



*Review*

## **Mealybug vectors: A review of their transmission of plant viruses and their management strategies**

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**Abstract:** Mealybugs cause mechanical damage and diseases to plants. Through their feeding activities, they reduce the yield, quality and productivity of crops. This review discusses mealybug vectors of plant viruses, the economic losses they cause, mealybug species and their hosts. Among the numerous mealybug species, *Planococcus* species are the most effective vector of plant viruses, transmitting many Ampeloviruses. Diverse methods for the control and regulation of mealybugs are also discussed. Physical, cultural and biological control methods are labor-intensive but environmentally friendly compared to chemical methods. However, chlorpyrifos are one the active ingredients of insecticides effective against several mealybug species. Using plant products such as neem oil as a biocontrol method has been effective, similar to other insecticides. Notwithstanding, the biological method of controlling mealybugs is effectively slow but safe and highly recommended. The *Anagyrus* species have the highest success rate amongst other natural parasites of mealybugs. Also, farm sanitation and pruning as cultural methods help reduce mealybug populations.

**Keywords:** Mealybugs; *Planococcus*; *Pseudococcus longispinus*; *Dysmicoccus brevipes*; Closteroviridae; Ampeloviruses

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## 1. Introduction

The world's population is growing so fast that at the end of 2021 it was 7.9 billion people [1]. This is a rapid growth rate compared to ten years ago (6.194 billion) [2]. With this growth rate, it is estimated that the world population will be around 9,782,061,758 in 2051 [3].

This exponential growth trend has an adverse impact on food security. To meet the dietary requirements for this population growth, food production needs to be scaled up. Among the various food sources, plants are the largest food source for humans. A total of 50–90% of the human diet is of plant origin [4]. However, these contributions of plant products to the human diet are likely to diminish due to several factors. The decrease in agricultural land use size, plant diseases and other biotic factors threaten plant productivity. Among these factors, plant pathogenic diseases are the major problem, where 16% of annual plant yield losses are due to plant pathogenic diseases [5].

Plant pathogens contribute a troubling decline in global food security and crop production [6]. Plant pathogens are transmitted through a variety of vectors. Insects and nematodes [7] play a role in pathogen transmission. Insects, the most popular and effective of all the vectors, pose a concern for plants, animals and human health [8].

Two orders of insects (Hemipterans and Thysanopteras) have the most devastating effect on crop yield [9]. Among the various orders of insects, Hemipteran [10], Coleopteras [11], Thysanoptera (generally thrips) [12–15], Lepidoptera [16] and Diptera [17,18] are known vectors of plant viruses, fungi and bacteria. Close to one-fourth of all plant viruses require insect vectors for effective transmission [9]. Coleopterans are effective transmitters of Bromoviruses, Carmoviruses, Comoviruses, Machlomoviruses, Sobemoviruses and Tymoviruses [19]. Hemipterans (aphids, whiteflies and leafhoppers), transmit most plant viruses and bacteria. They are infamous for the transmission of more than one pathogen. Furthermore, their brisk reproductive cycles and diverse plant hosts give them an advantage in plant virus transmission [20,21]. Although thrips, aphids and whiteflies account for over 50% of plant virus transmission [22,23], the role of mealybugs in plant viruses transmission is noteworthy. Of the Homoptera insect order, mealybugs are one of the major vectors of plant viruses [24]. With various biotic problems of plants, viral diseases are one of the biggest constraints to plant health [25]. Transmission of plant viruses is dependent on the mealybug life stage, temperature and suitable host. However, information about the viruses transmitted by mealybugs is not comprehensive as that of aphids, whiteflies and thrips. This article provides a comprehensive review of the different types of plant viruses transmitted by different species of mealybugs, and various management strategies to reduce and control the devastating effects of mealybugs.

## 2. Morphology of mealybugs

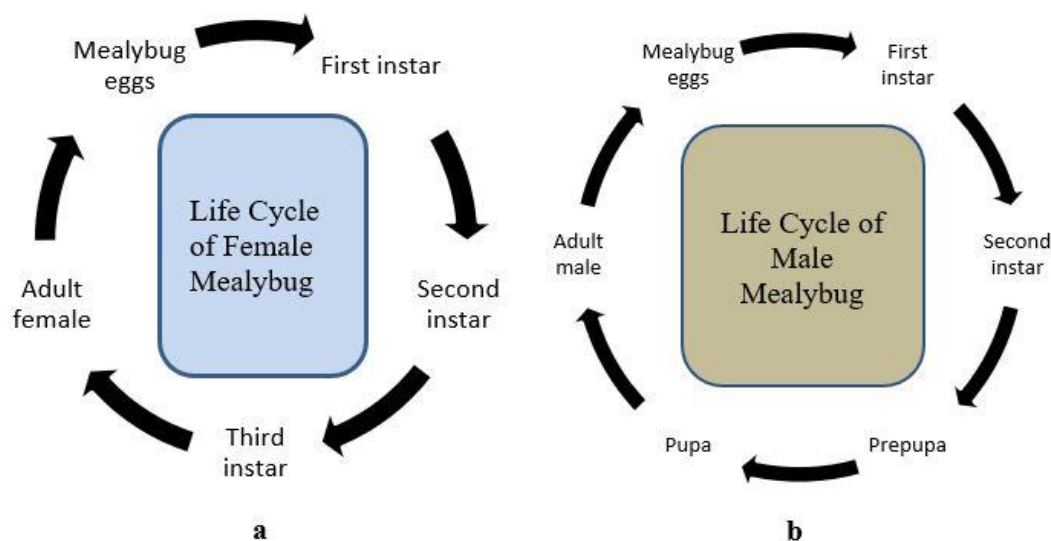
Mealybugs (*Pseudococcidae*) are destructive insect pests of crop plants. Mealybugs are either monophagous [26] or polyphagous. Mealybugs perfectly homogenize with their host plant, thanks to the wax produced by the host plant, which covers them and offers them camouflage. It is estimated that 149 mealybug species feed on plants with their piercing and sucking feeding behavior. The *Planococcus* species are the most common and destructive [27], causing severe mechanical damages to crop plants. Despite having a diverse feeding host, woody and herbaceous plants are most preferred. They pierce and suck the plant sap, which causes sooty mold from releasing sap materials, reduces the plant chlorophyll content and thus affect photosynthesis [28–30]. During feeding, viral particles (especially

those retained in the stylet and foregut) are released through their stylet [31]. The stylets are withdrawn into the body after and when not feeding [32].

Mealybugs are approximately 5mm long [33], with adult females 3-5mm and males average 3mm long [34,35]. Adult females retain some nymph-like features attributable to incomplete metamorphosis and are wingless. Similarly, male adults also undergo incomplete metamorphosis, but they are much smaller than the females and possess wings that aid them in moving to female mealybugs for mating [26,33,36].

### 2.1. Life cycle of mealybugs

The lifecycles of mealybugs differ according to their sex and species [37]. Male and female mealybugs have the same life cycle from the egg stage to the 2<sup>nd</sup> instar stage. In males, the prepupa stage is the next stage after the 2<sup>nd</sup> instar stage, then follows the Pupa, and finally to the adult male stage. However, unlike the male, the female mealybug has a 3<sup>rd</sup> instar stage that ends at the adult stage [38], as observed in Figure 1a and b below.



**Figure 1.** Illustration of female and male mealybug lifecycles (adapted and altered from [37,38]).

As observed from Figure 1a and b, male and female mealybugs have similar life cycles. However, certain mealybug species may require additional stages. The male pineapple mealybug (*Dysmicoccus brevipes* Cockerell), longtailed mealybug (*Pseudococcus longispinus*) were confirmed to have a third Instar stage between the second instar and prepupa stage [37,39]. Also, the female pineapple mealybug had a crawler stage instead of the first instar stage. Daane et al. (2008) also reported a similar life cycle of *Planococcus ficus* to that of *Dysmicoccus brevipes*.

### 2.2. Hosts of mealybugs

Different species of mealybugs are found on plants in greenhouses, nurseries, plants and landscapes. Over the world, approximately 246 of several plant families serve as hosts for almost 5000

species of mealybugs [41]. Poaceae are the most popular host plants (585 species) for mealybugs, with Cyperaceae having the least number of host plants (75 species), and [42–44] emphasized that mealybugs feed on nearly 149 plant species, through the sucking of plant sap which causes leaves to distort and fall.. Destruction and pathogen transmission by mealybugs have been reported on guava, citrus, pomegranate, grapes, sugarcane, banana, black pepper, pineapple plantain, stone fruit, berries, yam, cassava, cashew, papaya, pawpaw and cocoa [31,42,45–50].

Weeds such as *Amaranthus vividus*, *Bidens Pilosa*, *Sonchus oleraceus*, *Chenopodus ambrosoides*, *Commelina sp.*, *Cucumis anguria*, *Momordica charantia*, *Cyperus rotundus*, *Chamaesyce hirta*, *Croton sonderianus*, *Jatropha urens*, *Mimosa pudica*, *Piptadenia moniliformis*, *Serra macranthera*, *Herissanthia crispa*, *Sida cordifolia*, *Sida galheirensis*, *Sida rhombifolia*, *Sidastrum micranthum*, *Sidastrum sp.*, *Digitaria horizontalis*, *Talinum paniculatum*, *Watheria douradinha*, *Malva sylvestris* L., *Redroot pigweed*, *Amaranthus retriflexus* L., *Crimson clover*, *Trifolium incarnatum* L., *Toadflax*, *Linaria sp.* and *Chorizococcus rostellum* also serve as host plants for mealybugs [51,52]. Various degrees of mealybug infestation have been reported in Kenya [53], Nigeria [54], Ghana [48,50,55,56], Indonesia [57], New Zealand [58], India [57,59–61] and Israel [26]. In Turkey, 25 weed species from 14 plant families were found to host 5 mealybug species [51].

### 2.3. Some reported economic losses due to mealybugs

Several studies have confirmed the economic losses caused by the destructive effects of mealybugs and the virus diseases they transmit. According to Asare Bediako et al. [50], the mealybug wilt of pineapple (MWP) causes approximately US \$248/ha in losses to pineapple fruit yield in Ghana, while causing 30–50 % of fruit yield loss in Hawaii in the United States, depending on the age of the plant. Three cassava mealybugs (*Phenacoccus manihoti*, *Planococcus herreni* and *Planococcus* spp.) have been reported to cause cassava yield reduction in Sub-Saharan Africa. *Phenacoccus manihoti* is estimated to cause an 80% reduction in cassava yield [62]. Similarly, the Hibiscus mealybug (*Maconellicoccus hirsutus*) is indicated to cause a US \$75 million loss annually in the United States of America [26]. Prabhakar et al.[30] reported various economic losses in several countries due to cotton mealybug (*Phenacoccus solenopsis*), Papaya mealybug (*Paracoccus marginatus*) and several mealybugs on cotton plant yields. Previous studies show that green coloration occurs in situations where both the male and female mealybug are found (especially between *Dysmicoccus brevipes* and *Dysmicoccus neobrevipes*) but are absent in a situation where only one parent was found (either male or the female) [63]. This green colouration affects the quality and market value of the produce. It is worth noting that the direct effect of viruses transmitted by mealy bugs is difficult to estimate since other factors in combination with the virus diseases cause economic damages to the crops. In a review by Franco et al. [64], *Planococcus citri* and other species of mealybug cause economic losses in citrus orchards in the Mediterranean regions.

**Table 1.** A summary of selected plant virus mealybug vectors, their common names and host plant information.

Species of Mealybugs	Common Names	Host Plants	References
<i>Pseudococcus longispinus</i>	Longtailed mealybug	Citrus, grapes, nursery stock, indoor ornamentals, citrus, taro, avocado, guava, eggplant.	[34,35,65]
<i>Pseudococcus maritimus</i>	Grape mealybug	Grapes, Pears, Pomegranate other fruit trees, apricots	[34,35,66]
<i>Planococcus citri (cryptus)</i>	Citrus mealybug	Citrus, landscape shrubs	[34,35,51]
<i>Planococcus ficus</i>	Vine mealybug	Grapes, fruits, ornamental plants	[34,35,40,67]
<i>Rastrococcus iceryoides</i> and <i>R. invadens</i>	Mango Mealybug	Mango and Citrus	[35,68]
<i>Dysmicoccus brevipes</i>	Pineapple mealybug	Pineapple, avocado, banana, celery, citrus, clover, cocoa, coconut, coffee, custard apple, figs, ginger, guava, maize, mango, oil palm, orchids, groundnut, peppers, plantain, potato and sugarcane.	[26,35,69,70]
<i>Planococcus kenyae</i>	Kenya mealybug	Coffee, yam, pigeon pea, passion fruit, sugarcane and sweet potato	[27,71]
<i>Saccharicoccus sacchari</i>	Sugarcane mealybug	sorghum, rice and some grasses, sugarcane	[26,72]
<i>Ferrisia virgata</i>	Striped mealybug	Common on most crops	[26,34]
<i>Ferrisia gilli</i>	Gill's mealybug	Pistachios	[73]
<i>Heliococcus bohemicus</i>	Bohemian mealybug	Grapevine	[74]
<i>Phenacoccus aceris</i>	Apple mealybug	Grapevine, apple	[74]
<i>Planococcus solani</i> Ferris <i>Phenococcus solenopsis</i> Tinsley	Solanum mealybug	Solanaceous crops	[34,35]
<i>Maconellicoccus hirsutus</i>	Pink hibiscus mealybug	Hibiscus	[35,75]
<i>Paracoccus marginatus</i>	Papaya mealybug	Papaya, Solanaceous crops, cotton, pomegranate, pea, sweet potato.	[30,53,76]
<i>Nipaecoccus viridis</i>	Spherical mealybug	Cotton	[77]
<i>Planococcus kraunhiae</i>	Japanese mealybug	Broad bean	[26,78]
<i>Planococcus minor</i>	Passionvine mealybug	Vine	[79]
<i>Planococcus njalensis</i>	Cocoa mealybug	Cocoa	[54]
<i>Pseudococcus viburni</i>	Tuber mealybug	Donkey lettuce, Whitestem filaree, Tubular flower, Spanish needle, Hairy fleabane, grapes, persimmon	[80–82]

### 3. Mealybug vectors of plant viruses

Compared to aphids and whiteflies, mealybugs are transmitters of a few genera of plant viruses. Due to their less mobile nature, they are less effective in transmitting plant viruses than aphids, leafhoppers and other insect vectors. In addition, the sex and age of mealybugs affect virus transmission rates. For example, old female mealybugs are less efficient in transmitting plant viruses [83]. Also, the life stages of the nymph affect their transmission rate of viruses (adults are more effective than nymphs) [19].

Mealybugs transmit viruses of the genus *Ampelovirus* [31,63], and some *Closteroviruses* [84], of the *Closteroviridae* family. Mealybugs also transmit badnavirus [47,85] of the *Caulimoviridae* family. *Closteroviridae* generally consists of four genera- *Closterovirus*, *Ampelovirus* and *Crinivirus*, *Velarivirus* [86,87]. Some studies have also confirmed the transmission of vitiviruses by some mealybug species [83]. These viruses trigger leaf discoloration, deformation, mottling and leaf yellowing.

#### 3.1. *Ampeloviruses* transmitted by mealybugs

Based on the organization of the positive-strand RNA genomes, *Ampeloviruses* can be subdivided into different groups [87]. *Ampeloviruses* have a non-enveloped capsid, 1400–2200 nm long virion, 13.0–18.5 kb segmented genome [86] and filamentous shape. The genome of Ampelo-like air potato virus 1 (AiPoV1) is estimated to be around 13,398 nucleotides [88]. Mealybugs are the main vectors of *Ampeloviruses*. In a semi-persistent manner, mealybugs transmit *Ampelovirus* and other viruses in the *Ampelovirus* genus in a semi-persistent mode (GLRaV 3) [31,89]. In semi-persistent (foregut-borne) virus transmission, viruses are spread from the stylet of the insect up to the foregut. The virus does not spread beyond the foregut of the insect vector. Within 20 minute-period, the mealybug picks up the virus and infects the host [90]. The virus does not reproduce and multiply in the vector, and retention of the virus in the host spans from hours to days [9]. Studies indicate that semi-persistent viruses influence the feeding behavior of their host [91]. The injuries caused by their stylets during feeding, triggers plant defense response [62]. During feeding, the saliva of some mealybug species, especially *Maconellicoccus hirsutus*, causes harmful effects to plants [92]. *Ampeloviruses* cause vascular diseases with obscure symptoms. However, studies show that *Ampelovirus*, when combined with other viruses, causes mixed infection in plants [88]. Most *Ampeloviruses* are transmitted by *Dysmicoccus brevipes* (*Pseudococcus brevipes*), *Dysmicoccus neobrevipes* [63] and *Pseudococcus longispinus*.

From Table 1, *Planococcus* mealybug species are more active in transmitting plant *Ampeloviruses*. *Planococcus ficus* is a regular transmitter of five strains of Grapevine leafroll associated viruses [93]. These can cause mixed infections since the mealybugs are vectors of numerous viruses [88] as observed in Table 2. According to a study by Sether et al. [94], Pineapple mealybug-associated wilt viruses, when associated with pineapple's Mealybug wilt virus, resulted in 100% yield loss. Also, mealybugs acquire and transmit viruses with or without association with other viruses. For example, mealybugs (*Dysmicoccus brevipes* and *Dysmicoccus neobrevipes*) were found to transmit Pineapple Mealybug-associated virus-3 (PmaV-3) without the transmission of PmaV-1 [94], although they are vectors of these two viruses [95]. It is worth noting that some other insect species do actively transmit *Ampeloviruses*. For example, *Parthenolecanium corni* (Coccidae) was reported to transmit GLRaV-3 [96].

**Table 2.** A summary of some ampeloviruses and their mealybug vectors.

Virus species	Mealybug vectors	Hosts	References
Air potato ampelovirus (AiPoV 1)	<i>Planococcus</i> spp.	Air potato	[88]
Blackberry Vein banding associated virus	<i>Planococcus</i> spp.	Blackberry	[97,98]
Grapevine leafroll-associated virus 1	<i>Planococcus ficus</i> , <i>Pseudococcus longispinus</i> , <i>Phenacoccus aceris</i> , <i>Heliococcus bohemicus</i>	Grapevine	[19,74,99]
Grapevine Leafroll - associated virus 3	<i>Planococcus ficus</i> , <i>Pseudococcus longispinus</i> , <i>Ferrisia gilli</i> , <i>Phenacoccus aceris</i> , <i>Pseudococcus calceolariae</i> , <i>Heliococcus bohemicus</i> , <i>Pseudococcus maritimus</i>	Grapevine	[19,74,96,99–102]
Grapevine leafroll-associated virus 4	<i>Planococcus ficus</i> , <i>Pseudococcus longispinus</i> , <i>Phenacoccus aceris</i>	Grapevine	[19,101,103]
Grapevine leafroll associated virus 13	<i>Planococcus ficus</i> , <i>Pseudococcus longispinus</i>	Grapevine	[19,95]
Pineapple mealybug associated viruses 1 and 3	<i>Dysmicoccus brevipes</i> , <i>Dysmicoccus neobrevipes</i>	Pineapple	[19,104]
Pineapple mealybug associated virus 2	<i>Dysmicoccus brevipes</i> , <i>Dysmicoccus neobrevipes</i>	Pineapple	[19,50,63,98]
Pistachio ampelovirus	<i>Planococcus ficus</i>	Pistachio	[105,106]
Fig leaf mottle associated viruses 1 and 2	<i>Ceroplastes</i> spp.	Fig	[107,108]
Manihot esculenta virus 1	<i>Phenacoccus manihoti</i> , <i>Phenacoccus herreni</i>	Cassava	[62]

### 3.2. Closteroviruses transmitted by mealybugs

The genus Closterovirus belongs to the family Closteroviridae. Closteroviruses have two huge gene modules: one for genome replication, and the other for genome packaging and transport within the cells. The genome of Closterovirus is linear, positive RNA, with a maximum size of 19.3 kb [109].

In comparison to Ampeloviruses, fewer Closteroviruses are transmitted by mealybug vector species. For example, the Little cherry virus 2 belonging to the closterovirus genera is transmitted by *Phenacoccus aceris* [83,110].

### 3.3. Badnavirus transmitted by mealybugs

The genus Badnavirus belongs to the Caulimoviridae family. Viruses found in Caulimoviridae have semicircular double-stranded DNA. They have a genome length range of 7.2–9.2 kbp. Eight divisions (Badnavirus, Caulimovirus, Cavemovirus, Petuvirus, Rosadnavirus, Solendovirus, Soymovirus and Tungrovirus) are members of the Caulimoviridae family based on host range, insect vector and the basis of genome organization [111]. Badnaviruses affect monocots and dicots. Most Badnaviruses are horizontally transmitted through mealybugs and aphids [111,112]. Fewer or no symptom is associated with Badnavirus infections [113]. The effectiveness of their transmission is

dependent on the species of mealybugs. Badnavirus often have more than one species of the same vector as transmitters (Table 3). For example, 14 established vectors of Cocoa Swollen Shoot Virus [114], of which *Planococcoides njalensis*, *Planococcus citri*, *Ferrissia virgata* are potent transmitters of the Cocoa Swollen Shoot Virus [115]. Mealybugs usually feed on the flowers and pods. Like Ampelovirus, Badnaviruses are transmitted by mealybugs in a semi-persistent manner [115].

**Table 3.** A summary of badnaviruses transmitted by mealybug vectors.

Virus Species	Mealybug vectors	Hosts	Reference
Cocoa Swollen Shoot Virus	<i>Planococcoides njalensis</i> , <i>Planococcus citri</i> , <i>Ferrissia virgata</i>	Cacao	[114,115]
Banana Streak Virus	<i>Planococcus citri</i> Risso, <i>Saccharicoccus sacchari</i> , <i>Dysmicoccus brevipes</i> , <i>Ferrissia virgata</i>	Banana	[69,83]
Citrus Yellow Mosaic Badnavirus	<i>Planococcus citri</i>	Citrus	[33]
Sugarcane bacilliform virus	<i>Saccharicoccus sacchari</i>	Sugarcane	(Sastry, 2013)
Piper yellow mottle virus	<i>Ferrissia virgata</i> , <i>Planococcus citri</i> , <i>Pseudococcus elisae</i> ,	Black pepper	[19,83]
Sugarcane mild mosaic virus	<i>Saccharicoccus sacchari</i>	Sugarcane	[19]
Taro bacilliform badnavirus	<i>Pseudococcus solomonensis</i>	Taro	[83]
Schefflera ringspot virus	<i>Planococcus citri</i>	Schefflera	[83]
Dioscorea bacilliform RT virus	<i>Planococcus spp</i>	Yam	[116]

#### 3.4. Vitiviruses transmitted by mealybugs

Vitiviruses belong to the family Flexiviridae and they are flexuous, filamentous, 12–13 in diameter [117] and 725–825 nm in length [118]. They are monopartite, positive sense and single-stranded. Vitiviruses were initially considered Trichoviruses, but the differences in their genome organizations provided a basis for their differentiation [119]. Their virions contain RNA genome in a tail-like structure facilitating their transmission to plants by their insect vector [117].

**Table 4.** A summary of vitiviruses and mealybug vectors.

Plant virus	Mealybug vector	Hosts	References
Grapevine virus A (Kober Stem Grooving)	<i>Pseudococcus spp</i> , <i>Planococcus ficus</i>	Grapevine	[31,82,83]
Grapevine virus B (Corky bark disease)	<i>Planococcus ficus</i>	Grapevine	[31,82,83]
Grapevine Virus D	<i>Phenacoccus spp</i>	Grapevine	[83]
Grapevine Virus E	<i>Heliococcus spp</i>	Grapevine	[31,83]

Vitiviruses are transmitted by mealybugs and other insect genera (*Pseudococcus*, *Planococcus*, *Phenacoccus*, *Heliococcus*, *Neopulvinaria*, *Parthenolecanium*, *Cavariella* and *Ovatus*)(Table 4) in a semipersistent manner [83].



#### 4. Management strategies for mealybugs

Recent technological advances have influenced the methods and dynamics of controlling and managing mealybugs. Feeding behaviors determine the control strategy. The common management strategies are physical, chemical, cultural and biological. Environmental conditions such as temperature, humidity and others are considered when designing pest management strategies.

**Table 5.** A summary of mealybug species and physical control.

Mealybug Species	Physical Method	Key findings	Reference
<i>Dysmicoccus brevipes</i> , <i>Dysmicoccus neobrevipes</i>	Ant barriers	Red ants were controlled causing the decrease in pink pineapple mealybug transportation	[120]
<i>Planococcus njalensis</i>	Crop barriers, Barrier cropping	Farms with barrier crops had low mealybug infestation cases in comparison to those with none	[115,121]
<i>Drosica mangiferae</i>	Crop rotation	Adequate control of mango mealybug	[122]
<i>Planococcus ficus</i>	51–53 °C hot water treatment of grape cuttings	Eradication of more than half of <i>Planococcus ficus</i> population	[123]
<i>Planococcus ficus</i>	Ultralow oxygen treatment	Complete eradication of all life stages of <i>Planococcus ficus</i>	[82]
<i>Dysmicoccus brevipes</i> , <i>Dysmicoccus neobrevipes</i>	50 °C-30 minutes hot water treatment of pineapple propagules	Most of the mealybug population were destroyed	[124]
<i>Planococcus citri</i> Rossi, <i>Pseudococcus odematti</i> Miller and Williams	Hot water immersion of propagules	90–95% of the mealybug population were eliminated	[123]

##### 4.1. Physical methods

The physical (mechanical) pest control method involves using hurdle to reduce the contact between the pest and the crop. Physical control eliminates the pest or triggers behavioral or feeding changes in the pest [125].

Most physical methods share some similarities in their pest-elimination strategies. Despite their effectiveness, they are time-consuming and labor-intensive. Hand-picking of mealybugs, and cutting off tree parts heavily infested by mealybugs control mealybugs [34,35,115]. Growing barrier crops and destroying wild mealybug host plants have reduced contact between the mealybug vector and the host plant. Ameyaw et al.[115] reported on using citrus and oil palm in cocoa farms as barrier crops since they are not appropriate hosts for the mealybug vectors of Cocoa Swollen shoot virus. These crops break the mealybug vectors cycle since they are unsuitable hosts.

Results from studies performed by Franco et al.(2004) on pheromone traps to control *Planococcus citri* and *Pseudococcus cryptus* male mealybugs indicated that male mealybugs of the *Planococcus citri* population was significantly reduced. Also, trapping and eliminating mealybugs have proven to

be a population regulator of mealybugs. Sticky plate traps help regulate some mealybugs species, especially *Planococcus citri* [26]. Similarly, the pheromone of some mealybug species can be manipulated to attract predators or natural enemies to them (as in the case of *Anagyrus pseudococci* in the control of *Planococcus ficus*) [26]. Also, the use of biological barriers, heat treatment amongst others are suitable in the control of mealybug species as seen in Table 5.

#### 4.2. Cultural Methods

Like other pest control methods, cultural methods are diverse. They are environmentally friendly but labor-intensive. The cultural method involves a combination of practices that reduces the population and interrupt the infection cycle of pests. They include crop rotation, sanitation practices [34,35] and humidity control on the farm (Table 6).

**Table 6.** A summary of mealybug species and cultural controls.

Mealybug species	Cultural method	Key findings	References
<i>Planococcus ficus</i>	resistant rootstocks (IAC 572,10-17A, RS-3)	Resistant rootstocks were more resistant to <i>Planococcus ficus</i> infested as compared to other rootstocks	[82,123,126]
<i>Planococcus ficus</i>	Low soil nitrogen content	Grape plants on low nitrogen level soil had low mealybug presence in comparison to other grape plants on soils with high nitrogen content	[82]
<i>Formicoccus njalensis</i> , <i>Planococcus citri</i>	Breeding resistant varieties	Mealybug infestation was less in comparison to non-resistant varieties	[121]
<i>Saccharicoccus sacchari</i>	Resistant varieties (Giza 96/74, Ph 8013)	Self-peeling varieties were less infected by the <i>Saccharicoccus</i> mealybug as compared to other varieties	[127,128]
<i>Planococcus njalensis</i>	Roguing and pruning	Cocoa crops with pruned diseased parts had less mealybug infestation as compared to those not pruned	[121]
<i>Saccharicoccus sacchari</i>	Flood irrigation, burning of dry leaves in the field	Number of mealybug infestation per plant was reduced	[128]
<i>Saccharicoccus sacchari</i>	Low nitrogen fertilizer application, roguing, farm sanitation	Mealybug population was lower in farms where these practices were enforced	[128]
<i>Saccharicoccus sacchari</i>	Drip irrigation	Increased drip irrigation method significantly reduced <i>Saccharicoccus sacchari</i> population	[128]

Some crops have a genetic combination that helps them rejuvenate and regenerate after heavy mealybug feeding. AR23 (cassava genotype), an improved variety of cassava, was found to develop new leaves and rejuvenate into a healthy plant after severe damage was caused by the cassava mealybug [62]. Inter-Upper Amazon Hybrids of cocoa also have resistivity against heavy mealybug

infestation [90]. However, there is innate resistance in some plants against some species of mealybugs. For example, different citrus varieties are reported to show varying levels of susceptibility to the citrus mealybug [79]. This underlines mealybug species preferences for special kinds of plants over others.

In addition, regular pruning of trees in and around the farm is encouraged. Mealybugs develop and multiply rapidly in a warm and humid environment [83]. Pruning trees deprives mealybugs of the necessary moist conditions. Thus, it exposes them to harsh weather conditions, such as sunlight that will slow or stop their rapid growth and gradual extinction.

Sanitation practices on the farm should be considered. The destruction of old and new heavily infested plant propagules should be practiced. In addition, farm equipment should be sanitized to reduce the transport of mealybug eggs within the farm. The destruction of cocoa trees affected by the Cocoa swollen Shoot Virus reduced the spread of the plant virus to healthy cocoa plants [90].

Also, fertilizers and irrigation within the farm should be regulated. Studies have demonstrated a relationship between wet soils coupled with high nitrogen content and mealybug growth [92]. There is a significant multiplication of mealybugs in the farm if the soil has high water content with significantly higher nitrogen levels. Daane et al. [40] confirmed the increase in the *Planococcus ficus* population due to increased nitrogen fertilizer use. Soils with high moisture content and adequate nitrogen levels help regenerate new plant parts. The mealybug then has new and succulent plant parts to feed on, and reproduction is encouraged. Adversely, Rae et al. [72] observed an increase in the *Saccharicoccus sacchari* at 320mg/L of nitrogen, but their population declined at a relatively higher nitrogen concentration.

#### 4.3. Biological control

Biological pest control methods use natural enemies to eliminate or reduce the population of pests. Biological control methods, although labor-intensive, are environmentally friendly. Recently, biological pest control methods have been gaining popularity. Several natural parasitoids of mealybugs have been enacted, but only a few have proven very effective. Aphelinidae and Platygasterida species have yielded appreciable results [26]. Natural enemies of mealybugs are numerous e.g. parasitic wasps, ladybird beetles, hoverflies, lacewings [35], etc. This wasp lays its eggs on the maturing mealybugs, killing these mealybugs and feeding on them. *Gyranusoidea*, *Coccophagus*, *Leptomastix*, *Allotropa*, *Pseudaphycus* and *Acerophagus* are reported to be parasitic wasps of mealybugs [26,129]. In Africa and South America, *Apoanagyrus lopezi* and *Epidicarno lopezi* are reported to be effective in regulating the Cassava mealybug (*Phenacoccus manihoti*) [35,62]. *Gyranusoidea tebygi* and *Anagyrus mangicola* are natural enemies of the mango mealybugs, *Rastrococcus invadens* and *Rastrococcus iceryoides* [34,35]. In addition, the population of citrus mealybug is reported to be reduced by natural parasites, such as *Leptomastidea abnormis* (Girault), *Leptomastix dactylopii* Howard, *Chrysoplatycerus splendens* Howard and *Anagyrus pseudococci* (Girault). However, parasitic fungus, such as *Entomophthora fumosa* and other natural parasites (brown lacewing, *Symphorobius barberi* (Banks) and green lacewing, *Chrysopa lateralis* Guérin, trash bugs, syrphid fly larvae and scale-eating caterpillars, *Laetitia coccidivora*, *Cryptolaemus montrouzieri* Mulsant, *Decadiomus bahamicus* (Casey) *Scymnus flavifrons* Melsheimer, *Chilocorus stigma* (Say) and *Olla abdominalis* var. *plagiata* (Say), are reportedly effective against some species of mealybug [130].

The mode of action by which these parasitoids and predators suppress and eliminate different species of mealybugs differs. For example, *Epidicarnosis lopezi*, a parasitoid of cassava mealybugs,

lays eggs on the mealybug and their larvae feed on them [26]. Similarly, the mealybug predator *Cryptolaemus montrouzieri*, reported by Anjana and Joy [37], can feed on a maximum of 5000 mealybug eggs in various life stages. Additionally, *Anagyrus kamali* controls the pink mealybug population by piercing the adult mealybug and laying eggs in them. The eggs hatch and the contents of the mealybug are used to nourish itself until it attains adulthood [37].

Consideration should be given to other insects (especially ants) that may antagonize the success of this biological control based on their relationship with mealybugs. The population of ants must be under control since they can mitigate the effectiveness of this method. Some ants have a mutualistic relationship with mealybugs [26,37,40], since they benefit from the honeydews made by mealybugs. Ants have an antagonistic relationship with the natural enemies of mealybugs. Also, ants play a role in the transportation and dispersion of several mealybug species [90], as several studies have demonstrated the transport and dispersal of mealybugs by ants [26,131].

The citrus mealybug (*Planococcus citri*) is reported to be effectively controlled by a range of parasites such as *Eptomastidea abnormis* (Girault), *Leptomastix dactylopii* Howard, *Chrysoplatycerus splendens* Howard and *Anagyrus pseudococci* (Girault) (Table 7).

**Table 7.** A summary of mealybug species and biological control agents.

Mealybug species	Natural Predators	Key findings	References
<i>Planococcus citri</i>	<i>Leptomastix dactylopii</i>	<i>Leptomastix</i> was superior to other natural enemies	[26,132]
<i>Phenacoccus manihoti</i>	<i>Apoanagyrus lopezi</i> , <i>Epidinocarsis lopezi</i> , <i>Apoanagyrus diversicornis</i>	<i>Apoanagyrus</i> species had maximum control of the cassava mealybug species in relation to other natural enemies	[133–135]
<i>Rastrococcus invadens</i>	<i>Gyranusoide tebygi</i> , <i>Anagyrus mangicola</i>	Effective control of <i>Rastrococcus invadens</i>	[35]
<i>Planococcus ficus</i>	<i>Anagyrus pseudococci</i> , <i>Nephus angustus</i> , <i>Nephus quadrivittatus</i> , <i>Nephus ninaevatus</i> , <i>Nephus sp.</i> , <i>Hyperaspis felixi</i> , <i>Sycmnus nubilis</i> Mulsant, <i>Cynodia lunata</i> , <i>Rhizobiellus sp.</i> , <i>Hippodamia sp.</i> , <i>Chrysopa sp.</i>	The <i>Anagyrus</i> species was more effective in controlling <i>Planococcus ficus</i> mealybug	[26,136]
<i>Phenacoccus solenopsis</i>	<i>Oenopia</i> ( <i>Synharmonia</i> ) <i>conglobata</i> (L.), <i>Cheilomenes propingua</i> (Mulsant), <i>Chrysoperla carnea</i> (Stephens), <i>Chrysoperla mutata</i> (Mc Lachlan) (Neuroptera: Chrysopidae), <i>Symphorobius elegans</i> (Stephens); <i>Symphorobius fallax</i> (Navas), (Neuroptera: Hemerobiidae)	These parasitoids had higher parasitizing activity as compared to other predators	[137,138]
<i>Dysmicoccus brevipes</i>	<i>Heterorhabditis amazonensis</i> (NEPET 11 and IBCD.n40)	These two isolates reduced over 80% of the <i>Dysmicoccus brevipes</i> population	[139]

*Continued on the next page*

Mealybug species	Natural Predators	Key findings	References
<i>Dysmicoccus brevipis</i>	<i>Metarhizium anisopliae</i> , <i>Beauveria bassiana</i> and <i>Lecanicillium lecanii</i>	These fungi had maximum control of pink pineapple mealybug and other mealybugs	[140]
<i>Planococcoides njalensis</i>	<i>Acerophagus notativentis</i> , <i>Acerophagus pallidus</i> , <i>Aenasius abengoroui</i> , <i>Aenasius martini</i> , <i>Anagyrus aurantifrons</i> , <i>Anagyrus beneficiens</i> , <i>Arhopoides sp.</i> , <i>Blepyrus saccharicola</i> , <i>Leptomastix bifasciatus</i> , <i>Leptomastix dactylopii</i> , <i>Platynopsis higginsii</i> , <i>Pseudaphycus sp.</i> , <i>Scymnus sp.</i> , <i>Tetracnemoidea sydneyensis</i> , <i>Tropidophryne melvillei</i>	These predators have higher success in the control of <i>Planococcoides njalensis</i>	[141]
<i>Maconellicoccus hirsutus</i>	<i>Anagyrus kamali</i>	<i>Anagyrus kamali</i> fed on more than 78 % of <i>Maconellicoccus hirsutus</i> reducing their population	[142,143]

The use of chemicals during biocontrol methods should be regulated. In addition, non-selective insecticides tend to kill or neutralize several beneficial insect pollinators.

#### 4.4. Chemical control

In recent times, chemical control methods have generated public outcry due to the accumulation of chemical residues in plant and food products [144,145] and their negative effects on the environment [146,147]. Cocco et al. [82] reported on the harmful levels of imidacloprid and chlorpyrifos (active ingredients in the control of several mealybug species) in waterbodies in Spain. Similarly, Babar et al. [148] emphasized on the need to regulate the use of profenofos, carbosulfan and methidathion during the control of *Drosicha mangiferae* on citrus farms in Pakistan. Mansour et al. [149] proposed in their review paper that the use of spirotetramat in combination with other treatments will effectively help reduce the population of *Planococcus ficus* and *Planococcus citri*. Chemicals used in pest control include acaricides, insecticides, rodenticides, fungicides, larvicides.

The use of insecticides in the control of mealybugs is not recommended because their outer covering, made up of wax, protect them against the insecticides [26]. With time, they develop resistance to these chemical insecticides. *Phenacoccus solenopsis* is reported to show a minimal reaction to insecticides that are lethal to other mealybug species [150]. Also, mealybugs hide underneath leaves and their large group makes it difficult for the chemicals to have maximum contact [150]. Their rapid reproduction cycle is also reported to contribute to their resistivity to insecticides [151]. Insecticides containing dinotefuran, imidacloprid, or pyrethroids [26,152], which are active ingredients that are effective against crawling mealybugs but have serious irritations on other beneficial insect pollinators. Daane et al. [40] confirmed the reduction in the population of *Planococcus ficus* when insecticides with chlorpyrifos active ingredients were applied.

Alcohol is effective in the control of mealybug. A previous study confirmed the association between alcohol application and mealybug mortality. A spray with a 70% concentration of isopropyl alcohol killed 70-80% of most mealybug species when applied against them [92].

Biopesticides where plant extracts are used to combat mealybugs infestation are also effective against mealybugs. Extracts from plants, such as neem, have proven effective against plant pathogens and pests [153–156]. According to Abul Monjur Khan et al. [157], 2% of neem oil effectively reduced 30% of the papaya mealybug when applied. Azadirachtin, a compound in neem trees, slows insect metamorphosis and reproduction. the Azadirachtin compound leads to a reduced growth rate and death of insects [158]. Neem Kernel water extracts are deadly to young cassava mealybugs [34,35]. 1–2% concentration of insecticidal soaps and vegetable oil as biopesticides have successfully controlled mealybugs [34,35]. Additives, such as oil, dissolve and break up the thick covering of the mealybug [26].

Insecticides that disrupt the nervous system of insects, like the organophosphates class of insecticides (chlorpyrifos, acephate, dichlorvos and diazinon), are recommended to control mealybugs (Table 8). When applied in the right amount, this class of insecticides has been proven to eliminate most species of mealybugs [26].

**Table 8.** A summary of some chemical controls on mealybug species.

Mealybug species	Chemical Control	Key Findings	References
<i>Dysmicoccus brevipipes</i> (Cockerell)/Pineapple mealybug	50% Fenithrothion,50% Fenthion,40.8% Chlorpyrifos	After 21 days, the mixture of these chemicals resulted in higher mealybug mortality after the second dose than the other tested chemicals	[159]
<i>Dysmicoccus brevipipes</i>	Omethoate,48mg of AI Phorate per plant	More than half of the <i>Dysmicoccus brevipipes</i> population were eliminated	[160]
<i>Phenacoccus solenopsis</i>	Acephate, Chlorpyrifos	<i>Planococcus solenopsis</i> mealybug was reduced by 69% after Acephate and Chlorpyrifos as compared to other chemical treatments	[161]
<i>Phenacoccus solenopsis</i>	Brufozen	After 3 days, Brufozen decreased the mealybug population by 95%	[161]
<i>Phenacoccus manihoti</i>	Diazinon,Phosphamidon, Methidathion	Diazinon, Phosphamidon and Methidathion were 12.7,10.8 and 7.3% effective in controlling the cassava mealybug as compared to the control	[162]
<i>Pseudococcuscoccus njalensis</i>	(CR409) Bisdimethylamino-fluorophosphine oxide	CR409 was superior in the control of the cocoa mealybug	[163]
<i>Planococcus citri</i>	0.075% Zethiol,0.075% Nogos 100 EC, Bisdimethylamino-fluorophosphine oxide (CR409)	0.075% Zethiol and 0.075% Nogos 100EC completely eliminated <i>Pseudococcus citri</i> .CR409 had complete control over <i>Planococcus citri</i>	[164]
<i>Maconellicoccus hirsutus</i>	Spirotetramat, bifenthrin, flypyradifurone, fenpropathrin	In the nymph stage, the fecundity of mealybug was highly affected after day 6	[165]
<i>Planococcus ficus</i>	Chlorpyrifos, Mevinphos	Chlorpyrifos, mevinphos had superior control as compared to other methods	[126]

## 5. Conclusions

This paper reviewed the economic losses caused by mealybugs, mealybug-transmitted plant viruses, their mode of transmission, host plants of mealybugs and the control methods of mealybugs. The paper also highlighted some economic losses of mealybugs. In times of evolving plant viruses, the role of mealybugs cannot be underestimated.

Mealybugs are active in transmitting plant viruses' genera belonging to the Closteroviridae family. Of these genera, Ampeloviruses and Badnaviruses are actively transmitted by mealybug species.

Due to various environmental pollution problems, chemicals should be reduced or replaced by other safe control methods. Therefore, the biological control method of environmentally friendly mealybugs should be encouraged. For example, the *Anagyrus* species are effective against several mealybug species as biological control methods. Additionally, the use of plant products with insecticidal properties (neem seeds, leaves) to control mealybugs should be well researched.

Breeding of more mealybug-resistant varieties of plants should be encouraged. Genes that allow crop plants to withstand the aggressive feeding of mealybugs must be well studied. The acquisition and use of more tolerant varieties will help small-scale farmers who cannot afford expensive control methods.

Using one control method at a time makes the mealybug species build up resistance in a shorter time. In effect, further studies should be conducted on using Integrated Pest Management (IPM) strategies in the management of mealybug species. IPM strategies are critical in controlling and managing mealybugs in the long term.

### Use of AI declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

### Conflict of interest

The authors declare they have no conflict of interest.

### References

1. World Bank (2018) World Development Indicators, United Nations Population Division. World Population Prospects: 2019 Revision.
2. The World Bank (2021) Thailand Healthcare Spending, WDI-Home.
3. Vollset SE, Goren E, Yuan CW, et al. (2020) Fertility, mortality, migration, and population scenarios for 195 countries and territories from 2017 to 2100: A forecasting analysis for the Global Burden of Disease Study. *Lancet* 396: 1285–1306. [https://doi.org/10.1016/S0140-6736\(20\)30677-2](https://doi.org/10.1016/S0140-6736(20)30677-2)
4. Procheş Ş, Wilson JR, Vamosi JC, et al. (2008) Plant diversity in the human diet: Weak phylogenetic signal indicates breadth. *Bioscience* 58: 151–159. <https://doi.org/10.1641/B580209>
5. Ficke A, Cowger C, Bergstrom G, et al. (2018) Understanding yield loss and pathogen biology to improve disease management: Septoria nodorum blotch—A case study in wheat. *Plant Dis* 102: 696–707. <https://doi.org/10.1094/PDIS-09-17-1375-FE>

6. Wang A, Krishnaswamy S (2012) Eukaryotic translation initiation factor 4E-mediated recessive resistance to plant viruses and its utility in crop improvement. *Mol Plant Pathol* 13: 795–803. <https://doi.org/10.1111/j.1364-3703.2012.00791.x>
7. Ali Şevik M, Akyazi F, Karantina Müdürlüğü Z (2008) Bitki Patojeni Virüslerin Bitki Parazit Nematodlarla Taşınması. *Batı Akdeniz Tarımsal Araştırma Enstitüsü Derim Derg* 25: 1–12.
8. Heck M (2018) Insect transmission of plant pathogens: A systems biology perspective. *mSystems* 3: e00168-17. <https://doi.org/10.1128/mSystems.00168-17>
9. Shi X, Zhang Z, Zhang C, et al. (2021) The molecular mechanism of efficient transmission of plant viruses in variable virus–vector–plant interactions. *Hortic Plant J* 7: 501–508. <https://doi.org/10.1016/j.hpj.2021.04.006>
10. Cid M, Fereres A (2010) Characterization of the probing and feeding behavior of *planococcus citri* (Hemiptera: Pseudococcidae) on grapevine. *Ann Entomol Soc Am* 103: 404–417. <https://doi.org/10.1603/AN09079>
11. Wielkopolan B, Jakubowska M, Obrepalska-Stepłowska A (2021) Beetles as plant pathogen vectors. *Front Plant Sci* 12: 748093. <https://doi.org/10.3389/fpls.2021.748093>
12. Bandte M, Pestemer W, Büttner C, et al. (2009) Ecological aspects of plant viruses in tomato and pathogen risk assessment. *Acta Hort* 821: 161–168. <https://doi.org/10.17660/ActaHortic.2009.821.17>
13. Jones DR (2005) Plant viruses transmitted by thrips. *Eur J Plant Pathol* 113: 119–157. <https://doi.org/10.1007/s10658-005-2334-1>
14. Krishnareddy M (2013) Impact of climate change on insect vectors and vector-borne plant viruses and phytoplasma. In: Singh HCP, Rao NKS, Shivashankar KS (Eds.), *Climate-Resilient Horticulture: Adaptation and Mitigation Strategies*, Chapter 23, Springer, 255–277. [https://doi.org/10.1007/978-81-322-0974-4\\_23](https://doi.org/10.1007/978-81-322-0974-4_23)
15. Zimmer R, Mpyers K, Haber S, et al. (1992) Tomato spotted wilt virus, a problem on grass pea and field pea in the greenhouse in 1990 and 1991. *Can Plant Dis Surv* 72: 29–31.
16. Dawidowicz Ł, Rozwałka R (2016) Honeydew Moth *Cryptoblabes gnidiella* (MILLIÈRE, 1867) (Lepidoptera: Pyralidae): an adventive species frequently imported with fruit to Poland. *Polish J Entomol* 85: 181–189. <https://doi.org/10.1515/pjen-2016-0010>
17. Gharsan FN (2019) A Review of the Bioactivity of Plant Products Against *Aedes aegypti* (Diptera: Culicidae). *J Entomol Sci* 54: 256–274. <https://doi.org/10.18474/JES18-82>
18. Ordax M, Piquer-Salcedo JE, Santander RD, et al. (2015) Medfly ceratitis capitata as potential vector for fire blight pathogen erwinia amylovora: Survival and transmission. *PLoS One* 10: e127560. <https://doi.org/10.1371/journal.pone.0127560>
19. Sastry KS (2013) Chapter 1—Transmission of Plant Viruses and Viroids. In: *Plant Virus and Viroid Diseases in the Tropics*, Springer, 1–10. <https://doi.org/10.1007/978-94-007-6524-5>
20. Fereres A, Raccach B (2015) Plant Virus Transmission by Insects, *eLS*. <https://doi.org/10.1002/9780470015902.a0000760.pub3>
21. Perilla-Henao LM, Casteel CL (2016) Vector-borne bacterial plant pathogens: Interactions with hemipteran insects and plants. *Front Plant Sci* 7: 1163. <https://doi.org/10.3389/fpls.2016.01163>
22. Jones DR (2003) Plant viruses transmitted by whiteflies. *Eur J Plant Pathol* 109: 195–219. <https://doi.org/10.1023/A:1022846630513>
23. Ng JCK, Perry KL (2004) Transmission of plant viruses by aphid vectors. *Mol Plant Pathol* 5: 505–511. <https://doi.org/10.1111/j.1364-3703.2004.00240.x>



24. Sarwar M (2020) Chapter 27—Insects as transport devices of plant viruses. In: Awasthi LP (Ed.), *Applied Plant Virology: Advances, Detection, and Antiviral Strategies*, Academic Press, 381–402. <https://doi.org/10.1016/B978-0-12-818654-1.00027-X>
25. Chiquito-Almanza E, Acosta-Gallegos JA, García-Álvarez NC, et al. (2017) Simultaneous detection of both RNA and DNA viruses infecting dry bean and occurrence of mixed infections by BGYMV, BCMV and BCMNV in the Central-West Region of Mexico. *Viruses* 9: 63. <https://doi.org/10.3390/v9040063>
26. Franco JC, Zada A, Mendel Z (2009) Chapter 9—Novel Approaches for the Management of Mealybug Pests. In: Ishaaya I, Horowitz AR (Eds.), *Biorational Control Arthropod Pest (Application and Resistance Management)*, Springer, 233–278. [https://doi.org/10.1007/978-90-481-2316-2\\_10](https://doi.org/10.1007/978-90-481-2316-2_10)
27. Cox JM (1989) The mealybug genus *Planococcus* (Homoptera: Pseudococcidae). *Bull Br Museum (Natural Hist) Entomol* 58: 1–78. <https://biostor.org/reference/113927>
28. Naegele RP, Cousins P, Daane KM (2020) Identification of *Vitis* cultivars, rootstocks, and species expressing resistance to a *Planococcus* mealybug. *Insects* 11: 86. <https://doi.org/10.3390/insects11020086>
29. Pitino M, Hoffman MT, Zhou L, et al. (2014) The phloem-sap feeding mealybug (*Ferrisia virgata*) carries ‘*Candidatus Liberibacter asiaticus*’ populations that do not cause disease in host plants. *PLoS One* 9: e85503. <https://doi.org/10.1371/journal.pone.0085503>
30. Prabhakar M, Prasad YG, Vennila S, et al. (2013) Hyperspectral indices for assessing damage by the solenopsis mealybug (Hemiptera: Pseudococcidae) in cotton. *Comput Electron Agric* 97: 61–70. <https://doi.org/10.1016/j.compag.2013.07.004>
31. Alliaume A, Reinbold C, Uzest M, et al. (2018) Mouthparts morphology of the mealybug *Phenacoccus aceris*. *Bull Insectology* 71: 1–9. <http://www.bulletinofinsectology.org/>
32. Bhat AI, Hohn T, Selvarajan R (2016) Badnaviruses: The current global scenario. *Viruses* 8: 177. <https://doi.org/10.3390/v8060177>
33. Kaydan MB, Kozár F, Hodgson C (2015) A review of the phylogeny of Palaearctic mealybugs (Hemiptera: Coccoomorpha: Pseudococcidae). *Arthropod Syst Phylogeny* 73: 175–195.
34. Coaker TH, Hill DS (1984) Agricultural insect pests of the tropics and their control. *J Appl Ecol* 21: 721. <https://trove.nla.gov.au/work/16341512>
35. Neuenschwander P, Borgemeister C, Langewald J, et al. (2003) Biological control in IPM systems in Africa, 1–414. <https://doi.org/10.1079/9780851996394.0000>
36. Mendel Z, Protasov A, Jasrotia P, et al. (2012) Sexual maturation and aging of adult male mealybug (Hemiptera: Pseudococcidae). *Bull Entomol Res* 102: 385–394. <https://doi.org/10.1017/S0007485311000605>
37. Joy PP, Anjana R (2016) Insect pests of pineapple and their management. Pineapple Research Station (Kerala Agricultural University), Vazhakhulam 1–3.
38. Kono M, Koga R, Shimada M, et al. (2008) Infection dynamics of coexisting beta- and gammaproteobacteria in the nested endosymbiotic system of mealybugs. *Appl Environ Microbiol* 74: 4175–4184. <https://doi.org/10.1128/AEM.00250-08>
39. Byron MA, Gillett-kaufman JL (2020) Targioni Tozzetti (Insecta : Hemiptera : Pseudococcidae ) 1. *Biology (Basel)* 1–3.
40. Daane KM, Cooper ML, Triapitsyn SV, et al. (2008) Vineyard managers and researchers seek sustainable solutions for mealybugs, a changing pest complex. *Calif Agric* 62: 167–176. <http://dx.doi.org/10.3733/ca.v062n04p167>

41. Ben-Dov Y (1994) A systematic catalogue of the mealybugs of the world (Insecta: Homoptera: Coccoidea: Pseudococcidae and Putoidae) with data on geographical distribution, host plants, biology and economic importance, Intercept Limited. Available from: <https://www.cabdirect.org/cabdirect/abstract/19941106629>.
42. Khan M (2019) Abundance, damage severity and management of guava mealybug, *ferrisia virgata* ckl. *SAARC J Agric* 16: 73–82. <http://dx.doi.org/10.3329/sja.v16i2.40260>
43. Afzal M, Rahman SU, Siddiqui MT (2009) Appearance and management of a new devastating pest of cotton, *Phenacoccus solenopsis* Tinsley in Pakistan. *2009 Beltwide Cotton Conferences, San Antonio, Texas*, 1023–1039. Available from: <https://www.cotton.org/beltwide/proceedings/2005-2022/data/conferences/2009/papers/9051.pdf>.
44. Aheer GM, Shah Z, Saeed M (2009) Seasonal history and biology of cotton mealy, *Phenacoccus solenopsis* Tinsley. *J Agric Res* 4: 423–432.
45. Bhat AI, Devasahayam S, Sarma YR, et al. (2003) Association of a badnavirus in black pepper (*Piper nigrum* L.) transmitted by mealybug (*Ferrisia virgata*) in India. *Curr Sci* 84: 1547–1550. <https://www.jstor.org/stable/24108260>
46. Khumpumuang P, Urairong H, Yongsawatdigul J, et al. (2019) Selection of soil bacteria for controlling cassava mealybugs. *Suranaree J Sci Technol* 26: 166–186.
47. Roivainen O (1976) Transmission of cocoa viruses by mealybugs (Homoptera: Pseudococcidae). *Agric Food Sci* 48: 203–304. <https://doi.org/10.23986/afsci.71915>
48. Sarpong TM, Asare-Bediako E, Acheampong L (2017) Perception of mealybug wilt effect and management among pineapple farmers in Ghana. *J Agric Ext* 21: 1–16. <https://doi.org/10.4314/jae.v21i2.1>
49. Watson GW, Kubiriba J (2005) Identification of mealybugs (Hemiptera: Pseudococcidae) on banana and plantain in Africa. *African Entomol* 13: 35–47. <https://hdl.handle.net/10520/EJC32626>
50. Asare-Bediako E, Nyarko J, Puije GC (2020) First report of *Pineapple mealybug wilt associated virus-2* infecting pineapple in Ghana . *New Dis Reports* 41: 9. <https://doi.org/10.5197/j.2044-0588.2020.041.009>
51. Celepci E, Uygur S, Bora Kaydan M, et al. (2017) Mealybug (Hemiptera: Pseudococcidae) species on weeds in Citrus (Rutaceae) plantations in Çukurova Plain, Turkey Çukurova Bölgesi'nde turunçgil alanlarındaki yabancıotlar üzerinde bulunan unlubit (Hemiptera: Pseudococcidae) türleri. *Türk entomol bült* 7: 15–21. <https://doi: 10.16969/teb.14076>
52. Lopes FSC, de Oliveira JV, Oliveira JE de M, et al. (2019) Host plants for mealybugs (Hemiptera: Pseudococcidae) in grapevine crops. *Pesqui Agropecu Trop* 49. <https://doi.org/10.1590/1983-40632019v4954421>
53. Kansiiime MK, Rwomushana I, Mugambi I, et al. (2020) Crop losses and economic impact associated with papaya mealybug (*Paracoccus marginatus*) infestation in Kenya. *Int J Pest Manag* 69: 1861363. <https://doi.org/10.1080/09670874.2020.1861363>
54. Sosan MB, Ajibade RO, Udah O, et al. (2020) Preliminary survey of mealybug incidence and infestation on pawpaw (*Carica papaya* l .) in a rainforest ecology in Nigeria. *Ife J Agric* 32: 79–90. Available from: <https://ija.oauife.edu.ng/index.php/ija/article/view/337>.
55. Tachie-Menson J, Sarkodie-Addo J, Carlson A (2015) Effects of weed management on the prevalence of pink Pineapple mealybugs in Ghana. *J Sci Technol* 34: 17–25. <https://doi.org/10.4314/just.v34i2.3>

56. Wih K, Billah M (2012) Diversity of fruit flies and mealybugs in the upper west region of Ghana. *J Dev Sustain Agric* 7: 39–45. <http://197.255.68.203/handle/123456789/1766>
57. Muniappan R, Shepard BM, Watson GW, et al. (2008) First report of the papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae), in Indonesia and India. *J Agric Urban Entomol* 25: 37–40. <https://doi.org/10.3954/1523-5475-25.1.37>
58. Charles JG (1988) Economic damage and preliminary economic thresholds for mealybugs (*Pseudococcus longispinus* t-t.) in auckland vineyards. *New Zeal J Agric Res* 25: 415–420. <https://doi.org/10.1080/00288233.1982.10417905>
59. Fand BB, Kumar M, Kamble AL (2014) Predicting the potential geographic distribution of cotton mealybug *Phenacoccus solenopsis* in India based on MAXENT ecological niche Model. *J Environ Biol* 35: 973–982.
60. Nagrare VS, Kranthi S, Biradar VK, et al. (2009) Widespread infestation of the exotic mealybug species, *Phenacoccus solenopsis* (Tinsley) (Hemiptera: Pseudococcidae), on cotton in India. *Bull Entomol Res* 99: 537–541. <https://doi.org/10.1017/S0007485308006573>
61. Thennarasi A, Jeyarani S, Sathiah N (2021) Diversity of predators associated with the mealybug complex in cassava growing districts of Tamil Nadu, India. *Int J Plant Soil Sci* 33: 62–79. <https://doi.org/10.9734/ijpss/2021/v33i2230684>
62. Rauwane ME, Odeny DA, Millar I, et al. (2018) The early transcriptome response of cassava (*Manihot esculenta* Crantz) to mealybug (*Phenacoccus manihoti*) feeding. *PLoS One* 13: e0202541. <https://doi.org/10.1371/journal.pone.0202541>
63. Dey KK, Green JC, Melzer M, et al. (2018) Mealybug wilt of pineapple and associated viruses. *Horticulturae* 4. <https://doi.org/10.3390/horticulturae4040052>
64. Franco JC, Suma P, Da Silva EB, et al. (2004) Management strategies of mealybug pests of citrus in mediterranean countries. *Phytoparasitica* 32: 507–522. <https://doi.org/10.1007/BF02980445>
65. Woolf AB, Ben-Arie R (2011) Chapter 9—Persimmon (*Diospyros kaki* L.). In: Kader AA, Yahia EL (Eds.), *Postharvest Biology and Technology of Tropical and Subtropical Fruits*, Woodhead Publishing, 166–194e. <https://doi.org/10.1533/9780857092618.166>
66. Grasswitz TR, James DG (2008) Movement of grape mealybug, *Pseudococcus maritimus*, on and between host plants. *Entomol Exp Appl* 129: 268–275. <https://doi.org/10.1111/j.1570-7458.2008.00786.x>
67. Heppner JB, Heppner JB, Capinera JL, et al. (2008) Vine Mealybug, *Planococcus ficus* Signoret (Hemiptera: Pseudococcidae). In: Capinera JL (Ed.), *Encyclopedia of Entomology*, Springer, 4108–4111. [https://doi.org/10.1007/978-1-4020-6359-6\\_3979](https://doi.org/10.1007/978-1-4020-6359-6_3979)
68. Nébié K, Nacro S, Otoïdobia L, et al. (2016) Population dynamics of the mango mealybug *Rastrococcus invadens* Williams (Homoptera: Pseudococcidae) in western Burkina Faso. *Am J Exp Agric* 11: 1–11. <https://doi.org/10.9734/AJEA/2016/24819>
69. Kubiriba J, Legg JP, Tushemereirwe W, et al. (2001) Vector transmission of Banana streak virus in the greenhouse in Uganda. *Ann Appl Biol* 139: 37–43. <https://doi.org/10.1111/j.1744-7348.2001.tb00128.x>
70. Yu N, Luo Z, Fan H, et al. (2015) Complete genomic sequence of a *Pineapple mealybug wilt-associated virus-1* from Hainan Island, China. *Eur J Plant Pathol* 141: 611–615. <https://doi.org/10.1007/s10658-014-0545-z>

71. Kumar PKV, Reddy GVM, Seetharama HG, et al. (2016) Coffee. In: Mani M, Shivaraju C (Eds.), *Mealybugs and their Management in Agricultural and Horticultural crops*, Springer, 643–655. [https://doi.org/10.1007/978-81-322-2677-2\\_70](https://doi.org/10.1007/978-81-322-2677-2_70)
72. Rae DJ, Jones RE (1992) Influence of host nitrogen levels on development, survival, size and population dynamics of sugarcane mealybug, *Saccharicoccus sacchari* (Cockerell) (Hemiptera: Pseudococcidae). *Aust J Zool* 40: 327–369. <https://doi.org/10.1071/ZO9920327>
73. Haviland DR, Beede RH (2012) Seasonal phenology of *Ferrisia gilli* (Hemiptera: pseudococcidae) in commercial pistachios. *J Econ Entomol* 105: 1681–1687. <https://doi.org/10.1603/ec12070>
74. Bertin S, Cavalieri V, Gribaudo I, et al. (2016) Transmission of *Grapevine virus A* and *Grapevine leafroll-associated virus 1 and 3* by *Heliococcus bohemicus* (Hemiptera: Pseudococcidae) nymphs from plants with mixed infections. *J of Econ Entom* 109: 1504–1511. <https://doi.org/10.1093/jee/tow120>
75. Abdel-Moniem ASH, Farag NA, Abbass MH (2005) Vertical distribution of some piercing sucking insects on some roselle varieties in Egypt and the role of amino acids concentration in infestation. *Arch Phytopathol Plant Prot* 38: 245–255. <https://doi.org/10.1080/03235400400008390>
76. Myrick S, Norton GW, Selvaraj KN, et al. (2014) Economic impact of classical biological control of papaya mealybug in India. *Crop Prot* 56: 82–86. <https://doi.org/10.1016/j.cropro.2013.10.023>
77. Mani M, Krishnamoorthy A, Shivaraju C (2011) Biological suppression of major mealybug species on horticultural crops in India. *J Hortl Sci* 6: 85–100.
78. Ghosh AB, Ghosh SK (1985) Effect of infestation of *Nipaecoccus vastator* (Maskell) on host plants. *Indian Agric* 29: 141–147.
79. Roda A, Francis A, Kairo MTK, et al. (2013) *Planococcus minor* (Hemiptera: Pseudococcidae): Bioecology, survey and mitigation strategies. In: *Potential Invasive Pests Agric Crop*, Wallingford UK: CABI, 288–300. <https://doi.org/10.1079/9781845938291.0288>
80. Charles JG (2010) Using parasitoids to infer a native range for the obscure mealybug, *Pseudococcus viburni*, in South America. *BioControl* 56: 155–161. <https://doi.org/10.1007/s10526-010-9322-x>
81. Sakthivel P, Karuppuchamy, Kalyanasundaram M, et al. (2012) Host plants of invasive papaya mealybug, *Paracoccus marginatus* (Williams and Granara de Willink) in Tamil Nadu. *Madras Agric J* 99: 615–619. <https://doi.org/10.29321/MAJ.10.100154>
82. Cocco A, Pacheco da Silva VC, Benelli G, et al. (2021) Sustainable management of the vine mealybug in organic vineyards. *J Pest Sci* 94: 153–185. <https://doi.org/10.1007/s10340-020-01305-8>
83. Selvarajan R, Balasubramanian V, Padmanaban B (2016) Mealybugs as vectors. In: Mani M, Shivaraju C (Eds.), *Mealybugs and their Management in Agricultural and Horticultural Crops*, Springer, 123–130.
84. Sether DM, Hu JS (2002) Closterovirus infection and mealybug exposure are necessary for the development of mealybug wilt of pineapple disease. *Phytopathology* 92: 928–935. <https://doi.org/10.1094/PHYTO.2002.92.9.928>
85. Obok EE, Aikpokpodion PO, Ani OC, et al. (2021) Cacao swollen shoot virus detection and DNA barcoding of its vectors and putative vectors in *Theobroma cacao* L. by using polymerase chain reaction. *Biotechnologia* 102: 229–244. <https://doi.org/10.5114/bta.2021.108719>
86. Fuchs M, Bar-Joseph M, Candresse T, et al. (2020) ICTV virus taxonomy profile: *Closteroviridae*. *J Gen Virol* 101: 364–365. <https://doi.org/10.1099/jgv.0.001397>

87. Martelli GP, Abou Ghanem-Sabanadzovic N, Agranovsky AA, et al. (2012) Taxonomic revision of the family closteroviridae with special reference to the grapevine leafroll-associated members of the genus ampelovirus and the putative species unassigned to the family. *J Plant Pathol* 94: 7–19. <https://www.jstor.org/stable/45156004>
88. Dey KK, Sugikawa J, Kerr C, et al. (2019) Air potato (*Dioscorea bulbifera*) plants displaying virus-like symptoms are co-infected with a novel potyvirus and a novel ampelovirus. *Virus Genes* 55: 117–121. <https://doi.org/10.1007/s11262-018-1616-6>
89. Martelli GP, Agranovsky AA, Bar-Joseph M, et al. (2002) The family *Closteroviridae* revised. *Arch Virol* 147: 2039–2044. <https://doi.org/10.1007/s007050200048>
90. Ameyaw GA, Dzahini-Obiatey HK, Domfeh O (2014) Perspectives on cocoa swollen shoot virus disease (CSSVD) management in Ghana. *Crop Prot* 65: 64–70. <https://doi.org/10.1016/j.cropro.2014.07.001>
91. Fariña AE, Rezende JAM, Wintermantel WM (2019) Expanding knowledge of the host range of *tomato chlorosis virus* and host plant preference of *Bemisia tabaci* MEAM1. *Plant Dis* 103: 1132–1137. <https://doi.org/10.1094/PDIS-11-18-1941-RE>
92. Flint ML (2016) PEST NOTES Statewide integrated pest management program integrated pest management for homes, gardens, and landscapes mealybugs publication 74174. Available from: <https://ipm.ucanr.edu/PMG/PESTNOTES/pn74174.html>.
93. Tsai CW, Rowhani A, Golino DA, et al. (2010) Mealybug transmission of grapevine leafroll viruses: An analysis of virus-vector specificity. *Phytopathology* 100: 830–834. <https://doi.org/https://doi.org/10.1094/phyto-100-8-0830>
94. Sether DM, Melzer MJ, Busto J, et al. (2005) Diversity and mealybug transmissibility of ampeloviruses in pineapple. *Plant Dis* 89: 450–456. <https://doi.org/10.1094/PD-89-0450>
95. Ito T, Nakaune R (2016) Molecular characterization of a novel putative ampelovirus tentatively named grapevine leafroll-associated virus 13. *Arch Virol* 161: 2555–2559. <https://doi.org/https://doi.org/10.1007/s00705-016-2914-8>
96. Bahder BW, Poojari S, Alabi OJ, et al. (2013) *Pseudococcus maritimus* (Hemiptera: Pseudococcidae) and *Parthenolecanium corni* (hemiptera: coccidae) are capable of transmitting grapevine leafroll-associated virus 3 between *vitis x labruscana* and *vitis vinifera*. *Environ Entomol* 42: 1292–1298. <https://doi.org/10.1603/EN13060>
97. Thekke-Veetil T, Aboughanem-Sabanadzovic N, Keller KE, et al. (2013) Molecular characterization and population structure of blackberry vein banding associated virus, new ampelovirus associated with yellow vein disease. *Virus Res* 178: 234–240. <https://doi.org/10.1016/j.virusres.2013.09.039>
98. Larrea-Sarmiento A, Olmedo-Velarde A, Wang X, et al. (2021) A novel ampelovirus associated with mealybug wilt of pineapple (*Ananas comosus*). *Virus Genes* 57: 464–468. <https://doi.org/10.1007/s11262-021-01852-x>
99. Wallingford AK, Fuchs MF, Martinson T, et al. (2015) Slowing the spread of grapevine leafroll-associated viruses in commercial vineyards with insecticide control of the vector, *Pseudococcus maritimus* (Hemiptera: Pseudococcidae). *J Insect Sci* 15: 112. <https://doi.org/10.1093/jee/tow124>
100. Wistrom CM, Blaisdell GK, Wunderlich LR, et al. (2016) *Ferrisia gilli* (Hemiptera: Pseudococcidae) transmits grapevine leafroll-associated viruses. *J Econ Entomol* 109: 1519–1523. <https://doi.org/10.1093/jee/tow124>

101. Maguet J Le, Beuve M, Herrbach E, et al. (2012) Transmission of six ampeloviruses and two vitiviruses to grapevine by *Phenacoccus aceris*. *Phytopathology* 102: 717–723. <https://doi.org/10.1094/phyto-10-11-0289>
102. Petersen CL, Charles JG (1997) Transmission of grapevine leafroll-associated closteroviruses by *Pseudococcus longispinus* and *P. calceolariae*. *Plant Pathol* 46: 509–515. <https://doi.org/10.1046/j.1365-3059.1997.d01-44.x>
103. Reynard JS, Schneeberger PHH, Frey JE, et al. (2015) Biological, serological, and molecular characterization of a highly divergent strain of *grapevine leafroll-associated virus 4* causing grapevine leafroll disease. *Phytopathology* 105: 1164–1284. <https://doi.org/10.1094/PHYTO-12-14-0386-R>
104. Ochoa-Martínez DL, Uriza-Ávila DE, Rojas-Martínez RI (2016) Detection of Pineapple mealybug wilt-associated virus 1 and 3 in Mexico. *Revista Mexicana de Fitopatología* 34: 131–141. <https://doi.org/10.18781/R.MEX.FIT.1601-1>
105. Al Rwahnih M, Rowhani A, Westrick N, et al. (2018) Discovery of viruses and virus-like pathogens in pistachio using high-throughput sequencing. *Plant Dis* 102: 1189–1471. <https://doi.org/10.1094/pdis-12-17-1988-re>
106. Chouk G, Elair M, Chaabouni AC, et al. (2021) *Pistacia vera* L. hosts pistachio ampelovirus A in Tunisia. *J Plant Pathol* 103: 1335. <http://dx.doi.org/10.1007/s42161-021-00905-2>
107. Elbeaino T, Digiario M, De Stradis A, et al. (2007) Identification of a second member of the family *Closteroviridae* in mosaic-diseased figs. *J Plant Pathol* 89: 119–124. <https://www.jstor.org/stable/41998365>
108. Yorganci S, Açıkgöz S (2019) Transmission of fig leaf mottle-associated virus 1 by *Ceroplastes rusci*. *J Plant Pathol* 101: 1199–1201. <https://www.jstor.org/stable/48699659>
109. Dolja VV, Koonin EV (2013) The closterovirus-derived gene expression and RNA interference vectors as tools for research and plant biotechnology. *Front Microbiol* 4: 83. <https://doi.org/10.3389/fmicb.2013.00083>
110. Komorowska B, Hasiów-Jaroszewska B, Czajka A (2020) Occurrence and detection of little cherry virus 1, little cherry virus 2, cherry green ring mottle virus, cherry necrotic rusty mottle virus, and cherry virus A in stone fruit trees in Poland. *Acta Virol* 64: 100–103. [https://doi.org/10.4149/av\\_2020\\_112](https://doi.org/10.4149/av_2020_112)
111. Ferreira CHL de H, Jordão LJ, Ramos-Sobrinho R, et al. (2019) Diversification into the genus Badnavirus: Phylogeny and population genetic variability. *Rev Ciência Agrícola* 17: 59. <https://doi.org/10.28998/rca.v17i2.6286>
112. Kreuze JF, Perez A, Gargurevich MG, et al. (2020) Badnaviruses of sweet potato: Symptomless coinhabitants on a global scale. *Front Plant Sci* 11: 313. <https://doi.org/10.3389/fpls.2020.00313>
113. Borah BK, Sharma S, Kant R, et al. (2013) Bacilliform DNA-containing plant viruses in the tropics: Commonalities within a genetically diverse group. *Mol Plant Pathol* 14: 759–771. <https://doi.org/10.1111/mpp.12046>
114. Quainoo AK, Wetten AC, Allainguillaume J (2008) Transmission of cocoa swollen shoot virus by seeds. *J Virol Methods* 150: 45–49. <https://doi.org/10.1016/j.jviromet.2008.03.009>
115. Ameyaw GA (2020) Management of the cacao swollen shoot virus (CSSV) menace in Ghana: The past, present and the future. In: Topolovec-Pintarić S (Ed.), *Plant Diseases—Current Threats and Management Trends*, London, UK: IntechOpen., 1–3. <https://doi.org/10.5772/intechopen.87009>

116. Bömer M, Rathnayake AI, Visendi P, et al. (2018) Complete genome sequence of a new member of the genus *Badnavirus*, Dioscorea bacilliform RT virus 3, reveals the first evidence of recombination in yam badnaviruses. *Arch Virol* 163: 533–538. <https://doi.org/10.1007/s00705-017-3605-9>
117. Koch KG, Jones T-KL, Badillo-Vargas IE (2020) Chapter 26—Arthropod vectors of plant viruses. In: Awasthi LP (Ed.), *Applied Plant Virology—Advances, Detection, and Antiviral Strategies*, Academic Press, 349–379. <https://doi.org/10.1016/b978-0-12-818654-1.00026-8>
118. Adams MJ, Candresse T, Hammond J, et al. (2012) Family—Betaflexiviridae. In: King AMQ, Lefkowitz E, Adams MJ, et al. (Eds.), *Virus Taxonomy—Ninth Report of the International Committee on Taxonomy of Viruses*, London, Elsevier Academic Press, 920–941. <https://doi.org/10.1016/B978-0-12-384684-6.00078-1>
119. Hull R (2002) Chapter 6—Genome Organization. In: Matthews REF, Hull R (Eds.), *Matthews' Plant Virology*, Gulf professional publishing, 171–224. <https://doi.org/10.1016/B978-0-12-361160-4.X5050-6>
120. Mani M, Joshi S, Kalyanasundaram M, et al. (2013) A new invasive jack beardsley mealybug, *Pseudococcus jackbeardsleyi* (Hemiptera: Pseudococcidae) on papaya in India. *Florida Entomol* 96: 242–245. <https://doi.org/10.1653/024.096.0135>
121. Andres C, Gattinger A, Dzahini-Obiatey HK, et al. (2017) Combatting cocoa swollen shoot virus disease: What do we know? *Crop Prot* 98: 76–84. <https://doi.org/10.1016/j.cropro.2017.03.010>
122. Karar H, Sayyed AH, Arif MJ, et al. (2010) Integration of cultural and mechanical practices for management of the mango mealybug *Drosicha mangiferae*. *Phytoparasitica* 38: 223–229. <http://dx.doi.org/10.1007/s12600-010-0094-8>
123. Haviland DR, Bentley WJ, Daane KM (2005) Hot-water treatments for control of *Planococcus ficus* (Homoptera: Pseudococcidae) on dormant grape cuttings. *J Econ Entomol* 98: 1109–1115. <https://doi.org/10.1603/0022-0493-98.4.1109>
124. Carabalí-Banguero DJ, Wyckhuys KAG, Montoya-Lerma J, et al. (2013) Do additional sugar sources affect the degree of attendance of *Dysmicoccus brevipes* by the fire ant *Solenopsis geminata*? *Entomol Exp Appl* 148: 65–73. <http://dx.doi.org/10.1111/eea.12076>
125. Vincent C, Weintraub P, Hallman G (2009) Chapter 200—Physical control of insect pests. In: Resh VH, Cardé RT (Eds.), *Encyclopedia of Insects (Second Edition)*, Academic press, 794–798. <http://dx.doi.org/10.1016/B978-0-12-374144-8.00209-5>
126. Franco JC, Silva EB, Cortegano E, et al. (2008) Kairomonal response of the parasitoid *Anagyrus* spec. nov. near *pseudococci* to the sex pheromone of the vine mealybug. *Entomol Exp Appl* 126: 122–130. <http://dx.doi.org/10.1111/j.1570-7458.2007.00643.x>
127. Kaur Gill H, Gaurav G, Gillett-Kaufman JL (2019) Citrus mealybug *Planococcus citri* (Risso) (Insecta: Hemiptera: Pseudococcidae). University of Florida. Available from: <https://edis.ifas.ufl.edu/publication/IN947>.
128. Hartley DE (1992) 12—Poinsettias. In: Larson RA (Ed.), *Introduction to Floriculture (Second Edition)*, Academic Press, 305–331.
129. Le Vieux PD, Malan AP (2013) An overview of the vine mealybug (*Planococcus ficus*) in South African vineyards and the use of entomopathogenic nematodes as potential biocontrol agent. *South African J Enol Vitic* 34: 108–118. <http://dx.doi.org/10.21548/34-1-1086>
130. Tohamy TH, El-Raheem AAA, El-Rawy AM (2008) Role of the cultural practices and natural enemies for suppressing infestation of the pink sugarcane mealybug, *Saccharicoccus sacchari* (Cockerell) (Hemiptera: Pseudococcidae) in sugarcane fields at Minia Governorate, Middle Egypt. *Egypt J Biol Pest Control* 18: 177–188. Available from: <https://www.cabdirect.org/cabdirect/abstract/20093037731>.

131. Mani M, Shivaraju C (2016) *Mealybugs and their management in agricultural and horticultural crops*, Springer, 1–655.
132. Cadée N, Van Alphen JJM (1997) Host selection and sex allocation in *Leptomastidea abnormis*, a parasitoid of the citrus mealybug *Planococcus citri*. *Entomol Exp Appl* 83: 277–284. <https://doi.org/10.1046/j.1570-7458.1997.00182.x>
133. Giordanengo P, Nénon JP (1990) Melanization and encapsulation of eggs and larvae of *Epidinocarsis lopezi* by its host *Phenacoccus manihoti*; effects of superparasitism and egg laying patterns. *Entomol Exp Appl* 56: 155–163. <https://doi.org/10.1111/j.1570-7458.1990.tb01393.x>
134. Pijls JWAM, Poleij LM, Van Alphen JJM, et al. (1996) Interspecific interference between *Apoanagyrus lopezi* and *A. diversicornis*, parasitoids of the cassava mealybug *Phenacoccus manihoti*. *Entomol Exp Appl* 78: 221–230. <http://dx.doi.org/10.1111/j.1570-7458.1996.tb00785.x>
135. Lapointe SL (2015) A tribute to Dr. Anthony C. Bellotti and his contributions to Cassava entomology. *Fla Entomol* 98: 810–814. <https://doi.org/10.1653/024.098.0267>
136. Walton VM, Pringle KL (2017) A survey of mealybugs and associated natural enemies in vineyards in the Western Cape Province, South Africa. *South African J Enol Vitic* 25: 23–25. <http://dx.doi.org/10.21548/25-1-2134>
137. Çalışkan AF, Ulusoy MR (2018) Distribution, host plants, parasitoids, and predators of cotton mealybug. *Phenacoccus solenopsis* Tinsley (Hemiptera: Coccoomorpha: Pseudococcidae) from Eastern Mediterranean region, *4th International Agriculture Congress*, Muğla, 05–08.
138. Chen HY, Li HL, Pang H, et al. (2021) Investigating the parasitoid community associated with the invasive mealybug *Phenacoccus solenopsis* in Southern China. *Insects* 12: 290. <https://doi.org/10.3390/insects12040290>
139. Zart M, De MacEdo MF, Rando JSS, et al. (2021) Performance of entomopathogenic nematodes on the mealybug, *Dysmicoccus brevipes* (Hemiptera: Pseudococcidae) and the compatibility of control agents with nematodes. *J Nematol* 53: 2021–2041. <https://doi.org/10.21307/jofnem-2021-020>
140. Chellappan M (2019) Evaluation of entomopathogenic fungus for the management of pink mealybug, *Dysmicoccus brevipes* (Cockerell) (Hemiptera: Pseudococcidae) on pineapple in Kerala. *J Entomol Zool Stud* 7: 1215–1222.
141. Bigger M (1981) The relative abundance of the mealybug vectors (Hemiptera: Coccidae and Pseudococcidae) of Cocoa swollen shoot disease in Ghana. *Bull Entomol Res* 71: 435–448. <https://doi.org/10.1017/S0007485300008464>
142. Fuenmayor Y, Portillo E, Bastidas B, et al. (2021) Infection parameters of *Heterorhabditis amazonensis* (Nematoda: Heterorhabditidae) in different stages of Hibiscus pink mealybug. *J Nematol* 52: 1–7. <https://doi.org/10.21307/jofnem-2020-077>
143. Katiyar RL, Kumar V, Manjunath D, et al. (2000) Biology of *Anagyrus kamali* (Moursi) (Hymenoptera: Encyrtidae)—A parasitoid of the mealybug, *Maconellicoccus hirsutus* (Green), with a note on its incidence. *Int J Ind Entomol* 1: 143–148.
144. Singh KD, Mobolade AJ, Bharali R, et al. (2021) Main plant volatiles as stored grain pest management approach: A review. *J Agric Food Res* 4: 100127. <https://doi.org/10.1016/j.jafr.2021.100127>
145. Taylor A, Birkett JW (2020) Pesticides in cannabis: A review of analytical and toxicological considerations. *Drug Test Anal* 12: 180–190. <https://doi.org/10.1002/dta.2747>
146. Farahy O, Laghfiri M, Bourioug M, et al. (2021) Overview of pesticide use in Moroccan apple orchards and its effects on the environment. *Curr Opin Environ Sci Heal* 19: 100223. <http://dx.doi.org/10.1016/j.coesh.2020.10.011>



147. Kaur R, Mavi GK, Raghav S, et al. (2019) Pesticides classification and its impact on environment. *Int J Curr Microbiol Appl Sci* 8: 1889–1897. <https://doi.org/10.20546/ijcmas.2019.803.224>
148. Babar M, Afzal S, Sikandar Z, et al. (2018) Efficacy of different insecticides under laboratory conditions against *Drosicha mangiferae* Green (Homoptera : Margarodidae ) collected from citrus orchards of Sargodha , Pakistan. *Pakistan J Entomol Zool Stud* 6: 2855–2858.
149. Mansour R, Belzunces LP, Suma P, et al. (2018) Vine and citrus mealybug pest control based on synthetic chemicals. A review. *Agron Sustain Dev* 38: 37. <http://dx.doi.org/10.1007/s13593-018-0513-7>
150. Edde PA (2022) 4—Arthropod pests of cotton (*Gossypium hirsutum* L.). In: *Field Crop Arthropod Pests of Economic Importance*, Academic Press, 208–274. <http://dx.doi.org/10.1016/B978-0-12-818621-3.00003-3>
151. Akhter A, Hage-Ahmed K, Soja G, et al. (2016) Potential of *Fusarium* wilt-inducing chlamydospores, in vitro behaviour in root exudates and physiology of tomato in biochar and compost amended soil. *Plant Soil* 406: 425–440. <https://link.springer.com/article/10.1007/s11104-016-2948-4>
152. Sequeira RV, Khan M, Reid DJ (2020) Chemical control of the mealybug *Phenacoccus solenopsis* (Hemiptera: Pseudococcidae) in Australian cotton–glasshouse assessments of insecticide efficacy. *Austral Entomol* 59: 375–385. <https://doi.org/10.1111/aen.12446>
153. Waiganjo MM, Waturu CN, Mureithi JM (2011) Use of entomopathogenic Fungi and neem bio-pesticides for Brassica pests control and conservation of their natural enemies. *East Afr Agric For J* 77: 1&2.
154. Gahukar RT (2014) Factors affecting content and bioefficacy of neem (*Azadirachta indica* A. Juss.) phytochemicals used in agricultural pest control: A review. *Crop Prot* 62: 93–99. <https://doi.org/10.1016/j.cropro.2014.04.014>
155. Pascoli M, de Albuquerque FP, Calzavara AK, et al. (2020) The potential of nanobiopesticide based on zein nanoparticles and neem oil for enhanced control of agricultural pests. *J Pest Sci* 93: 793–806. <https://link.springer.com/article/10.1007/s10340-020-01194-x>
156. Ahmed S, Grainge M (1986) Potential of the neem tree (*Azadirachta indica*) for pest control and rural development. *Econ Bot* 40: 201–209. <https://doi.org/10.1007/BF02859144>
157. Abul Monjur Khan M (2016) Efficacy of insect growth regulator Buprofezin against Papaya mealybug. *J Entomol Zool Stud* 4: 730–733.
158. Ujváry I (2010) Chapter 3—Pest control agents from natural products. In: Krieger R (Ed.), *Hayes' Handbook of Pesticide Toxicology (Third Edition)*, Academic press, 119–229. <https://doi.org/10.1016/B978-0-12-374367-1.00003-3>
159. ShouHorng H, ChingYi L (2014) Distribution and control of pink pineapple mealybug and survey of insect pests on pineapple. *J Taiwan Agric Res* 63: 68–76.
160. Rai BK, Sinha AK (1980) Pineapple: Chemical control of mealybug and associated ants in Guyana. *J Econ Entomol* 73: 41–45. <https://doi.org/10.1093/jee/73.1.41>
161. Hussain M, Noureen N, Fatima S, et al. (2016) Cotton mealybug management: A Review. *Middle-East J Sci Res* 24: 2424–2430. <https://doi.org/10.5829/idosi.mejsr.2016.24.08.101221>
162. Atu UG, Okeke JE (2009) Effect of insecticide application on cassava yield in control of cassava mealybug (*Phenacoccus Manlhotl*). *Trop Pest Manag* 27: 434–435. <https://doi.org/10.1080/09670878109413818>

163. Hanna AD, Heatherington W, Judenko E (1952) Control of the mealybug vectors of the swollen shoot virus by a systemic insecticide. *Nature* 169: 334–335. <https://doi.org/10.1038/169334a0>
164. Islam M, Ahmad M, Islam K, et al. (2006) Chemical control of citrus mealybug planococcus Citri risso (Pseudococcidae: Hemiptera) and the toxicological effects of insecticides on its predators Menochilussexmaculatus F. and Micraspis discolor F. (Coccinellidae: Coleoptera). *J Sci Found* 4: 27–30.
165. Ganjisaffar F, Andreason SA, Perring TM (2019) Lethal and sub-lethal effects of insecticides on the pink hibiscus mealybug, *Maconellicoccus hirsutus* (Hemiptera: Pseudococcidae). *Insects* 10: 31. <https://doi.org/10.3390/insects10010031>



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