Andalasian International Journal of Entomology (AIJENT) - Vol. 2 No. 1 (2024) 48-59 http://aijent.lppm.unand.ac.id

AIJENT OPEN ACCESS

Original Research

Insects Induced Mango Fruit Rot: Unraveling the Culprits

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Article Information

Received : February 25, 2024
Revised : March 17, 2024
Accepted : April 13, 2024
Published : April 18, 2024

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Citation

Subramaniam, S., Aisyah Md Noordin, N., Azrizal-Wahid, N., & Ain Izzati Mohd Zainudin, N. (2024). Insects Induced Mango Fruit Rot: Unraveling the Culprits. *Andalasian International Journal of Entomology*, 2(1), 48–59. https://doi.org/10.25077/aijent.2.1.48-59.2024

E-ISSN: 3026-2461
https://doi.org/10.25077/aijent.2.1.48-59.2024

Abstract

Plant diseases and pests are important factors determining plant yield production, including mango. Mango is an economically important fruit crop in tropical and subtropical areas. Mango fruit rot caused by insects and microbes has become a significant threat to mango production in Southeast Asia and worldwide. Insect plant pathogens affect crop yields' profitability, quality, and quantity. Some infections could occur before harvest and remain dormant until the favourable condition is achieved, and the disease will break out after harvest, reducing mango production. They act as a threat to the crops through various mechanisms of pathogenesis that compromise the immune system of the plants, such as developing any ways to attack the plants, seeking entry *via* open pores or exposed surface or wound, and sourcing nutrients forcefully for their growth and development. Depending on the environmental factors, the insect contracts the host through primary or secondary infection. This paper summarizes mango fruit rot disease caused by insects groups such as fruit borers (*Autocharis albizonalis* and *Citripestis eutraphera*), fruit flies (*Bactrocera dorsalis*), and mango seed weevils (*Sternochetus mangiferae).* This review will provide information about fruit rot diseases on mangoes caused by insects, the mechanism of infection, the interaction between insect damage and fungal infections, effective control methods, and related integrated pest management approaches.

Keywords

Fruit rot, insects, mango, plant disease, pest

INTRODUCTION

Mango (*Mangifera indica* L.) is an economically important fruit crop in tropical and subtropical areas. It begins in Asia and then gradually increases in developed countries (FAO, 2022). From an economic aspect, food production in the agricultural sector is one of the important sources of income and employment for many growers and exporters. Mango was grown over 5.1 million hectares in 94 countries (Singh et al., 2013), with the largest producer of mangoes in the world being India (Kusuma & Basavaraja, 2014). Instead of India, other countries like China, Thailand, Indonesia, Pakistan, Mexico, Brazil, and Bangladesh were among the major mango producing countries (Nur Afiqah et al., 2014). Mango also has become an essential fruit crop in Southeast Asia, such as the Philippines, Myanmar, Malaysia, and Sri Lanka, besides becoming favored in Egypt, South East Africa, South Africa, the USA (Hawaii and Florida), West Indies, Israel, and tropical Australia (Vivekananthan et al., 2004). Mango also has been well-reported as a vital source of micronutrients, vitamins, and phytochemicals such as carotenoids, dietary fiber, and polyphenols (Ajila et al., 2010) that play an important role in the predominant function and antioxidant properties (Jahurul et al., 2015).

As mentioned by Agrios (2005), interactions between three factors of environmental conduciveness, virulence of pathogen, and susceptibility of the host in the disease triangle concept contributed to the amount of disease produced. Generally, mango is attacked by various pathogens, fungi, bacteria, nematodes, and viruses (Nasir et al., 2014) that cause severe diseases in pre- and postharvest phases, such as powdery mildew and bacterial black spot. The diseases have reportedly been caused by several types of fungi, such as *Dothiorella dominicana*, *Dothiorella mangiferae*, *Lasiodiplodia theobromae*, *Phomopsis mangiferae*, *Pestalotiopsis* sp., and *Alternaria* sp. (Johnson et al., 1992; Karunanayake et al., 2014). Apart from that, insects also play a vital role as a causal agent to infect crop plants, especially mangoes, in this focus review. Fruit flies, mango seed weevil, and mango fruit borer are examples of insect-induced mango fruit rot that are further discussed, including the process of infection, how insect damage and fungal infections interact, practical control measures, and related integrated pest management strategies.

Mango Fruit Rot Caused By Insects

Fruit flies

The Tephritidae family, renowned for its frugivorous nature, poses a pervasive threat to orchards and crop plantations worldwide, sparing not even the esteemed mango. The presence of these pests confers a substantial challenge throughout the pre- and postharvest phases of mango production and marketing, as expounded upon by Grechi et al. (2021). Among these intruders, *Bactrocera dorsalis* (Hendel), in particular, has precipitated a staggering reduction of yield, reaching a notable 80% decline in both Africa and India, which are the major mango-producing regions globally (Verghese et al., 2012). Within the vast expanse of Tephritidae, the preeminent concern lies with the universal impact of *Bactrocera dorsalis*, alongside its counterpart, *Bactrocera carambolae*, eliciting pronounced occurrence within Peninsular Malaysia, as meticulously detailed by Salmah et al. (2017).

Generally, adult fruit flies exhibit a size range of approximately 2 to 25 mm in length. They are equipped with a needle-like, chitinized ovipositor sheath, a specialized tool facilitating the deposition of eggs within healthy and favored host tissues (Steck, 2008). These eggs manifest as elongated-cylindrical capsules, some featuring tail-like extensions while others lack this embellishment. Upon hatching, the larvae embark on an active feeding phase, driven by an unappeasable appetite for nutrients, particularly pronounced during the third instar stage. However, these fully developed larvae descend to the soil for pupation, having established themselves as fruit infesters (Susanto et al., 2022). Thus, the central challenge in managing fruit flies revolves around restricting the egg-laying process within the fruit tissues.

Given their inclination towards warmer temperatures, fruit flies thrive more in tropical climates compared to the winter and fall seasons of countries with distinct seasons. Within tropical environments, these adult fruit infesters can subsist for several months due to a continuous cycle of year-round breeding, with various hosts serving as sites for egg ovipositing (Clarke et al., 2022). Consequently, all life stages of these pests persist uniformly throughout the year. Hence, the compulsion to combat these pests becomes particularly pronounced within tropical regions. In contrast, seasonal climates present an opposing scenario, characterized by a shortened lifespan for fruit flies and a diminished span of the adult flight period. Consequently, the most extended phase of their existence becomes the pupal stage, which can endure for numerous years, only culminating upon the advent of a favorable climate that prompts emergence (Rull et al., 2019).

Like other insect divisions, fruit flies adhere to specific prerequisites when infesting fruits, a phenomenon particularly reliant upon the quality of the host fruit. The allure the *Bactrocera* genus holds for delectable mangoes is intricately linked to their olfactory response to aromas. Aromas, often composed of volatile compounds, become trapped within the sensory antennae of these flies, thus generating varying levels of appeal depending on the mango variety (Handaru et al., 2019). Additionally, the heightened presence of protein compounds within ripe mangoes, specifically terpinolene trans-2-heptenal, 1-hexanol, hexanal, p-cymene, and γ-terpinene contents, compared to their unripe mangoes, serves as a potent attractant for adult flies, predominantly luring them towards oviposition within ripe mangoes (Liu et al., 2020). Furthermore, the female fruit flies meticulously assess potential substrates, not only for their suitability for oviposition but also for ensuring the survival of their offspring. This exacting evaluation encompasses considerations such as shape, durability, color, size, scent, organic compounds, and the proportion of starch to free sugars, underscoring their commitment to progeny viability (Rattanapun et al., 2009).

Jaleel et al. (2021) substantiate that female *B. dorsalis* exhibit a predilection for softer-skinned fruits, particularly mangoes in the presence of guava and banana, as sites for egg deposition within the flesh. When these females endeavour to puncture the tougher fruit skins, including those of unripe mangoes, utilizing their ovipositors, a secretion of resin ensues prior to completing egg injection, a mechanism that prevents deeper penetration. The prevalence of heightened resin levels, rich in phenolic compounds across many fruits, serves to force the eggs outwards toward the outer fruit skin, thereby giving rise to the deposition of inviable eggs upon the surface (Grechi et al., 2021). To counteract this, oviposition strategies encompass prevalence in selecting the plausible skin texture, enabling easier and deeper puncturing to expedite cluster-based oviposition. It is notable, however, that certain instances involve female fruit flies occasionally ovipositing in unripe mangoes. In a comparative context, the diminished number of eggs found within unripe mangoes, as opposed to ripe ones, might be attributed to the significant influence of the chlorophyll-rich pericarp (Salmah et al., 2017).

The mango, serving as a substrate, not only ensures the vitality of the eggs but also grants a nutritional regimen upon larval hatching. Typically, every oviposition event within a cluster yields a numerical range of 10 to 50 eggs by mean (Steck, 2008). Following a brief period of incubation within the mango flesh, the larvae undertake a subterranean journey, consuming the interior flesh and, in the process, loading the flesh with their frass. This action inadvertently carves a gateway for the entry of microbial agents responsible for inducing fruit rot. Consequently, the fruit undergoes a transformative softening, succumbing to decay, damage, and eventual detachment. While fruit flies may not serve as the primary architect of mango fruit rot, they serve as the ultimate catalyst, facilitating a pathway for the eventual destruction of genuine fruit rot pathogens.

Seed weevil

Conversely, another notable fruit-rot pest affecting mangoes is *Sternochetus mangiferae* (Fabricius), commonly known as the mango seed weevil. Unlike the generalist feeding behavior in polyphagous fruit flies, the seed weevil exhibits a species-specific preference, exclusively targeting mango fruits. While under controlled laboratory conditions, they could infest other crops, such as plums, peaches, and potatoes. They encountered obstacles in completing their life cycle within these fruits due to the need for suitable seeds for pupation. The robust texture of potatoes poses a challenge for larval penetration, and the presence of toxic compounds within the prunus family fruits (peaches and plums) proves detrimental to larval growth and pupation within the seeds (Kroschel et al., 2020).

Additionally, *S. mangiferae* weevils favor immature to half-mature mango fruits, as their more rigid flesh provides an optimal environment for oviposition. However, as the larvae mature, they carve a path to the seed, where they pupate in their ultimate destination. Unfortunately, the seeds of prunes contain a notable quantity of amygdalin, which doubles as an insecticide, obstructing larval pupation (Lee et al., 2017; Jaszczak-Wilke et al., 2021). Consequently, experimental trials conducted in vitro on these fruits result in late larval stage failure, underscoring the mango seed as their plausible ecological niche.

While originating in India, these weevils have evolved into a widespread and devastating menace worldwide. In contrast to the morning fruit flies, these weevils have a predilection for darkness when engaging in essential life activities such as feeding, mating, and ovipositing (Dukas, 2020). Intriguingly, this frugivore poses more significant challenges in terms of control, attributed to its ability to undergo diapause in every life stage comprising adults, pupae, and larvae for extended periods spanning several months (Bhattacharyya et al., 2016).

Selection of an optimal fruit for oviposition follows a pattern similar to other weevils, with recognition and olfaction guided by the terpene and terpenoid volatile compounds predominantly detected in unripe mangoes, including 3-Carene, a-Humulene, a-Terpinolene, Decanal, and Octanal (Nouri et al., 2014). Once guided by olfactory cues, female adult weevils deposit their eggs when the fruit attains a size of approximately 3 to 5 cm. Within each boat-shaped depression meticulously created by the female weevil on the fruit's epicarp, a solitary egg is laid. To ensure egg viability and safeguard the dug bore, this structure is subsequently concealed beneath an opaque brown exudate (Woodruff & Fasulo, 2006).

Notably, a female weevil can lay around 15 eggs daily, potentially accumulating up to a monthly count of 100 eggs (Woodruff & Fasulo, 2006). As the fruit matures, the inflicted wound becomes entirely obscured, rendering the infestation inconspicuous and imperceptible unless the fruit is dissected. After emerging from their eggs, the active-feeder larvae consume the mango's whitish flesh before tunneling to the seed, where they pupate. These elongated, white larvae, resembling slender grubs, lack teeth (Obra et al., 2013). Therefore, they may rely on their mandibles and digestive saliva to perforate the immature fruit seed's wall. Usually, the larval stage, lasting around a month, is closely mirrored by the pupal stage's duration in the weevil's life cycle (Woodruff & Fasulo, 2006).

Interestingly, the larva feeding on the seed triggers the plant's internal phytochemical pathways. The plant's ethylene secretion rises in response to the seed's nutrient deficiency, resulting in premature fruit dropping (Binder & Patterson, 2009). Essentially, the pest deceives the plant into interpreting nutrient uptake as an indicator of germplasm for fruit development, thereby inducing abscission in the fruit stalk. An alternative theory suggests that the heightened ethylene production might stem from ethylene signaling triggered by the recognition of abiotic stress and wounds caused by *S. mangiferae* (Wang et al., 2020).

Upon reaching adulthood, the pupae transform into weevils after the premature fruit drop. They then depart from the host plant to engage in a new mating cycle and oviposition. Typically, a few months after falling off the tree, the adult weevils puncture a small hole in the concave edge of the endocarp (Bhattacharyya et al., 2016). In rare instances, weevils may emerge from the seed before fruit detachment and carve their way through the ripening fruit, causing significant destruction (Bragard et al., 2018). The exit wounds created by adult weevils on the outer skin provide an entry point for additional fruit-rotting microbial pathogens.

Furthermore, inner fruit rot can arise from the outer surfaces of the stones, which are formed solely by mango weevils. This contributes to the development of black cotyledons, marking the initial stages of the rot within the flesh. Conversely, when weevil larvae deplete nutrients during their stage, the viability of seeds for germination diminishes. Consequently, this may result in a reduced availability of high-quality seeds for the subsequent planting season.

As the mango seed weevil achieved global prevalence, its adaptation has been honed. Besides, its diapause activity is confined to winter months in seasonal countries. In tropical regions where the climate remains warm, insect hibernation is uncommon. This diapausal ability empowers these pests to endure extended periods, even several years (Woodruff & Fasulo, 2006). The diapause strategy may serve as an advanced adaptation mechanism, allowing this population to remain inactive within the plant's softer stems or other non-woody parts until the emergence of the fruiting season. Breeding a seedless mango variety may resolve this issue.

Furthermore, discernible interactions between the fruit flies and the seed weevil still need to be improved, as they target mangoes at distinct stages of maturity to coexist. The seed weevil's infestation primarily occurs within unripe fruits, prompting early dropping before the fruit's full ripeness. Conversely, fruit flies rely on ripe or overripe fruits for sustenance. Consequently, only those fruits that have escaped seed weevil infestation may become potential food sources for the fruit flies.

Fruit borer

Like other pests, mango fruit borer is also an imperative causal agent to trigger fruit rotting in mango plantations. This may include a few species, such as *Autocharis albizonalis* (Hampson) and *Citripestis eutraphera* (Meyrick). Notably, the *A. albizonalis*, also recognized as the red-banded caterpillar, has recently garnered attention as a prominent mango pest in regions including the Philippines, Thailand, Papua New Guinea, and India (Royer, 2009). These monophagous pests can only piercing mangoes and remain diapause during the off-season (Rao et al., 2020).

In contrast, *C. eutraphera* has emerged as a significant mango fruit borer widely distributed across the eastern hemisphere, including Indonesia, Australia, and India (Kumar et al., 2021). This pest has achieved comparable notoriety for its impact on cashew trees. Additionally, *Conogethes punctiferalis*, a yellow peach moth, is noted as a minor contributor to mango fruit infestation, while *A. albizonalis,* recognized as the red-banded caterpillar, is characterized by its distinctive appearance; meanwhile, *C. eutraphera* exhibits a reddish-violet hue (Choudhary et al., 2019).

This pest exhibits a notable briefer life cycle when contrasted with the groups above. From the moment of hatching, its larvae can subsist for fewer than two weeks before entering the pupal phase, typically taking refuge in decaying wood or crevices (Sahoo et al., 2023). Intriguingly, nutritional requirements diminish during pupation, as this stage involves an active diapause marked by non-feeding behavior. However, this pest showcases an extended diapause duration as pupae throughout the off-season. Analogous to fruit flies, a warmer climate accentuates the likelihood of heightened disease occurrence prompted by this pest (Abbas et al., 2018).

Simultaneously, adult female moths prefer oviposition during daylight hours on shaded fruits. This strategy shields their eggs from direct climatic exposure and preserves egg texture, even when enveloped by a protective waxy layer that adheres to the fruit skin (Reddy et al., 2018). As for fruit preferences and olfaction, there is a correlation with the behavior of the mango seed weevil. Both pests share a tendency to infest fruits during a developmental stage resembling a diminutive marble-size suitable for oviposition. Nonetheless, tunneling by these pests may also occur in more mature fruits nearby, even if oviposition does not transpire (Bhattacharyya, 2014). An intriguing phenomenon is the swift resurgence observed within a month, evidencing the abbreviated reproductive span of adult moths. Consequently, while the first larval stage pupates, a second larval generation thrives within the same orchard.

Like most frugivorous species, the fruit borer moth employs a strategy of laying oval, white eggs in clusters of 2 to 14 on the fruit's apex or the distal end (Chin et al., 2010). Once hatched, the larvae are pivotal in penetrating the mango fruit, entering through the tender flesh from the distal end. During pupation, they encase themselves in loosely woven silken cocoons, positioning them inconspicuously in locations such as branches or crevices. This arrangement grants them an adhesive and suspended habitat. In contrast to fruit flies and seed weevils, the fruit borer larvae demonstrate a broader scope, capable of affecting both the flesh and seeds of mangoes during later developmental stages (Hiremath et al., 2017). This strategic shift aims to mitigate interspecific competition within the feeding niche. However, when food is scarce, these two cm-long larvae display an intriguing ability to traverse from one fruit to another, employing silk threads they create as they initiate drilling the other (Sarkar & Chakraborty, 2020).

As they burrow through the fruit from the distal end toward the seeds, the resulting unclosed bore becomes a haven for various microbial agents responsible for mango fruit rot. In certain instances, this bore may become filled with abundant fecal matter from the larvae as they delve deeper into the seeds (Hiremath et al., 2017). Like other arthropods, fruit borers contribute significantly to fruit rot by creating a conducive environment, even though they may not be direct causal agents. In contrast, the larvae of fruit flies and seed weevils benefit from an initial entrance point created by the adult female during oviposition. Hence, they cannot drill other fruit as they are enclosed within one during larval.

Initial signs of infestation become apparent through observing sap stains streaming from the bore and dripping at the apex (Singh et al., 2021). Over time, these stains evolve into darkened trails. Analogous to typical butterflies, although the fruit borer caterpillar can reach a size of up to 2 cm, the ensuing adult, with a wingspan of approximately 2 to 2.4 cm, remains relatively diminutive. Compared to other pests, the fruit borer undergoes a mere half-month pupation phase, ensuring their prevalence during mango availability. Aligning with the adult moth's week-long lifespan, they can lay roughly 125 to 450 eggs on the rougher areas of the fruit to prevent slippage (Soumya et al., 2016). These adult moths tend to favor a sedentary mode of existence, and migration is only observed in growing regions if they accidentally hitch a ride on human-assisted fruit transportation.

Typically, the fruit borers impact through two sequential waves of attacks. The initial assault, undertaken by early larval stages, primarily targets smaller-sized fruits. Subsequently, a second wave ensues during the later larval stages, accompanied by larvae from successive generations (Reddy et al., 2022). This phase focuses on the seeds and larger fruits, strategically diminishing inter-species competition and securing their viability. Characterized by its heightened intensity, the second wave of attack often results in fruit cracking and prompts premature fruit drop prior to full maturation (Bhattacharyya, 2014).

Interactions Between Insect Damage And Fungal Infections

The primary cause of mango fruit rot is a fungal pathogen named *Lasiodiplodia theobromae*, an ascomycete that predominantly sporulates in dead tree bark or wood. As a waterborne fungus, its spores can float in water, facilitating transport and germination (Gnanesh et al., 2022). While initially functioning as a saprophyte, upon encountering a suitable host, it colonizes the dead tissues on the fruit stalk. Typically, manifestations of this infestation remain elusive until the harvest season approaches. However, in mango trees, initial indicators of *L. theobromae* may have been identified as gummosis and dieback (Khanzada et al., 2004a). As mentioned earlier, the infection of fruit rot disease accelerates when insect pests create openings.

Conditions conducive to the fungus's proliferation include mango plants thriving in environments with humidity exceeding 50% and temperatures at or above 22°C (Hussen, 2021). These factors provide an ideal breeding ground, encouraging *L. theobromae* to favor mango as a suitable host. Consequently, tropical regions serve as favorable habitats for diverse pathogens.

On the other hand, the pH and nutrient composition of the host also contribute to germination and infection potential. Given that mango flesh shares an acidic pH with certain other citrus fruits within its host range, the fungus seems inclined towards colonizing an acidic environment (Saha et al., 2008). Nutrient content and chemical composition also influence germination in general. The abiotic stress induced by fruit flies, seed weevils, and fruit borers prompts mango plants to release more ethylene via ethylene signaling. This heightened ethylene content facilitates the colonization and growth of *L. theobromae*, as it effectively breaks the dormancy of waterborne spores (Abo-Hamed et al., 1984). Notably, the presence of water might not be the most efficient mechanism for breaking spore dormancy within the pycnidia of waterborne fungi, potentially leading to non-host germination. Consequently, germinated mycelia may deteriorate due to inadequate nutrients for growth.

Unlike specific other fungal pathogens, *L. theobromae* does not employ insects as vectors for transportation, as its spores lack appendages to cling onto arthropod tarsi and tibiae. Post-germination within wounds, the pathogen experiences accelerated growth on the initially conditioned flesh by pest insects. Ultimately, it triggers soft brown rotting symptoms, primarily from the stalk or apex—areas punctured by insects (Zhang, 2014). The infection's rapidity is more pronounced through the wound than from deceased stalk tissue, as insects effectively eliminate the primary layer of a defense mechanism known as the "PAMP triggered mechanism," thereby expediting the infection process.

Although non-wetted spores can be produced, this fungal pathogen does not sporulate on the infected host fruits. Instead, sporulation occurs on dead portions or stalks of the host tree, remaining dormant until the subsequent fruiting season. Hence, the initial sporulation at the stalk while the fruit is still attached to the tree ensures the pathogen's persistence and succession. Khanzada et al. (2004b) postulate that the pathogen's colonization of dead branches could potentially induce gradual necrosis in the plant tissues, leading to the eventual demise of the entire plant. Considering the climate preferences of weevils and borers, their affinity for hot and humid climates aligns with the fungal colonization requirements. Consequently, these entities can coexist within the same ecosystem, albeit potentially infecting the fruit at distinct phases. Intriguingly, the interplay between *L. theobromae* and insect frugivores occupying coexisting niches has not received extensive scrutiny.

Integrated Pest Management Approaches

Various strategies have been implemented to manage mango insect pests and ensure a consistent global supply to meet the demand. These integrated approaches encompass multiple facets to tackle the issue effectively.

Biological Control

Biological control encompasses two main strategies: introducing natural predators and applying organic insect deterrents to the fruit or plant. Utilizing natural predators helps maintain the ecological balance and is a more sustainable method. A study by Salmah et al. (2017) demonstrated significant differences in infestation rates of *Bactrocera dorsalis* between organic and chemically managed mango farms. Organic farms exhibited only an 11% fruit infestation rate compared to a high 93% in chemically managed orchards. This contrast could be attributed to weaver ants and *Oecophylla smaragdina*, which act as effective predators for fruit flies along with some birds, lizards, and rodents. These ants emit 1-Octanol, deterring fruit flies from ovipositing on mangoes (Kempraj et al., 2022). It is worth noting that excessive chemical pesticide use may negatively impact ant populations more than fly populations, rendering natural predation more efficient. For mango seed weevils, the weaver ant and arboreal ant, *Oecophylla longinoda*, demonstrated comparable effectiveness in reducing disease incidence to synthetic insecticides like Dudumida (Abdulla et al., 2016). However, predation against mango fruit borers remains largely unexplored.

Furthermore, applying biological insecticides can positively influence mango fruit development. To deter oviposition by *B. dorsalis*, plant extracts such as neem and garlic were sprayed on jackfruit, effectively reducing oviposition rates by about 85% and 67%, respectively (Hanh & Hang, 2023). Similar observations were made against seed weevils using neem extract (Braimah & Emden, 2010). The essential insecticidal compound in neem, azadirachtin, disrupts chitin and cuticle synthesis, hampers hormone biosynthesis, and leads to abnormal development, acting as a lethal insecticide (Shu et al., 2021). Importantly, neem extract demonstrated no adverse effects on plant growth and yield and even indirectly enhanced yields by reducing pest emergence. This lessened biotic stress allowed plants to allocate more energy to growth and fruiting (Agbo et al., 2019). When applying plant extracts, focusing on specific pest life stages can precisely target pests, reducing application frequency while safeguarding fruits during their early stages.

Furthermore, introducing entomopathogenic fungi, such as *Metarhizium robertsii*, can also prove effective in reducing pest activity without causing harm to the host fruit and plant. These fungi have the ability to modify the insect's gut physiology and diminish the microflora within the gut, ultimately leading to their demise (Kryukov et al., 2021). Since bio-control measures permeate deep within host tissues to hinder insect infestation or larvae development, they consistently stand out as the most sustainable approach in disease control.

Chemical

Due to their swift efficacy over the short term, chemical practices for deterring frugivorous insects are prevalent, particularly in larger farms and expansive markets. One method involves employing methyl eugenol to trap fruit flies before the fruiting season, curtailing mating and oviposition rates (Ballo et al., 2020). Methyl eugenol is a pheromone to lure male flies, as females exhibit lower responsiveness to it (Shelly et al., 2010). However, the introduction of malathion methyl eugenol by the pesticide industry raised concerns due to its capacity to ensnare a wide array of non-targeted insect species, including beneficial honeybee populations and other pollinators, potentially disrupting the natural ecosystem (Vayssières et al., 2007).

Furthermore, chemical pesticides like thiamethoxam, imidacloprid, and fipronil are extensively employed to combat mango fruit borers, leading to a noticeable decline in *Autocharis albizonalis* occurrences (Tirthankar & Kumar, 2021). However, even at minimal concentrations of thiamethoxam (25 µg per litre), a substantial 75% reduction in phosphate solubilization activity within the plant has been documented (Ahemad & Khan, 2011). Moreover, applying fipronil impacts unintended insects and negatively affects earthworms and essential microbial populations (Pisa et al., 2015). This demonstrates that applying chemical pesticides can disturb the targeted pests and disrupt the broader ecosystem, potentially leading to reduced soil fertility, compromised plant growth, and diminished yields.

Furthermore, the efficacy of chemical pesticides is limited in managing insect pests that dwell within the plant structures or fruits, as their penetration ability is restricted. Consequently, larvae and pupae remain shielded from these chemical approaches (Shaurub, 2022), fostering a growing reliance on more sustainable alternatives due to the evident drawbacks of chemical solutions.

Cultural

Cultural practices demand meticulous attention to human-caused errors or the potential for disease occurrence, necessitating active human intervention to mitigate such risks. Among these practices, sanitation is a standard approach widely adopted by most farms to avert disease outbreaks. Specifically, when it comes to fallen fruits, an essential practice involves promptly removing them from the ground and burying them at a depth of at least 0.5 meters (Mutamiswa et al., 2021). This practice significantly contributes to preventing postharvest mango diseases. Notably, fruit flies, a notorious pest, prefer ripe or overripe fruits for infestation and oviposition. In cases where diseased or decaying fruits are identified, it is essential to segregate and adequately dispose of them. This involves isolating them in separate plastic containers, exposing them to sunlight, and grinding them to eliminate any larvae within the fruit.

While insect pests tend to thrive in warmer temperatures, they typically avoid direct sunlight during oviposition to prevent detrimental effects on their eggs, such as cocoon desiccation, egg shrinkage, and larvae mortality (Ganie et al., 2022). Larvae in a sluggish worm-like stage rely on moisture for movement, making direct sunlight exposure detrimental to their survival.

Regarding *B. dorsalis*, another effective preventive measure is early harvesting, as the pest primarily targets mature fruits. Research by Chikez et al. (2021) indicates that fruit fly infestations are more prevalent during harvesting (17%) and marketing (79%) seasons. To counter this, employing plastic materials like crates for storage, cold storage facilities, sanitized tools for harvesting and transportation, and multiple fly traps can collectively curtail infestations. Conversely, creating traps can present additional challenges, as this approach could prompt neighboring farms to apply extra control measures using pesticides.

Furthermore, in the case of mango seed weevils and mango fruit borers, covering the fruit with plastic during the early developmental stage can significantly reduce disease incidence (Roge, 2021). Implementing movement restrictions from previously infected or uninfected farms, especially during more extended transportation periods, can minimize pest exposure. Therefore, movement restriction becomes a crucial emphasis. Proper field management, including frequent weeding to prevent falling fruit concealment, contributes to their swift removal, reducing pest attraction. Similarly, pruning trees enhances sunlight penetration and improves ventilation in the farm environment, reducing humidity levels and, in turn, minimizing the presence of other insect pests like seed weevils and fruit borers (Braimah & Emden, 2010).

In a comprehensive approach, integrated pest management (IPM) proves to be highly effective as it collectively amalgamates various strategies to thwart the same diseases or pathogens. In mango cultivation, the synergy between bio-control and cultural practices is a harmonious solution to elevate disease control strategies, ultimately leading to a bountiful yield of mango fruits.

CONCLUSIONS

In conclusion, the interplay between frugivorous insect pests and fungal pathogens in mango production is complex and multifaceted. Fruit flies, seed weevils, and fruit borers represent significant challenges, leading to substantial yield losses and contributing to fruit rotting caused by microbes' pathogens. The interdependencies between pest behaviors, host fruit characteristics, and pathogen colonization strategies are intricate and context-specific. Integrated pest management approaches, encompassing biocontrol, cultural practices, and limited chemical intervention, offer promising solutions to mitigate the impact of these pests and manage disease incidence. However, it is crucial to recognize that a holistic and sustainable approach requires a deep understanding of the ecological dynamics within mango ecosystems and the integration of various strategies to ensure successful fruit production and minimize postharvest losses.

ACKNOWLEDGMENT

Sivagami Subramaniam and Noor Aisyah Md Noordin received sponsorship from Universiti Putra Malaysia under the Special Graduate Research Allowance Scheme (SGRA) and Graduate Research Fellowship (GRF), respectively.

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