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REVIEW ARTICLE

INSIGHTS INTO ARTHROPOD PESTS OF *Moringa oleifera*: EMERGING THREATS AND MANAGEMENT STRATEGIES

M. Duvaraga Devi[1], M. Muthuswami[1, *], A. Suganthi[1], C. Indu Rani[2] and N. Manikanda Boopathi[3]

[1]Department of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore, 641003, Tamil Nadu, India
[2]Department of Vegetable Science, Tamil Nadu Agricultural University, Coimbatore, 641003, Tamil Nadu, India
[3]Department of Plant Biotechnology, Tamil Nadu Agricultural University, Coimbatore, 641003, Tamil Nadu, India
*Corresponding author's E-mail: muthuswami.m@tnau.ac.in

ABSTRACT

Moringa, often revered as the "miracle tree," is witnessing a remarkable surge in global demand due to its exceptional nutritional contents and numerous health benefits. The increasing inclination towards natural and sustainable products has significantly enhanced its market appeal, positioning moringa as a highly lucrative crop for both farmers and businesses. Its hardy nature and ability to thrive in diverse climates and soil conditions make moringa an ideal crop for sustainable cultivation. However, its production is imperiled by various insect species. Among the Lepidopterans, the budworm (*Noorda moringae*) is known to cause flower bud drop, while the leaf-eating caterpillar (*N. blitealis*) is a major pest responsible for severe defoliation, and the hairy caterpillar (*Eupterote mollifera*) also poses a threat. Coleopterans, particularly the ash weevil (*Myllocerus* sp.), also contribute to the defoliation of moringa. Invasive Hemipteran pests, such as the tea mosquito bug (*Helopeltis antonii*) and the rugose spiraling whitefly (*Aleurodicus rugioperculatus*), have also been reported to attack moringa. Additionally, other pests like bark borers, aphids, mites, and scales have also been recorded. These pests can inflict substantial yield losses, thereby complicating management practices. The inadequate documentation of moringa insect pests poses a significant challenge in studying their biology, ecology, and management. This review provides a comprehensive insight into the potential insect pest communities affecting moringa, examines current control options, and identifies knowledge gaps. These gaps include insufficient understanding of the biology and ecology of important insect pests, their population dynamics, insecticides used for their management, and the need for fully compatible Integrated Pest Management packages for moringa.

Keywords: Moringa; Insect Pests; IPM; Natural enemies; Insecticides

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INTRODUCTION

Moringa oleifera L., (F: Moringaceae) commonly referred to as "drumstick", originates from Northwest India. However, it is also found in various regions worldwide, including South Africa, Northeast Africa, Madagascar, Tropical Asia, Southwest Asia, and Latin America (Anwar *et al.*, 2005). Moringa is a slender, fast-growing, deciduous to semi-evergreen, perennial shrub or small tree that grows to a height of 9 to 15 meters (Anwar *et al.*, 2007). Growing moringa from seeds or stem cuttings depends on factors such as temperature and seed viability. Seeds, sown 2 cm deep, typically germinate within 7 to 20 days, with freshly collected seeds showing higher germination rates (80–90%). Trees from cuttings usually start flowering six to twelve months after planting (Emongor, 2009). The PKM1 variant is recognized as a top moringa variety, primarily cultivated in Tamil Nadu, India (Saravanan, 2000). Moringa adapts to various soils but thrives in well-drained clay or clay loam. Extended waterlogging is detrimental, and deep soils (>1 m) are preferred. Moringa can tolerate a wide pH range, but the ideal pH is 5.5 to 7.0 (Nair *et al.*, 2021). Understanding these cultivation parameters is crucial for successful moringa cultivation, ensuring optimal growth and yield.

Indigenous populations of Africa and northern India are aware of the many health advantages of moringa for millennia. Recently, there has been a resurgence of interest in the nutritional properties of moringa in non-native countries (Sánchez-Machado *et al.*, 2010). All parts of moringa contain a wealth of significant nutrients and anti-inflammatory nutrients. Moringa leaves are particularly abundant in minerals such as calcium, potassium, zinc, magnesium, iron, and copper (Biel, 2017). Moringa also contains a range of vitamins, including beta-carotene (a form of vitamin A), vitamin B such as folic acid, pyridoxine, and nicotinic acid, as well as vitamins C, D, and E (Anwar *et al.*, 2007). The rich nutritional profile of moringa has made it a valuable resource for enhancing health and nutrition across diverse populations.

In spite of this, it is frequently utilized as food and spice, notably from its leaves, fruits, seeds, flowers, and oil derived from seeds. It can also be employed as medicine and cattle feed (Emongor, 2009). Cuttings are used for constructing live fences and are also beneficial for windbreaks, soil fertility enhancement, and soil conservation (Nautiyal and Venhataraman, 1987). Rich in vitamins, minerals, and antioxidants, moringa leaves have been staple in traditional medicine for treating ailments ranging from digestive disorders to skin infections (Gopalakrishnan *et al.*, 2016). The versatile properties of moringa underscore its significant contributions to health, skincare, and agriculture.

Despite being recognized as a hard crop, moringa is vulnerable to attacks by various insect pests. Several authors have reported various pests affecting moringa worldwide, particularly in India and Africa (Math and Kotikal, 2014; El-Saeady *et al.*, 2017). Given the significance of moringa for its nutritional and medicinal benefits, it is vital to improve moringa cultivation by effectively managing pests. Hence, in response to the limited research and fragmented knowledge on moringa insect pests and their control, this review provides comprehensive insights into the major and emerging pests that damage moringa globally, their impacts, and the available management practices to combat these pests. The goal is to assist future researchers in identifying gaps and devising feasible integrated pest management packages for sustainable and eco-friendly moringa cultivation.

Moringa: Global Export and Distribution: Moringa is grown as a multipurpose crop in over 60 countries (Mridha, 2015). It has become widely established across various tropical regions worldwide (Figure 1). Its presence is documented in Southern and Eastern Asia, Africa, particularly in sub-Saharan Africa (Verdcourt, 1985), as well as in tropical America, and the Pacific islands (Liogier and Martorell, 2000). Given its extensive establishment in such diverse regions, moringa can be characterized as a highly adaptable species (Trigo *et al.*, 2020).

The *Moringa* genus encompasses a total of 13 species, namely *M. arborea, M. longituba, M. borziana, M. pygmaea, M. hildebrandtii, M. drouhardii, M. peregrina, M. stenopetala, M. rivae, M. ruspoliana, M. ovalifolia, M. concanensis*, and the widely recognized *M. oleifera* (Abd Rani *et al.*, 2018). Among these, *M. oleifera* stands out as the most recognized, extensively studied, and widely utilized species (Anwar *et al.*, 2005). *M. stenopetala, M. peregrina* and *M. concanensis* also possess significant potential comparable to *M. oleifera* (Arora *et al.*, 2013). Traditionally, leaves of *M. oleifera, M. concanensis,* and *M. stenopetala* are consumed, and the tubers of young *M. peregrina* are sometimes eaten roasted. All other species have local medicinal uses (Olson, 2017).

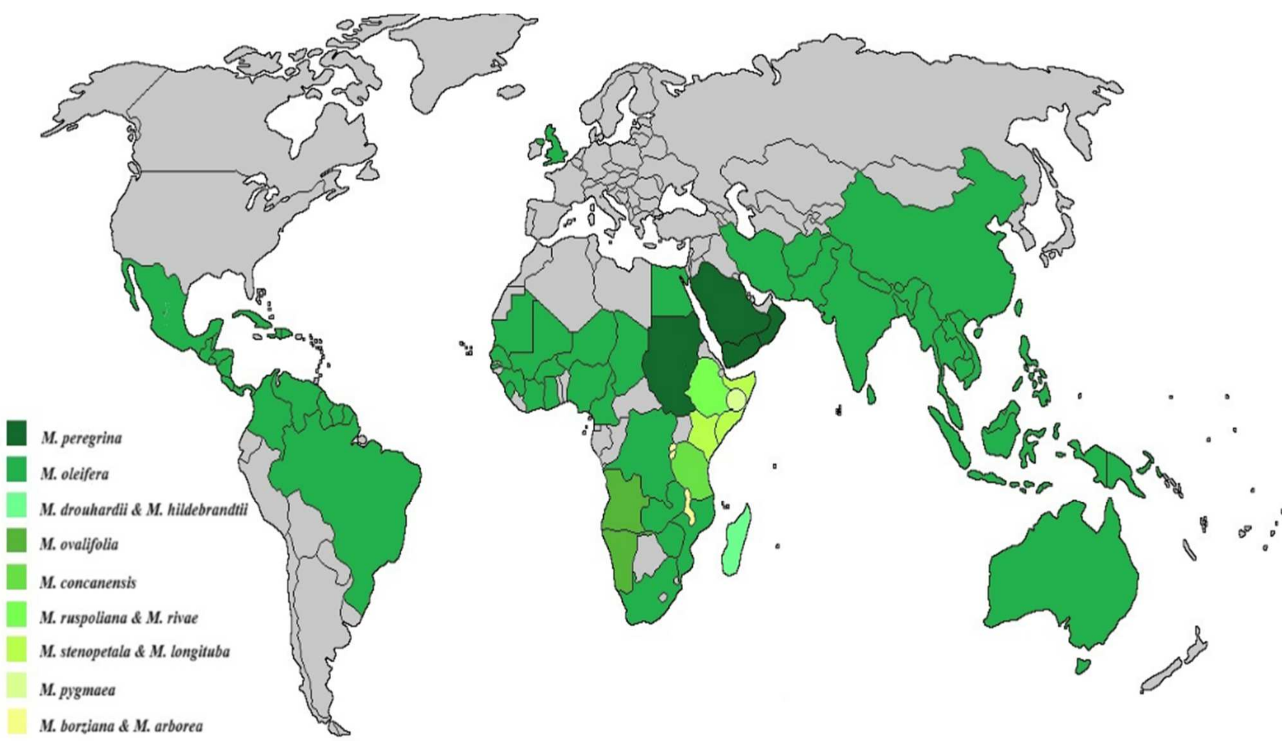

Figure 1: Distribution of *Moringa* tree sp. in world countries

A paradigm shift towards adopting natural, nutrient-rich alternatives for health and wellness is reflected in the global surge in demand for moringa. India is the leading producer of moringa, yielding an annual production of 2.2 million tonnes of tender pods from a cultivation area spanning 43,600 hectares, resulting in a productivity of approximately 51 tonnes per hectare (Sekhar *et al.*, 2018). India currently dominates the global market, fulfilling over 80% of the worldwide demand for moringa. Moringa leaf powder, as a dietary supplement, is gaining attention in developed nations (APEDA, 2018).

Pest dynamics: A global overview: Extracts from various components of the moringa plant are used to combat insect pests such as *Spodoptera litura* (Kaur *et al.*, 2021), stored insect pests such as *Sitophilus zeamais, S. oryzae, Callosobruchus maculatus* (Oliveira *et al.*, 2020; Okwor *et al*., 2021), and mites (Heinz-Castro *et al.*, 2021). While moringa extract can be used to combat some pests, the plant itself is also vulnerable to attacks by certain pests (Math and Kotikal., 2014; Joshi *et al.*, 2016; Prasannakumar *et al.*, 2024). Research indicates that 32 insect species belonging to 30 different genera, 22 families, and 9 orders are associated with *Moringa oleifera*. In this context, insect pests were found to be more prevalent than their predators (El-Saeady *et al*., 2017). Table 1 lists the key pests of moringa.

Emerging insect pest scenario in moringa: Although the occurrence of *N. moringae* in moringa was documented as early as 1940 (Cherian and Basheer), this pest continues to pose a significant threat in tropical and subtropical climatic regions (Manikandan and Rengalakshmi, 2024). The larvae bores into unopened flowers and the affected buds will dry out and fall off. The larvae pupate in a silken cocoon encased in soil particles. Severe infestations can result in damage, up to 78%. Infested buds tend not to blossom and fall prematurely, and typically, only one caterpillar is found in each infested bud (Cherian and Basheer, 1940). One contributing factor for budworms increasing infestation is the positive correlation between budworm infestation and temperature, alongside a negative correlation with precipitation (Math *et al.*, 2014; Manikandan and Rengalakshmi, 2024). Rising temperatures can accelerate pest development within a season, allowing for multiple generations to be completed in a single year. This, in turn, results in an increased pest density due to reduced exposure to cold stress (Schneider *et al.*, 2022). The lack of research findings (Figure 2) on the biology, and management aspects of budworm is another critical factor contributing to the potential damage this pest could cause in the future.

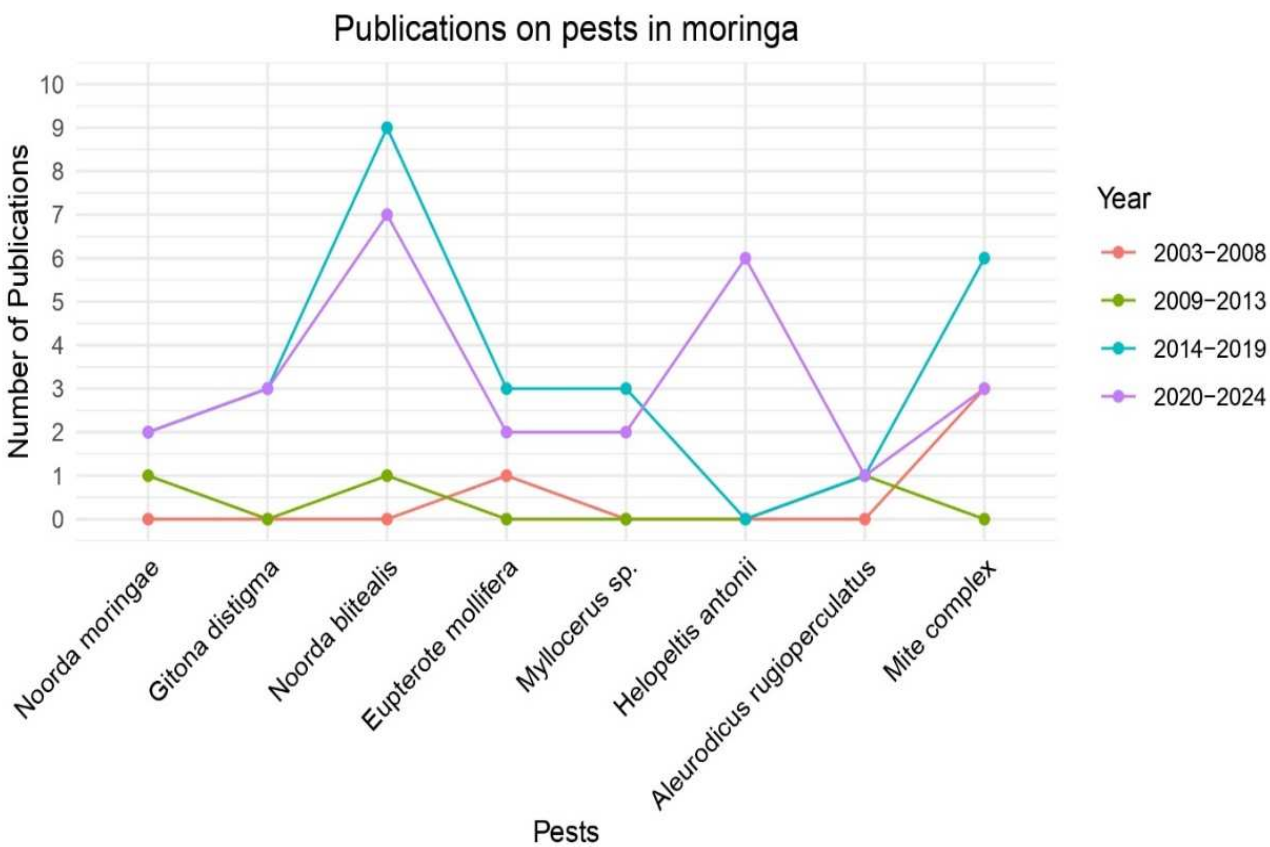

Figure 2: Number of publications on potential moringa pests from the year 2003 to 2024

Table 1. List of important insect pests of moringa

Common Name	Scientific Name	Family	Category	Distribution	Destructive Stage	References
Lepidoptera						
Budworm	*Noorda moringae* Tams	Crambidae	Flower bud feeder	India, Africa	Larvae	Cherian and Basheer, 1940; Manikandan and Rengalakshmi, 2024
Leaf eating caterpillar	*Noorda blitealis* Walker	Crambiade	Defoliator	India, Sri Lanka, Australia, Niger, China, Nigeria, Ethiopia.	Larvae	Ratnadass *et al.*, 2010; Math and Kotikal, 2014; Sharjana and Mikunthan, 2018; Zhang *et al.*, 2021; Halilou *et al.*, 2021; Prasannakumar *et al.*, 2024
Hairy caterpillars	*Eupterote mollifera* Walker	Eupterotidae	Defoliator	India, Sri Lanka	Larvae	Sivagami and David, 1968; Sri *et al.*, 2009; Kannan *et al.*, 2018
	Metanastria hyrtaca Cramer	Lasiocampidae	Defoliator	India, South Africa, Sudan	Larvae	Sivagami and David, 1968
	Streblote siva Lef.	Lasiocampidae	Defoliator	India, Philippines	Larvae	Sivagami and David, 1968; Outani *et al.*, 2023; Rajmohana *et al.*, 2024
Wooly bear	*Olepa (=Pericallia) ricini* Fabricius	Erebidae	Defoliator	India	Larvae	Raja *et al.*, 2000
Bark borer	*Indarbela* sp. Fletcher	Metarbelidae	Bark feeder	India	Larvae	Math and Kotikal, 2014
Diptera						
Pod fly/ Fruit fly	*Gitona distigma* Meigen	Drosophilidae	Pod feeder	India, Africa, Sri Lanka,	Maggot	Okonkwo *et al.*, 2014; Sharjana and Mikunthan, 2018; Prasannakumar *et al.*, 2024; Manikandan and Rengalakshmi, 2024
	Physiphora aenea Fabricius	Ulidiidae	Pod feeder	India	Maggot	Prasannakumar *et al.*, 2024
	Diarrhegma modestum Fabricius	Tephritidae	Pod feeder	Bangladesh, India	Maggot	Hancock and Drew, 1994; Hossain and Khan, 2013
Bud midge	*Contarinia (=Stictodiplosis) moringae* Mani	Cecidomyiidae	Flower bud feeder	India	Maggot	Cherian and Basheer, 1938
Coleoptera						
Ash weevils	*Myllocerus* sp. Schönherr	Curculionidae	Defoliator	India	Grub and Adult	Math and Kotikal, 2014; Rajan and Ghosh, 2019; Ramesh *et al.*, 2023; Prasannakumar *et al.*, 2024
Long horn beetle	*Batocera rubus* Linnaeus	Cerambycidae	Stem borer	India	Grub and adult	Reddy *et al.*, 2018; Prasannakumar *et al.*, 2024
	Batocera rufomaculata DeGeer	Cerambycidae	Stem borer	India	Grub and adult	Jiji *et al.*, 2016; Prasannakumar *et al.*, 2024

Hemiptera						
Aphid	*Aphis craccivora* Koch	Aphididae	Sap feeder	Nigeria, India, Egypt, Hawaii, Pacific Island	Nymph and Adult	Math and Kotikal, 2014; Okonkwo *et al.*, 2014; El-Saeady *et al.*, 2017
	Aphis loti Kaltenbach	Aphididae	Sap feeder	India	Nymph and Adult	Prasannakumar *et al.*, 2024
Tea mosquito bug	*Helopeltis antonii* Signoret	Miridae	Sap feeder	India	Nymph and Adult	Mala *et al.*, 2020; Aravinthraju *et al.*, 2023b; Ramesh *et al.*, 2023; Prasannakumar *et al.*, 2024
Spiralling white fly	*Aleurodicus dispersus* Russell	Aleyrodidae	Sap feeder	India, Australia	Nymph and Adult	Lambkin, 1999; Ramani, 2000
Rugose spiralling white fly	*Aleurodicus rugioperculatus* Martin	Aleyrodidae	Sap feeder	India	Nymph and Adult	Dubey and Ko, 2008; Nandhini and Srinivasan, 2023
Scale	*Drepanococcus (=Ceroplastodes) cajani* Maskell	Coccidae	Sap feeder	India	Nymph and Adult	Sivagami and David, 1968; Joshi *et al.*, 2016
Acari						
Spider mite	*Tetranychus urticae* Koch	Tetranychidae	Non-insect pest	Africa, Philippines, India	Nymph and Adult	Dube *et al.*, 2015; Abdallah *et al.*, 2019; Verghese and Rashmi, 2023
	Tetranychus neocaledonicus Andre	Tetranychidae	Non-insect pest	India	Nymph and Adult	Kaimal and Ramani, 2007; Ramani, 2008; Briozo *et al.*, 2023; Prasannakumar *et al.*, 2024
	Tetranychus merganser Boudreaux	Tetranychidae	Non-insect pest	Mexico	Nymph and Adult	Monjarás-Barrera *et al.*, 2015; López-Bautista *et al.*, 2016
	Oligonychus punicae Hirst	Tetranychidae	Non-insect pest	Mexico	Nymph and Adult	Vásquez *et al.*, 2008; Monjarás-Barrera *et al.*, 2015; Ferraz *et al.*, 2019; Abo-Elmaged *et al.*, 2021
Snail	*Macularia (=Cepaea) sylvatica* Draparnaud	Helicidae	Non-insect pest	Barkino fasa	Larva and Adult	Dao *et al.*, 2015

Gitona distigma has emerged as one of the most serious pests affecting moringa pods. The maggots of *G. distigma* enter through a bored hole at the terminal end of the pods causing infected pod to become brown, dried, and split from the tip, exposing the fruit's pulp. Brown gummy exudates ooze out, and the pod becomes rotten due to infestation. (Sivagami and David, 1968; Sharjana and Mikunthan, 2018). Unlike budworm, pod fly infestation can be particularly severe during periods of low temperature and high rainfall, with infestation rates ranging from 35.10% to 60.7% (Math and Kotikal, 2014; Manikandan and Rengalakshmi, 2024). Additionally, for the first time, a newly discovered pod fly, *P. aenea* was identified in India, causing substantial damage ranging from 50% to 80% (Prasannakumar *et al.*, 2024). In the absence of effective management strategies, the infestation of pod flies could result in significant yield losses, given their impact on the economically valuable parts of the moringa plant.

The increasing volume of research on *N. blitealis* underscores the substantial harm causes to moringa cultivation. Farmers consider *N. blitealis* as the most significant biotic constraint in moringa cultivation (Halilou *et al.*, 2021). Initially, the caterpillar scraps chlorophyll from the leaves, giving them a papery appearance. As it matures, it consumes entire leaves, leaving only veins. Severe infestations result in complete defoliation. The caterpillar prefers tender leaves in its early stages and mature leaves later on. While previous reports mentioned the caterpillar feeds on moringa leaves, it also damages pods by consuming pulp and seeds, leading to gummy exudation. (Munj *et al.*, 1998; Math and Kotikal, 2014). A survey conducted in the Tamil Nadu district of India found that 68% of moringa crops were affected by *N. blitealis* (Ramesh *et al.*, 2023). *Noorda blitealis* infestations have the potential to cause 90-100% yield loss (Halilou *et al.*, 2021; Prasannakumar *et al.*, 2024). Although this pest is known to infests moringa year-round, its population significantly decreases during the rainy season as it is easily washed away (Halilou *et al.*, 2021). Several hairy caterpillars also defoliate moringa. Notably, *E. mollifera* larvae exhibit a collective feeding behavior, scraping the bark and gnawing on the foliage. In cases of severe infestation, the tree may experience complete defoliation (Butani and Jotwani, 1984).

Myllocerus sp. has already been reported as notorious pest of several ornamental, horticultural, and agro-forestry plants (Josephrajkumar *et al.*, 2011;Paunikar, 2015; Nagesh *et al.*, 2016; George *et al.*, 2019; Rajan and Ghosh, 2019). Although *Myllocerus* sp. are considered minor pests in moringa (Prasannakumar *et al.*, 2024). A survey conducted in Tamil Nadu, India (Ramesh *et al*, 2023) revealed that ash weevil infested 54% of moringa cultivation, making it the second most prevalent pest after *N. blitealis*. Among the *Myllocerus* species, *M. subfasciatus* is the most predominant, followed by *M. viridanus* (Prasannakumar *et al.*, 2024). Adult insects act as defoliators, causing damage by completely removing a plant's foliage. Grubs create holes near the main root tip, consuming internal tissues and forming tunnels as they move upward resulting in the hollowing of the root (Paunikar, 2015). Research on this insect pest's impact on moringa is necessary to prevent it from becoming a major defoliator in moringa cultivation.

Research findings over the past five years indicate *Helopeltis antonii* infestations in moringa. This pest, originally known for infesting plantations (Asokan *et al.*, 2012), has expanded its host range including moringa (Aravinthraju *et al.*, 2023b). *Helopeltis antonii* prefers feeding on young twigs, flowers, and occasionally pods, leading to the drying of twigs and flowers. It results in a wilted appearance with honey-like resins oozing from the tree. Infestation occurs at any crop stage but shows a higher preference for older trees, which are more susceptible. Severe damage transforms affected moringa trees into snags, resembling sharp sticks without leaves (Aravinthraju *et al.*, 2023a). In India, *H. antonii* has attained a major pest status in moringa causing an estimated yield loss of about 20-30% (Prasannakumar *et al.*, 2024).

Aleurodicus rugioperculatus was recently identified as a pest of moringa (Nandhini and Srinivasan, 2023). However, no research findings are currently available regarding its infestation patterns and damage potential on this plant. *Tetranychus urticae* and *T. neocaledonicus* have been documented as pests of moringa worldwide (Yousuf and Chouhan, 2009; Kaimal and Ramani, 2007; Okonkwo *et al.*, 2014; Dube *et al.*, 2015; Abdallah *et al.*, 2019), while *T. merganser* was recorded for the first time on moringa (Monjarás-Barrera *et al.*, 2015). In warm and humid greenhouse environments, *M. oleifera* seedlings encounter infestations from spider mite, leading to the withering of the seedlings (Dube *et al.*, 2015; Olson, 2017). *Tetranychus neocaledonicus*, induces the formation of noticeable white spots, resulting in leaf chlorosis on *M. oleifera*. The affected leaves undergo chlorophyll loss, leading to subsequent drying and shedding (Kaimal and Ramani, 2007).

Secondary insect pests on moringa: Bud midge, *Contarinia (=Stictodiplosis) moringae,* consumes the internal contents of flower buds, leading to the significant buds shedding in large quantities (Kotikal and Math, 2016). Stem borer, *Indarbela* sp. though commonly found on various host plants, exhibits a preference for moringa trees as alternate host. The caterpillars feed just beneath the bark, creating zigzag galleries. While they bore inside the burrows during the day, they often emerge at night to feed on the bark. A prominent indicator of their presence is the formation of large silken webbed masses, composed of chewed wooden particles and larval excreta (Saha *et al.*, 2014; Math and Kotikal, 2014). The grubs of long horn beetle, *Bactocera rubus* creates zigzag burrows under the bark, feeding on internal tissues and potentially reaching the sapwood, which can result in the death of branches or stem. Pupation occurs within these tunnels, with emerging adults feeding on the bark of young twigs and petioles (Reddy *et al.*, 2018; Prasannakumar *et al.*, 2024). *Aphis craccivora* is identified as one of the foremost prevalent piercing-sucking insects on moringa (El-Saeady *et al.*, 2017). Nymphs and adults extract vital sap from twigs, potentially causing complete devitalization of the entire tree during severe infestations. Given its mainly parthenogenic reproduction, the population proliferates swiftly (Butani and Jotwani, 1984). *Ceroplastodes cajani* Maskell and various *Diaspidiotus* species have been reported as scale insects, posing a threat to moringa trees in India (Butani and Jotwani, 1984). The cumulative impact of numerous insects continuously feeding on sap can adversely affect pod size (Joshi *et al*., 2016; Kotikal and Math, 2016).

Pest surveillance: Monitoring involves the regular scouting of crops after germination to check for signs and symptoms of pests, aiding in making better pest management decision (Bateman *et al.*, 2021). Weekly monitoring can be conducted through pest scouting using various monitoring devices such as pheromone and coloured sticky traps. To fully count every kind of insect in moringa, at least fifteen places at acceptable distances should be inspected in a zigzag pattern that follows a cross-diagonal pattern (DPPQS, 2016). The field will be considered fit for export if insect pests are found to be absent in 95% of the plants (DPPQS, 2016). Information gathered can help prevent pest populations from establishing on a crop and can inform control tactics, particularly targeting early stages (Oyafuso *et al.*, 2002).

Integrated pest management practices for moringa: Globally, a plethora of methodologies have been employed to manage pest infestations and avert yield losses. Integrated Pest Management is the combined use of various compatible components to keep populations of one or more insect pests at threshold levels in an agricultural system while safeguarding humans, animals, plants, and the environment from all harm (FAO, 2022). Initially there was a pronounced dependence on pesticides and insecticides; however, alternative approaches have gained popularity because of their detrimental effects on the environment and human health. These substitutes include insect pests' host selection behavior and preference, biocontrol (Fu *et al.*, 2017), resistant cultivars (Ahmed *et al.*, 2018), botanical extracts (Khater, 2012), and volatile organic substances.

Cultural control: Cultural control entails modifying the environment or management practices to render it less conducive to pests (Rajput *et al.*, 2024). Farmers in Niger have practiced pruning trees to eliminate *N. blitealis* and employed poultry to forage for caterpillars and chrysalids on the ground (Halilou *et al.*, 2021). Raking the soil beneath the trees or ploughing the infested field is recommended to eliminate puparia which will eventually get exposed (Kamaraj and Manisegaran, 2019). The collection and disposal of damaged buds and caterpillars to reduce further infestations of *Noorda* sp. (Saha *et al.*, 2014). Collection and destruction of all fallen and damaged fruits to manage pod fly infestation (Outani *et al.*, 2023; Ratnadass *et al.*, 2010). Soil application of Neem cake at the rate of 250kg/ha is effective in managing pod fly (Prasannakumar *et al.*, 2024).

Host plant resistance: Host plant resistance offers numerous benefits over other pest management tactics (Adkisson and Dyck, 1980). Its effect on target pests is consistent and cumulative, and the implementation of resistant varieties is simple and cost-effective for farmers. Additionally, plant resistance is compatible with other methods such as insecticide applications and biological control (Wiseman, 1994; Wilde, 2002) and it reduces the negative environmental impacts associated with insecticides (Wilde, 2002). In moringa, out of 56 genotypic lines, six genotypes M-26, M-63, M-19, M-46, M-54, and M-66 exhibit less than one percent infestation of *N. blitealis*. This resistance may be attributed to the plant's inherent hardness, toughness, and bitter taste (Chandrakar and Gupta, 2020a). These resilient lines hold significant potential for breeding programs aimed at developing varieties resistant to *N. blitealis*. In West Africa, the prevalent *M. oleifera* strains, specifically PKM1 and PKM2, and *M. stenopetala* variant display significant vulnerability to this pest (Outani *et al.*, 2023). In a study, thirty-eight accessions and hybrids of moringa were evaluated for resistance against *G. distigma* and ended with the identification of resistant (MT18, MT6, MT28), moderately resistant (H7, H11, H24), and highly susceptible (MT5, M17, M21) accessions to *G. distigma* (Ragumoorthi *et al.*, 1998). Despite many advantages, the potential of host-plant resistance remains underutilized in many crops (Smith and Clement, 2012; Wilde, 2002). Regrettably, there is currently no single type of moringa that shows resilience against a variety of pests, and research on screening or breeding resistant moringa varieties is still in its infancy.

Mechanical control: Mechanical control refers to measures involving the operation of machinery or manual operations (Sorensen *et al.*, 2016). Light traps at 1-2 /ha are used to attract and destroy adults of nocturnal pests such as adults of *N. moringae, N. blitealis, Euproctis* sp. of the moringa ecosystem (Saha *et al.*, 2014). Implementation of elevated sitting arrangements for birds above the height of the moringa crop in fields facilitates bird visits and predation. This provision supports natural insect pest control by encouraging birds to perch at advantageous heights, contributing to a balanced ecosystem within the moringa cultivation and utilizing a burning torch to eliminate congregating larvae on the trunk is an effective method to control hairy caterpillars (Joshi *et al*., 2016). Handpicking of immature stages from the field and destruction helps in preventing further damage (Halilou *et al.*, 2021). Eliminating larvae of bark-eating caterpillars within tunnels involves inserting a sharp metallic probe into the tunnels to kill the larvae. Afterwards, sealing the tunnel entrance with tar or wax helps prevent further infestation and promotes effective pest control in the affected area (Saha *et al.*, 2014).

Biological control: Currently, the use of entomopathogens as biological control agents for numerous insect pests is gaining significant attention due to their reliability, cost-effectiveness, and environmental safety (Wraight *et al.*, 2001). For instance, in moringa, *Beauveria bassiana* @ 2 g/L was treated against *N. blitealis* larvae resulting in a 64.29% mortality rate in a laboratory study (Moumouni and Mahamane, 2021). Similarly, several other biopesticides have shown efficacy against moringa pests. A liquid formulation of *Bacillus thuringiensis* at 2 mL/L has proven to be effective against *N. blitealis* larvae (Prasannakumar *et al.*, 2024), while a granular form of *B. thuringiensis* (Delfin) at 0.25 g/L achieved 100% mortality in neonate larvae of *E. mollifera* (Babu *et al.*, 2003). Furthermore, the application of entomopathogenic nematode *Steinernema glaseri*, applied at 1000 infective juveniles per 10 mL, showed 83% mortality rate against fourth-instar *E. mollifera* larvae (Subramaniyan *et al.*, 2005).

In addition to biocontrol agents, plant-based extracts with insecticidal properties are indigenously available and are considered comparatively safe for the environment and public health (Iqbal *et al.*, 2011). Several botanical extracts tested against moringa pests have been enumerated in table 2.

Besides, the moringa ecosystem hosts a diverse array of natural enemies. Among these, spiders are found in substantial numbers on new shoots, where they naturally regulate and control the growing insect pest population (Saha *et al.*, 2014). In a study conducted in the annual moringa ecosystem, 15 spider species were recorded, including *Tetragnatha* sp., *Zygiella indica* Tikader and Bal, *Neoscona mukerjei* Tikader, *Larinia chloris* (Audowin), *Neoscona* sp., *Clubiona* sp., *Phintella vittata* (Koch.), *Thomisus* sp., *Olios*sp., *Marpissa* sp., *Neoscona theisi* (Walckenaer), *Heteropoda* sp., *Araneus* sp., *Oxyopes* sp., and *Peucetia* sp. Additionally, predaceous coccinellids, *Cheilomenes sexmaculatas* (F.), and *Anegleis cardoni* (Weise) and three parasitoid species: *Mesostenidea* sp. *Viereck* (Ichneumonidae), *Clinocentrus* sp. (Braconidae), and *Cystamastax* sp. (Braconidae) were recorded in the same ecosystem (Selvi and Muthukrishnan, 2009). Similarly, in another study, the moringa plant was found to hosts 19 natural enemies, including four insect predators, one parasitoid, one bird, and thirteen species of spiders (Kumari and Kotikal, 2016).

The larval parasites of *N. moringae* recorded from field include *Microbracon brevicornis* Wesmmael, *Elasmus hybleae* Ferriere, *Pristomerus* spp. (Ichneumonidae), *Chelonus* spp. (Braconiae), *Perilampus* spp., *Systasis* spp. (Chalcidoideae) and *Apanteles* spp. (Cherian and Basheer 1940).

Table 2. Botanicals tested against moringa pests.

Target pest	Botanicals	Extract	Dosage	Reference
Noorda blitealis	*Prosopis juliflora Pongamia pinnata* Neem Seed Kernel Extract	Leaf extract Seed extract Seed kernel extract	5%	Rachana *et al.*, 2021
	Neem oil	Leaf extract Seed kernel	2.5g/L 1%	Sharjana and Mikunthan, 2019
	Neem soap	Leaves	10g/L	Prasannakumar *et al.*, 2024
Gitona distigma	NSKE	Seed kernel extract	5%	Math *et al.*, 2014
Eupterote mollifera	NSKE Neem leaf extract	Seed kernel extract Leaf extract	5% 5%	Kannan *et al.*, 2018
	Vitex negundo	Leaf extract	-	Ramamurthy *et al.*, 2012
Aphis craccivora	Neem oil	Seed kernel	2.5 mL/L	Prasannakumar *et al.*, 2024
Helopeltis antonii	Neem soap	Leaves	10 g/L	Prasannakumar *et al.*, 2024
	NSKE	Seed kernel extract	5%	Dutta *et al.*, 2013
Tetranychus neocaledonicus	*Cassia alata*	Leaf methanol extract	3%	Roy *et al.*, 2011

Chemical control: In developing nations, farmers primarily rely on conventional practices to manage insect pests affecting vegetable crops, which involves the extensive use of synthetic, persistant agrochemicals (Chagnon *et al.*, 2015; Halilou *et al.*, 2021). Among moringa cultivators in India, the organophosphorus compound, monocrotophos has been commonly employed to address pest problems, despite its prohibition on vegetable crops (Ramesh *et al.*, 2023). However, the indiscriminate application of persistent pesticides has led to various issues, including development of insecticide-resistant pests, destruction of beneficial organisms, resurgence of secondary and invasive pest species, and significant environmental pollution (Edwards, 2013).

Experimental studies on the use of novel insecticides for combating moringa pests are reviewed here, excluding banned chemicals (Table 3). Nevertheless, there is a conspicuous lack of information regarding pesticide residue in moringa. Moreover, there is currently no standard recommended practice for insecticide application listed by the Central Insecticides Board and Registration Committee (CIB & RC) for moringa, nor a Maximum Residue Level (MRL) reference available. Given the consumption of moringa for their fresh leaves, employing plant protection strategies becomes imperative to minimize pesticide residues. Consequently, further research in this area is essential before making recommendations.

Table 3. Insecticides used against moringa pests

Target pest	Insecticide	Dosage	Mode of Action	Mode of application	Reference
Noorda blitealis	Chlorantraniliprole 18.5 SC	0.15 mL/L	Nerve and muscle action	Foliar spray	Rachana *et al.*, 2021
	Spinosad 45 SC	0.1-0.3 mL/L	Nerve action	Foliar spray	Rachana *et al.*, 2021; Prasannakumar *et al.*, 2024
	Indoxacarb 15.8 EC Emamectin benzoate 5 SG	0.3 mL/L 0.2- 0.25 g/L	Nerve action Nerve and muscle action	Foliar spray	Kumari *et al.*, 2015; Rachana *et al.*, 2021
Gitona distigma	Thiamethoxam 25 WG	200 g a.i./ha	Nerve action	Soil application	Selvi and Muthukrishnan, 2009
	Spinosad 45 SC	56 g a.i./ha (or) 0.2-0.3 mL/L	Nerve action	Foliar spray	Selvi and Muthukrishnan, 2009; Math *et al.*, 2014; Prasannakumar *et al.*, 2024
	Profenofos 50 EC	250 g a.i./ha (or) 1.0 mL/L	Nerve action	Foliar spray	Selvi and Muthukrishnan, 2009; Math *et al.*, 2014
	Emamectin benzoate 5 SG	0.25 g/L	Nerve and muscle action	Foliar spray	Math *et al.*, 2014; Saha *et al.*, 2014
Eupterote mollifera	Quinalphos 25 EC Chlorpyriphos 20 EC	1.0 L in 500 -750 L of water per ha	Nerve action	Trunk and Foliage	Saha *et al.*, 2014
Helopeltis antonii	Lamda cyhalothrin 5 EC Spinosad 45 SC Fipronil 5 SC	0.6 mL/L 0.3 mL/L 1.0 mL/L	Nerve action	Foliar spray	Prasannakumar *et al.*, 2024

Conclusion and Future prospects: Despite the global cultivation and increasing demand for moringa, research on its pests remains limited. This review highlights the vulnerability of moringa to a wide range of insect pests, with significant damage reported globally. Notably, *N. moringae*, *G. distigma*, *N. blitealis*, *E. mollifera*, *Myllocerus* sp., and sucking pests such as *H. antonii* and mite complex, pose significant threats to moringa cultivation. As the cultivation area expands, pest-related issues are becoming more prevalent, underscoring the urgent need for comprehensive research on protection of moringa. Current studies are inadequate to fully comprehend the distribution and severity of these pests. While research efforts have primarily focused on *N.*

blitealis, other pests such as *G. distigma*, *N. moringae*, and *Myllocerus* sp., that cause significant yield loss have been largely overlooked. Additionally, insect pests like *H. antonii* and *A. rugioperculatus* have been recorded in moringa, necessitating further research on their biology, population dynamics and preventive measures to curb their spread. Mite complex also warrants thorough investigation to prevent population surges due to changing climatic conditions. Research gaps persist in understanding the distribution and severity of these pests as well as the impact of changing climatic factors.

A particular concern is the reliance on persistent chemicals such as organophosphates for managing moringa pests. Suitable recommendations for novel, less persistent insecticides, including application rates and specific action threshold levels, still need to be determined and tailored to specific pest species. The threshold level of each insect damaging moringa should be developed as this is the main concern in the pest management. Furthermore, there is a critical need for studies on insecticide residue levels in moringa, especially given the economic importance of its leaves. Priorities should include developing pest-resistant cultivars, exploring suitable biopesticides, and establishing Maximum Residue Limits (MRLs). Overall, proactive and Integrated Pest Management approaches are essential to mitigate the impact of pests on moringa cultivation and ensure its long-term sustainability.

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