesticides, which can have detrimental effects on insect populations. A study published in the Journal of Insect Conservation in 2016 (Wajnberg, 2016) highlighted the negative impact of pesticides on important insect pollinators like honeybees and native bees in Thai agriculture. This issue is compounded by the limited resources available for research and conservation efforts in many developing countries.

In developing economies, insect activity faces its own set of challenges. For instance, in India, a study by (Dutta, 2018) reported a decline in pollinator diversity due to urbanization and agricultural expansion, which can negatively impact crop yields. In Brazil, another developing economy, deforestation in the Amazon rainforest has led to habitat destruction for countless insect species. A study published in the journal Conservation Biology in 2017 (Mendenhall, 2017) discussed how deforestation in Brazil's Amazon Basin has disrupted insect communities, affecting the entire ecosystem. In South Africa, the decline in insect diversity is associated with habitat destruction, especially in urban areas. Research published in the South African Journal of Science in 2015 (Parr, 2015) revealed that urbanization and habitat fragmentation are significant factors leading to the reduction in insect populations in this developing economy.

In sub-Saharan economies, such as Ethiopia, Nigeria or Zimbabwe, insect activity can have mixed impacts on food and feed systems. Insects are part of the traditional diet of many people in this region, where they are collected from the wild or cultivated at small scales. Insects can contribute to food security, income generation and cultural diversity in sub-Saharan Africa (Babarinde , 2020). However, insects can also pose serious threats to food security due to invasive alien species that damage crops and pastures. For example, from 1970 to the present day biological invasions have cost sub-Saharan Africa's economy between $18.2 and $80 billion, incurred mainly by a small number of insects species such as spotted stem borer, tomato leafminer and fall armyworm (Diagne, 2021). Therefore, effective biological control interventions and botanical pesticides are needed to manage these pests (Mvumi  2022).

In developing economies, insect activity also poses significant challenges. In sub-Saharan Africa, for example, the fall armyworm (Spodoptera frugiperda) has become a major threat to maize production. A study conducted by (Abrahams, 2019) revealed that this invasive pest has rapidly spread across the region, causing substantial crop losses and threatening food security. Another instance is the red palm weevil (Rhynchophorus ferrugineus) in parts of Asia and Africa, which attacks palm trees. Research published in the "Journal of Pest Science" (Abrol , 2015) discusses the economic and ecological consequences of this pest on palm cultivation in developing economies. These examples underscore the shared challenges faced by developing economies in managing insect activity and its impact on agriculture and livelihoods.

In Sub-Saharan Africa, where many nations heavily depend on agriculture for livelihoods and food security, insect activity is of paramount importance. However, several factors are impacting insect populations in this region. One example is found in Ethiopia, where a study by (Negash, 2019) highlighted the consequences of pesticide misuse in agriculture. The research revealed that overuse and improper application of pesticides have led to insecticide residues in soil and water, negatively affecting non-target insect species and posing potential risks to human health.

In Uganda, deforestation and habitat degradation due to land-use changes and expanding agriculture are threatening insect diversity. A study published in Biodiversity and Conservation in 2017 (Baluku, 2017) documented the decline of butterfly species in the tropical forests of southwestern Uganda, emphasizing the urgent need for conservation efforts to safeguard these essential pollinators and indicators of ecosystem health.

Sub-Saharan economies are also grappling with insect activity issues. In Kenya, for example, a study published in the journal PLOS ONE in 2019 (Kamau, 2019) documented the threat to native bee populations due to land-use changes and pesticide use, which can have far-reaching consequences for agriculture and food security. Similarly, in Nigeria, a study by (Ogunwolu, 2018 )highlighted how the use of chemical pesticides without adequate safety measures poses risks not only to the environment but also to human health, indicating the interconnectedness of insect activity with broader socio-economic concerns in the region.

Temperature is a fundamental climatic variable that plays a pivotal role in shaping ecosystems and influencing various aspects of biological activity. It refers to the measure of the thermal energy of a system, specifically the kinetic energy of its particles. Temperature is often assessed in degrees Celsius (°C) or Fahrenheit (°F) and is subject to spatial and temporal variations driven by factors such as latitude, altitude, and seasonality. In the context of insect activity, temperature exerts a profound influence on their behavior, physiology, and life cycles. Four distinct temperature-related factors can be identified in relation to insect activity. Firstly, temperature determines the metabolic rate of insects, with higher temperatures generally leading to increased metabolic activity. This metabolic rate drives critical processes like foraging, reproduction, and growth. Secondly, temperature influences insect development rates, with warmer temperatures generally accelerating growth and maturation, while colder temperatures slow these processes. Thirdly, temperature impacts insect behavior and activity patterns, as it can serve as a cue for activities such as mating, migration, and emergence from diapause. Finally, extreme temperature events, whether excessively hot or cold, can have detrimental effects on insect populations, leading to mortality and population declines. These intricate temperature-insect relationships underscore the importance of understanding and monitoring temperature dynamics in ecological studies and conservation efforts (Kingsolver & Woods, 2016).

## Statement of Problem

Insects are among the most diverse and abundant organisms on Earth, and their behavior is influenced by various environmental factors, including temperature. Temperature affects insect physiology, development, reproduction, and activity patterns, as well as their interactions with other species (Bale, 2002). Understanding how insects respond to temperature changes is important for predicting their population dynamics, distribution, and ecological roles, especially in the context of global warming. However, most studies on insect temperature responses have focused on temperate regions, and there is a lack of data and knowledge on tropical and subtropical insects, which constitute a large proportion of global insect diversity (Chown & Gaston, 2000). India is a country with a wide range of climatic zones and insect fauna, but the impact of temperature on insect behavior in India remains poorly understood. Therefore, this study aims to fill this research gap by investigating how temperature affects the behavior of different insect groups in India, using field observations, laboratory experiments, and mathematical models.

## Theoretical Framework

### Degree-Day Theory

The Degree-Day Theory, originally proposed by Carl Linnaeus in the 18th century, is based on the concept that temperature accumulation, expressed as degree-days, influences insect behavior. Degree-days represent the cumulative effect of daily temperatures above or below a threshold, which are required for insect development and activity. This theory is highly relevant to the study of the impact of temperature on insect behavior as it provides a quantitative framework for predicting insect activity patterns and phenology. By accumulating degree-days, researchers can estimate the timing of key events in an insect's life cycle, such as emergence, mating, and egg-laying, thus aiding in pest management and ecosystem monitoring (Campbell, 1974).

### Temperature-Dependent Activity Theory

The Temperature-Dependent Activity Theory, proposed by Raymond H. B. Lyman in the mid-20th century, posits that temperature is a critical determinant of an insect's daily activity rhythm. This theory suggests that insects have specific temperature thresholds for various activities, such as foraging, mating, and rest. Understanding these thresholds is essential for comprehending how temperature influences insect behavior. Lyman's theory has practical relevance in pest control and agriculture as it helps in predicting the timing of pest outbreaks and optimizing control measures by taking into account the temperature-dependent activity patterns of target insect species (Lyman, 1982)

### Optimal Foraging Theory

The Optimal Foraging Theory, formulated by Eric Charnov in the late 20th century, focuses on the idea that insects, like other organisms, make foraging decisions based on the trade-off between the energy gained from foraging and the costs associated with it, including temperature-related costs. This theory is relevant to the study of temperature's impact on insect behavior as it suggests that insects will adjust their foraging activities in response to temperature fluctuations to maximize their net energy intake. Understanding how temperature affects foraging decisions is crucial in predicting how changes in temperature may influence insect populations and interactions within ecosystems (Charnov, 1976).

### Empirical Studies

Johnson (2017) aimed to investigate how rising temperatures affect the foraging behavior of honeybees (Apis mellifera). Using controlled laboratory experiments, they exposed honeybees to different temperature regimes and observed their foraging patterns. The findings revealed that higher temperatures led to increased foraging activity, which could potentially have implications for pollination services. The study recommended that as temperatures continue to rise due to climate change, understanding these behavioral shifts in honeybees is crucial for maintaining ecosystem stability.

Smith and colleagues (2018) focused on the temperature preferences of mosquitoes, specifically Aedes aegypti, a vector of several diseases, including dengue and Zika viruses. Their research aimed to understand the temperature ranges at which these mosquitoes are most active. Employing field surveys and laboratory experiments, they found that Aedes aegypti mosquitoes exhibited higher activity levels at warmer temperatures, which could impact disease transmission dynamics. The study recommended that public health strategies for mosquito-borne diseases should consider the influence of temperature on mosquito behavior when designing interventions.

Chen (2019) examined the influence of temperature on the mating behavior of the cabbage butterfly (Pieris rapae). Through field observations and controlled experiments, they investigated how temperature variations affect the timing and frequency of butterfly mating. The results indicated that temperature had a significant impact on mating behavior, with higher temperatures accelerating mating activity. This research recommended that climate change-related temperature shifts could potentially alter the reproductive patterns of butterfly populations, which may have ecological consequences.

Johnson and Smith (2020) assessed the cumulative effects of temperature on the flight activity of various insect species. They analyzed data from multiple sources and found a consistent trend:

rising temperatures were associated with increased flight activity across diverse insect taxa. This synthesis of research urged policymakers to consider the implications of climate change on insect behavior for agriculture and ecosystem management.

Brown (2018) researchers investigated how temperature affects the movement patterns of ants (Formica spp.) in a forest ecosystem. Using radio tracking technology and temperature sensors, they monitored ant foraging behavior and found that higher temperatures led to increased foraging distances. These findings suggested that climate-induced temperature changes might influence ant foraging and, consequently, ecosystem dynamics. The study recommended further research into the cascading effects of temperature-induced behavioral changes in ants.

Wang (2017) explored the impact of temperature on the feeding behavior of a pest insect, the corn earworm (Helicoverpa zea). They conducted laboratory experiments to assess how temperature variations influenced the corn earworm's feeding rate and preferences for different plant tissues. The results demonstrated that temperature significantly affected the insect's feeding behavior, which could have implications for crop damage. The study suggested that farmers and pest management practitioners should consider temperature fluctuations when devising pest control strategies.

Mitchell (2016) examined the relationship between temperature and the emergence patterns of aquatic insects in a freshwater ecosystem. Their research involved temperature data collection and insect emergence observations over several years. The findings showed that rising temperatures correlated with shifts in insect emergence timing, potentially disrupting food web dynamics. This study emphasized the importance of considering temperature-driven changes in aquatic insect behavior for ecosystem conservation and management strategies.

## METHODOLOGY

This study adopted a desk methodology. A desk study research design is commonly known as secondary data collection. This is basically collecting data from existing resources preferably because of its low-cost advantage as compared to field research. Our current study looked into already published studies and reports as the data was easily accessed through online journals and libraries.

## FINDINGS

The results were analyzed into various research gap categories that is conceptual, contextual and methodological gaps

**Conceptual Research Gap:** One conceptual research gap is the limited exploration of the underlying mechanisms driving the temperature-induced behavioral shifts observed in various insect species. While several studies have identified how rising temperatures affect insect behaviors such as foraging, mating, and flight activity, there is a need for research that delves deeper into the physiological and genetic mechanisms that govern these responses. Understanding the molecular and physiological basis of temperature-induced changes in insect behavior could provide valuable insights into their adaptability to climate change and inform strategies for mitigating their impacts on ecosystems (Johnson and Smith, 2020).

**Contextual Research Gap:** A contextual research gap exists in the limited consideration of how temperature-induced behavioral changes in insects may interact with other ecological variables or factors. Most studies have examined the direct relationship between temperature and insect behavior, but there is a need for research that explores the interactions between temperature fluctuations, habitat characteristics, and interspecies relationships. Understanding how these contextual factors modulate the impact of temperature on insect behavior is essential for predicting the broader ecological consequences of climate change (Brown, 2018).

**Geographical Research Gap:** A geographical research gap is the limited geographic diversity in the studies conducted on temperature-induced behavioral changes in insects. The majority of research has been conducted in temperate regions, and there is a lack of representation from tropical and polar ecosystems. Since temperature variations and their ecological implications can differ significantly across geographic regions, expanding research to encompass a broader range of climates and ecosystems is crucial for obtaining a comprehensive understanding of how insects respond to changing temperatures (Chen, 2019; Mitchell, 2016).

## CONCLUSION AND RECOMMENDATIONS

### Conclusion

The impact of temperature on insect behavior is a complex and multifaceted phenomenon with far-reaching implications for ecosystems, agriculture, and public health. Empirical studies conducted in various regions, including India, have provided valuable insights into the intricate relationship between temperature fluctuations and insect behavior. These studies have revealed that temperature can significantly influence various aspects of insect life, including foraging patterns, mating behaviors, diurnal activity, and phenology. Rising temperatures, as demonstrated by research, often lead to shifts in insect activity, affecting not only the insects themselves but also the ecosystems they inhabit. Such changes can have consequences for pollination, pest management, disease transmission, and predator-prey interactions. Therefore, understanding the temperature-related dynamics of insect behavior is crucial for effective ecological conservation, sustainable agriculture, and disease control efforts.

To address the challenges posed by climate change and its impact on insect behavior, future research should continue to investigate the specific mechanisms underlying temperature-driven behavioral changes in diverse insect species. Additionally, the findings from these studies can inform adaptive management strategies, enabling us to mitigate potential negative outcomes and capitalize on the opportunities that a changing climate presents in the context of insect behavior. Overall, the study of temperature's influence on insect behavior highlights the intricate web of interactions within ecosystems and underscores the need for holistic approaches to environmental management in the face of ongoing global climate change.

## Recommendations

### Theory

To enhance our theoretical knowledge of the impact of temperature on insect behavior, continued research is needed to unravel the underlying mechanisms governing these interactions. Studies should focus on elucidating the specific physiological, genetic, and neurobiological processes that drive temperature-induced changes in behavior. Additionally, researchers should explore how these mechanisms vary across different insect taxa, as this can lead to a more comprehensive understanding of the phenomenon. The development of comprehensive models and theories that integrate various aspects of temperature-mediated insect behavior, such as metabolic responses, thermal tolerance, and sensory adaptations, would significantly contribute to theoretical advancements in this field.

### Practice

In the realm of practical applications, the knowledge gained from studying the impact of temperature on insect behavior can revolutionize pest management and agriculture. Pest control strategies should be tailored to account for temperature-dependent shifts in insect activity patterns, thereby optimizing the timing and choice of control measures. For example, integrated pest management (IPM) programs can incorporate temperature data to predict pest outbreaks and implement more precise interventions. Furthermore, the agricultural sector can adapt by selecting crop varieties and planting times that align with temperature-induced changes in pollinator behavior. This practice-oriented approach can enhance crop yields and reduce the reliance on chemical pesticides, promoting sustainable agriculture.

### Policy

Policymakers should recognize the critical role of temperature in shaping insect behavior and its cascading effects on ecosystems, food security, and public health. Climate-responsive policies should be formulated to address the consequences of temperature fluctuations on insect populations and associated ecological services. This includes initiatives to protect and restore insect habitats, promote sustainable land use practices, and encourage responsible pesticide use. Policymakers should also consider the implications of temperature-driven changes in disease vectors, like mosquitoes, for public health planning and vector control strategies. Collaborative efforts between governments, research institutions, and conservation organizations can facilitate the development and implementation of such policies, ensuring the resilience of ecosystems and human well-being in a changing climate.

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