Bulletin of Nexus
Multidisciplinary International Research Journal, Double-Blind Peer Reviewed, Open Access Journal
ISSN : 3065-7865 / Volume-3, Issue-2 , February 2026

Original Article

Integrated Pest Management of Major Insect Pests of *Moringa oleifera* Lam. (*Noorda blitealis*, *Eupterote mollifera and Noorda moringae*) for Sustainable Moringa Production

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Manuscript ID: BN-2026-030225

ISSN: 3065-7865

Volume 3

Issue 2

February 2026

Pp. 130-140

Submitted: 15 Jan 2026

Revised: 27 Jan 2026

Accepted: 15 Feb 2026

Published: 28 Feb 2026

DOI: 10.5281/zenodo.19850958
DOI link: https://doi.org/10.5281/zenodo.19850958

Abstract

Moringa oleifera Lam., a nutritionally and economically valuable multipurpose tree widely grown in tropical and subtropical regions, suffers significant yield losses due to major insect pests, particularly the moringa leaf caterpillar (Noorda blitealis), hairy caterpillar (Eupterote mollifera), and bud worm (Noorda moringae). These pests cause severe defoliation and damage to buds and flowers, reducing both crop quality and productivity. Excessive dependence on chemical pesticides has created environmental risks, pest resistance, and disruption of beneficial organisms. Integrated Pest Management (IPM) provides a sustainable and ecologically balanced alternative by combining cultural, mechanical, biological, and need-based chemical approaches. This review summarizes current knowledge on pest biology, damage symptoms, and effective IPM strategies, with emphasis on eco-friendly practices such as field sanitation, conservation of natural enemies, and the use of botanical pesticides. Adoption of IPM enhances long-term pest suppression, maintains agro-ecosystem stability, and supports sustainable moringa production. Strengthening farmer awareness and regular pest monitoring are essential for improving yield and ensuring environmentally safe cultivation of moringa.

Keywords: *Moringa oleifera, Integrated Pest Management, Sustainable Agriculture, Major Insect Pests, Noorda blitealis, Eupterote mollifera, Noorda moringa, Biological control.*

Introduction-

Moringa oleifera, commonly known as the drumstick tree, is a fast-growing multipurpose crop widely cultivated in tropical and subtropical regions for its edible leaves, pods, and seeds. It is highly valued for its nutritional and medicinal properties and plays an significant role in food security and rural livelihoods. *Moringa oleifera* is a highly nutritious multipurpose tree in which almost every part is beneficial for human health. Its leaves, seeds, flowers, and roots are rich in essential amino acids, vitamins, carotenoids, and other bioactive compounds with strong nutraceutical value. Because of its high content of vitamins A and C and quality proteins, moringa is widely used as a dietary supplement and in traditional medicine. It serves as an important source of phytonutrients for both humans and animals (Sharma *et al.*, 2020).

Moringa oleifera is grown for its edible pods, leaves, and flowers and is valued worldwide as a rich dietary supplement. Native to the sub-Himalayan region of India, moringa is now naturalized across Africa, Southeast Asia, and other tropical regions. It belongs to the family Moringaceae, which includes several species, but *Moringa oleifera* remains the most widely cultivated and economically important (Bahadur, 2015).

M. oleifera is grown primarily for its edible pods and leaves, which are used as a vegetable, in traditional medicine, and to purify water. India is the world's leading producer, with major cultivation in southern states and significant exports to international markets. Although moringa is highly nutritious and valuable, it remains underutilized in some regions and is sometimes regarded as a subsistence or famine food despite its strong potential for improving nutrition and livelihoods (Swamy and K.R.M., 2024).

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How to cite this article:
Ahirwar, S., & Ahirwar, R. M. (2026). Integrated Pest Management of Major Insect Pests of Moringa oleifera Lam. (Noorda blitealis, Eupterote mollifera and Noorda moringae) for Sustainable Moringa Production. Bulletin of Nexus Journal, 3(2), 130–140. https://doi.org/10.5281/zenodo.19850958

Moringa oleifera is grows best in warm conditions (about 25–30 °C) with moderate rainfall and tolerates drought and a wide range of soils, though it is sensitive to frost and waterlogging. The tree reaches about 10–12 m in height with an open crown and feathery compound leaves. It produces white flowers in clusters and long, tri-lobed pods that resemble drumsticks. These pods contain several oil-rich seeds and are an important edible part of the plant (Kumar and Jakhar, 2020).

The Moringaceae family includes tropical trees and shrubs with compound leaves, clustered zygomorphic flowers, and capsule fruits containing oil-rich seeds, characterized by gum-producing bark and soft, lightweight wood (Olson, 2010).

Moringa oleifera leaves, pods, and seeds are used as nutritious products, and leaf extracts show antioxidant and protective biological effects, including antidiabetic and antihypertensive properties, mainly due to natural bioactive compounds (Bashir *et al.*, 2016).

Moringa is used as food for humans and animals, valued for its medicinal properties, and also serves important environmental and industrial purposes (Outani *et al.*, 2023).

However, moringa production is seriously constrained by insect pests, particularly the leaf caterpillar (*Noorda blitealis*), hairy caterpillar (*Eupterote mollifera*), and bud worm (*Noorda moringae*), which cause severe defoliation and damage to buds and flowers, leading to major yield losses.

Conventional pest control based mainly on synthetic insecticides is often unsustainable because it can result in pest resistance, environmental contamination, and destruction of beneficial organisms. Integrated Pest Management (IPM) provides a more sustainable alternative by combining compatible cultural, mechanical, biological, and selective chemical methods to keep pest populations below economic threshold levels. Understanding pest biology and ecology is essential for designing effective IPM programs. This review focuses on eco-friendly IPM strategies for managing the major insect pests of moringa to support sustainable and productive cultivation.

Objectives-

The primary objectives of this review are:

- To review the biology and damage of major moringa pests.
- To assess eco-friendly IPM control methods.
- To examine the ecological benefits of IPM and biodiversity protection.
- To suggest sustainable pest management strategies for moringa cultivation.

Data and Methodology-

This review is based entirely on secondary information gathered from peer-reviewed research papers, books, technical reports, and agricultural extension publications related to moringa pest management. A systematic literature search was conducted using major scientific databases such as Google Scholar, ScienceDirect, Scopus, PubMed, AGRIS, and CAB Abstracts. Studies published between 1980 and 2025 were selected using keywords related to moringa major insect pests, sustainable agriculture, biological control, and integrated pest management (IPM).

The reviewed literature included laboratory experiments, field trials, and farmer-level observations from major moringa-growing regions. Relevant information on pest biology, damage patterns, seasonal distribution, and effectiveness of IPM components—such as cultural practices, biological control agents, and biopesticides—was extracted and critically evaluated. The findings were synthesized through a qualitative, thematic approach to present a clear overview of sustainable and farmer-adaptable pest management strategies. No primary experiments or quantitative meta-analysis were conducted in this study.

Integrated Pest Management and Sustainable Agriculture-

Integrated Pest Management (IPM) is a key component of sustainable agriculture that aims to control pests through an ecological and economically balanced approach. It integrates cultural, biological, mechanical, and need-based chemical methods to keep pest populations below damaging levels while reducing dependence on synthetic pesticides. By emphasizing prevention, regular monitoring, and threshold-based decision-making, IPM helps conserve natural enemies, protect soil and water quality, and maintain long-term farm productivity.

Integrated Pest Management (IPM) is a sustainable pest control approach that combines biological, cultural, mechanical, and selective chemical methods to reduce pesticide dependence while maintaining crop productivity. Through regular monitoring and farmer awareness, IPM helps conserve biodiversity, protect ecosystems, and support long-term agricultural sustainability. The integration of modern tools such as precision farming and digital pest monitoring further strengthens IPM, making it an important strategy for addressing food security, climate change, and environmental challenges (Ilieva *et al.*, 2025).

Integrated Pest Management (IPM) is an eco-friendly pest control system that combines preventive cultural, biological, mechanical, and selective chemical methods based on monitoring and economic thresholds. It reduces pesticide use, supports biodiversity, and maintains crop productivity, but wider adoption depends on improved farmer training, extension support, and access to modern technologies (Ahirwar and Ahirwar, 2025).

India's fast population growth is putting strong pressure on food production, while land and natural resources are becoming limited. Sustainable increases in agricultural productivity are therefore essential. As emphasized by M. S. Swaminathan, modern farming should combine bioengineering, information technology, and environmental science, and Integrated Pest Management (IPM) is a key approach that supports higher yields while protecting the environment and human health (Mohamed, 2023).

Integrated Pest Management (IPM) is a sustainable approach that reduces dependence on chemical pesticides while improving crop yield and ecosystem health. Recent advances highlight stronger use of biological and genetic control, eco-friendly biopesticides, and precision pesticide delivery systems that lower environmental impact (Zhou *et al.*, 2024).

Despite major gains in agricultural output over recent decades, pest damage and post-harvest losses remain serious barriers to food security. Integrated Pest Management (IPM) addresses these challenges through a systems-based approach that combines resistant varieties, biological control, cultural methods, and careful pesticide use to keep pest populations below harmful levels while reducing environmental and health risks (Istatu *et al.*, 2025).

Excessive pesticide use has raised serious concerns about environmental safety and human health. Integrated Pest Management (IPM) offers a sustainable alternative by combining biological, cultural, and resistant-based strategies to control pests effectively while reducing chemical dependence and supporting long-term agricultural sustainability (Shivam *et al.*, 2024).

Integrated Pest Management (IPM) addresses the negative impacts of excessive pesticide use by combining cultural, biological, resistant, and limited chemical methods for long-term pest control. It relies on careful pest monitoring, coordinated farmer action, and the integration of multiple strategies rather than a single control method. While early expectations of drastically reducing pesticide use were not fully achieved, IPM remains an ecologically sound approach that protects crops while minimizing risks to human health, beneficial organisms, and the environment (Singh and Sharma, 2004).

Worldwide, agriculture must become more sustainable to meet rising human needs while protecting the environment. With rapid population growth—especially in Asia and Africa—food production must increase despite limited land and resources. Developing countries face greater pressure due to faster population growth than agricultural expansion. At the same time, demand for high-quality food and global economic changes have transformed farming systems. Insect pests remain a major barrier to productivity, and shifts in cropping patterns and the spread of new pests continue to challenge sustainable agricultural development (Thakur *et al.*, 2024).

Integrated Pest Management is a sustainable crop protection approach that combines cultural, mechanical, biological, and limited chemical methods to control pests while maintaining productivity and environmental safety. It reduces dependence on pesticides and supports ecological balance for long-term agricultural sustainability (Wijesundara, 2024).

Sustainable agriculture benefits from IPM through improved crop yields, reduced environmental risks, and enhanced biodiversity. The approach promotes efficient resource use and strengthens ecosystem resilience, making farming systems more adaptable to climate variability. Adoption of IPM also lowers production costs and supports safer food systems. Therefore, IPM is widely recognized as an essential strategy for achieving environmentally sound and economically viable agricultural development.

Results and Discussion-

Major Insect Pests of *Moringa oleifera* :

Moringa oleifera is attacked by several insect pests that reduce leaf area, damage reproductive parts, and lower overall yield.

Moringa oleifera is an important multipurpose crop valued for its nutritional, medicinal, antimicrobial, and industrial uses. As its cultivation expands worldwide under diverse climatic conditions, the plant becomes exposed to a wider range of pests and diseases (Mridha and Barakah, 2017).

Moringa oleifera is a widely consumed vegetable in Southeast Asia and West Africa and is seriously affected by the leaf caterpillar *Noorda blitealis*, a major year-round pest. This insect causes heavy leaf damage and significant yield loss (Outani *et al.*, 2023).

The moringa leaf caterpillar (*Noorda blitealis*) is a serious pest that causes heavy crop losses. Laboratory observations showed that its larvae pass through five growth stages, developing rapidly with high survival rates and causing the greatest leaf damage during later instars. Understanding its life cycle and feeding pattern is important for designing effective biological control strategies (Kabre *et al*., 2024).

Laboratory studies on the drumstick leaf caterpillar, *Noorda blitealis*, showed that females lay single eggs on leaf petioles and tips. The insect develops through five larval stages with a short incubation and larval period, followed by brief pre-pupal and pupal phases. Adults live only a few days, and females produce a moderate number of eggs, indicating a rapid life cycle that supports quick population buildup (Rachana *et al.*, 2020).

Noorda blitealis lays single eggs on the underside of moringa leaf petioles and completes its life cycle in about 34 days. Its development includes short incubation, larval, pre-pupal and pupal stages, with moderate egg production and slightly longer adult survival when fed honey solution (Yadav *et al.*, 2024).

Bud worm (*Noorda moringae*) and leaf caterpillar (*Noorda blitealis*) are major pests of moringa, causing severe damage as borers and defoliators in tropical growing regions. Although these pests occur most of the year and can cause heavy yield loss. (Aman *et al.*, 2023).

The moringa leaf caterpillar (*Noorda blitealis*) is one of the most destructive pests. Its larvae feed voraciously on tender leaves, often causing heavy defoliation and weakening plant growth. Another serious pest is the hairy caterpillar (*Eupterote mollifera*), which feeds gregariously and can rapidly strip foliage, especially during warm seasons. The bud worm (*Noorda moringae*) targets flower buds and young shoots, resulting in poor flowering and reduced pod formation.

1. **Leaf Caterpillar, *Norda blitealis* Walker (Crambidae: Lepidoptera)—**

The leaf caterpillar, *Noorda blitealis*, is a major defoliating pest of moringa that significantly reduces plant productivity. The larvae feed on tender foliage by scraping and consuming leaf tissues, often forming silken webs and causing skeletonization and extensive defoliation under severe infestations. Eggs are deposited on young leaves, and the larvae undergo several developmental instars before pupating in soil or plant residues. The insect completes multiple generations annually, with rapid population buildup under warm and humid environmental conditions. Continuous defoliation lowers photosynthetic efficiency, weakens plant vigor, and can result in substantial yield losses. Therefore, systematic monitoring and timely implementation of management strategies are essential to minimize economic damage.

2. **Hairy Caterpillar, *Eupterote mollifera* Walker (Eupterotidae: Lepidoptera)—**

The hairy caterpillar, *Eupterote mollifera*, is an important gregarious pest of moringa characterized by its capacity to cause rapid and severe defoliation. The larvae feed collectively on tender foliage and occasionally on soft bark, leading to substantial reduction in photosynthetic area and plant vigor. Females deposit eggs in clusters on host leaves, and the emerging larvae undergo multiple instars before pupating in soil or plant residues. Early instars exhibit strong group-feeding behavior that intensifies localized damage, whereas later instars disperse and consume large quantities of foliage individually. The larvae possess dense urticating hairs that can cause skin irritation, posing challenges for manual control measures. Population outbreaks are generally associated with warm and humid environmental conditions, and repeated infestations may result in considerable yield losses, particularly in young plantations. Systematic surveillance and timely implementation of integrated management strategies are therefore critical for minimizing economic impact.

3. **Bud Worm, *Noorda moringae* Tams (Crambidae: Lepidoptera)—**

The bud worm, *Noorda moringae*, is a key reproductive pest of moringa that attacks flower buds, tender shoots, and developing pods, thereby reducing pod formation and yield. The larvae bore into buds and young pods and feed internally, causing bud drop, malformed pods, and destruction of developing seeds. This concealed feeding habit protects the larvae from many external control measures and makes early detection difficult. Females lay eggs singly or in small groups on flower buds and tender plant parts, and the larvae pass through several instars before pupating in nearby plant material or soil.

The life cycle is closely associated with the flowering and fruiting stages of moringa, allowing multiple overlapping generations during the production season. Warm temperatures favor population buildup, and heavy infestations can result in substantial economic losses. Because the damage directly affects reproductive growth, regular field monitoring and timely implementation of integrated pest management strategies are essential for effective control.

In addition to the major defoliators and borers, several secondary pests such as pod flies, bark caterpillars, Long-Horn Beetles and sap-sucking insects also contribute to yield losses in moringa. Their incidence is often seasonal and closely linked to temperature and humidity, with severe infestations reducing photosynthetic efficiency and the marketable quality of produce. Climate variability, including rising temperatures, extended dry periods, and irregular rainfall, can accelerate pest population growth while simultaneously weakening host plant resistance. Consequently, sustainable pest suppression depends on early surveillance and the coordinated use of cultural, biological, and eco-friendly control measures. Developing climate-responsive integrated pest management strategies is therefore essential to maintain pest populations below economic thresholds and ensure stable crop productivity.

Damage Caused by the Pests-

These pests inflict substantial economic losses through direct feeding and indirect effects on plant health. *Noorda blitealis* larvae scrape leaf chlorophyll, making foliage papery and transparent, progressing to complete defoliation in severe cases (up to 100% yield loss). They also damage pods by consuming pulp, leading to gummy exudation. *Eupterote mollifera* causes bark scraping and foliage gnawing, resulting in defoliation and weakened trees, especially in gregarious attacks. *Noorda moringae* bores into flower buds, causing them to dry and drop without blossoming (up to 78% bud loss), severely reducing pod set and overall yield. Combined infestations exacerbate stress, making plants more susceptible to diseases and reducing nutritional quality for sustainable production.

Principles of Integrated Pest Management in Moringa :

Integrated Pest Management (IPM) in moringa is founded on an ecological understanding of pest dynamics and combines both preventive and corrective approaches to maintain pests below damaging levels. It emphasizes a systematic framework that prioritizes early prevention, continuous monitoring, and the integration of multiple compatible control methods.

The key principles include:

1. **Regular Monitoring and Pest Surveillance-**

   Regular field scouting is the foundation of IPM in moringa. Systematic observation of leaves, buds, and pods helps detect early pest infestation and assess population trends. Tools such as light traps and pheromone traps support surveillance by tracking adult insect activity. Continuous monitoring enables timely intervention before pests reach damaging levels and helps farmers understand seasonal pest patterns.

2. **Economic Threshold–Based Interventions-**

   IPM recommends taking control action only when pest populations exceed economic threshold levels, where expected crop loss outweighs control costs. This decision-making approach prevents unnecessary pesticide use and reduces production expenses. Threshold-based management ensures that interventions are scientifically justified and aligned with sustainable crop protection goals.

3. **Conservation of Natural Enemies-**

   Protecting beneficial organisms such as predators, parasitoids, and entomopathogenic microbes is essential for natural pest regulation. Habitat management, reduced pesticide exposure, and the use of selective bio-pesticides encourage the survival of natural enemies. These beneficial species help maintain ecological balance and suppress pest populations over the long term.

4. **Use of Eco-Friendly Control Measures-**

   Eco-friendly methods include botanical extracts (e.g., neem-based products), microbial pesticides, mechanical removal of infested plant parts, and cultural practices such as field sanitation and proper spacing. These approaches minimize environmental contamination and protect non-target organisms. Integrating such measures strengthens sustainable pest management in moringa cultivation.

5. **Judicious and Need-Based Pesticide Application-**

   Chemical pesticides should be used only when other methods are insufficient and pest levels exceed thresholds. Preference should be given to selective and low-residual products applied at recommended doses and timings. Responsible pesticide use reduces the risk of resistance development, environmental pollution, and harm to beneficial organisms.

Integrated Pest Management Strategies-

Integrated Pest Management (IPM) is a holistic and environmentally sound approach that combines multiple compatible methods to keep pest populations below economic injury levels while minimizing risks to human health and ecosystems. According to guidelines promoted by organizations such as the Food and Agriculture Organization, IPM emphasizes prevention, monitoring, and the judicious use of control tactics rather than sole dependence on chemical pesticides.

Integrated pest management strategies are as follows –

- **Cultural Control:**

  Cultural control is a key component of IPM in moringa and focuses on reducing pest establishment through improved crop management. Field sanitation, including the removal and destruction of infested plant parts and residues, interrupts pest life cycles and lowers carry-over populations. Proper plant spacing and timely pruning enhance air circulation and create less favorable conditions for pest development. Intercropping with non-host plants and maintaining balanced soil fertility improves plant vigor and natural tolerance to pest attacks. Additional practices, such as shallow ploughing around plants and early removal of damaged tissues, help minimize reinfestation. Together, these cultural measures form a preventive strategy that supports long-term and sustainable pest management.

- **Biological Control:**
  Biological control is an essential component of IPM in moringa, relying on natural enemies to suppress pest populations in an environmentally safe manner. Predators, parasitoids, and entomopathogenic microorganisms naturally regulate caterpillar pests and reduce the need for chemical pesticides. Conservation of beneficial organisms through reduced use of broad-spectrum insecticides and habitat management helps maintain ecological balance in the crop ecosystem. Microbial biopesticides such as *Bacillus thuringiensis* and entomopathogenic fungi like *Beauveria bassiana* and *Metarhizium anisopliae* provide effective and selective control of larval pests with minimal impact on non-target species. Botanical products, particularly neem-based formulations, further support eco-friendly pest suppression. Together, these biological approaches strengthen sustainable and long-term pest management in moringa cultivation.
- **Mechanical and Physical Control:**
  Mechanical and physical control methods provide practical and immediate pest reduction in moringa, especially during early infestation stages and in small-scale plantations. Hand collection and destruction of egg masses, larvae, and heavily infested plant parts directly lowers pest populations and prevents their spread. Installing light traps and pheromone or sticky traps helps monitor and reduce adult moth activity, enabling timely intervention. Additional measures such as pruning infested shoots and removing webbed foliage eliminate pest shelters and breeding sites. These approaches, when combined with regular field scouting, serve as effective, low-cost tools for early pest suppression within an integrated pest management program.
- **Botanical and Biopesticides:**
  Botanical pesticides are plant-derived products that provide eco-friendly alternatives to synthetic insecticides in moringa IPM. Neem-based formulations containing azadirachtin act as antifeedants, repellents, and growth regulators, effectively reducing larval feeding and development. Other plant extracts such as garlic, chili, tobacco, and pongamia also show insecticidal or repellent properties and can be prepared locally for low-input farming systems. Essential oils from aromatic plants further disrupt pest behavior and feeding. Although botanical pesticides may require repeated application due to their rapid biodegradation, they are generally safer for non-target organisms and compatible with biological control agents. Their integration into pest management programs supports sustainable and residue-free crop protection.
- **Chemical Control:**
  Chemical control in moringa IPM should be applied only when pest populations exceed economic threshold levels and other methods are insufficient. Preference should be given to selective and low-toxicity insecticides that effectively target larval stages while minimizing harm to beneficial organisms. Timely application against early pest stages improves control efficiency and reduces the number of sprays required. Rotation of insecticides with different modes of action is essential to delay resistance development. Spot or need-based treatments, rather than blanket spraying, help lower environmental impact and preserve natural enemies. When integrated with cultural, biological, and botanical measures, judicious chemical use supports effective and sustainable pest management.

Benefits of IPM in Sustainable Moringa Production-

Integrated Pest Management (IPM) plays a vital role in achieving sustainable production of *Moringa oleifera* by reducing reliance on synthetic pesticides and promoting environmentally safe pest control. Major pests such as the leaf caterpillar (*Noorda blitealis*), hairy caterpillar (*Eupterote mollifera*), and bud worm (*Noorda moringae*) can cause serious damage to foliage and reproductive parts, resulting in yield loss. IPM addresses these challenges through regular field monitoring, cultural practices like sanitation and pruning, conservation of natural enemies, and the use of biological and botanical control measures. Selective chemical pesticides are applied only when necessary and in a judicious manner. This balanced strategy lowers production costs, minimizes pesticide residues, and protects soil and ecosystem health. By conserving biodiversity and maintaining ecological balance, IPM supports stable yields, safer food production, and climate-resilient moringa farming. Farmer education and continuous research further strengthen the adoption of IPM, ensuring long-term productivity and sustainability of moringa cultivation systems.

Conclusion-

The major insect pests of moringa—leaf caterpillar (*Noorda blitealis*), hairy caterpillar

(*Eupterote mollifera*), and bud worm (*Noorda moringae*)— significantly limit crop productivity by damaging foliage and reproductive parts. An integrated pest management (IPM) strategy that combines cultural, mechanical, biological, botanical, and selective chemical measures offers an effective and sustainable solution. By focusing on prevention, ecological balance, and reduced reliance on synthetic pesticides, IPM helps minimize yield losses while protecting environmental and human health. Successful IPM implementation requires regular monitoring, threshold-based decision-making, and strong farmer awareness. Future research should prioritize the development of pest-resistant varieties, improvement of biological control options, and climate-responsive management practices. Broad adoption of IPM will play a vital role in ensuring sustainable moringa production and long-term agricultural resilience.

Acknowledgement-

The authors sincerely acknowledge the academic support and encouragement provided by the Department of Zoology, PMCoE Government P.G. College, Tikamgarh, Madhya Pradesh, for creating a supportive research environment that facilitated this review. They are also grateful to Maharaja Chhatrasal Bundelkhand University, Chhatarpur, for academic affiliation and guidance. Special appreciation is extended to Krishi Vigyan Kendra, Tikamgarh (M.P.), for their institutional support. The authors extend their appreciation to the scientific community whose published research formed the foundation of this study and to colleagues and well-wishers for their valuable suggestions, cooperation, and motivation during the preparation of the manuscript.

Financial support and sponsorship

Nil.

Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper

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DOI:
https://doi.org/10.20546/ijcmas.2020.912.257
Citation: Alavilli, H.; Poli, Y.; Verma,