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Cotton Mealybug Management: A Review

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Abstract
Cotton Mealybug, *Phenacoccus solenopsis* (Pseudococcidae; Hemiptera) is an exotic pest of several crops including maize, okra, brinjals, potato, sorghum, marigold, ground nuts, pigeon peas, holly hock, sunflower, cucurbits, beat root, mulberry, *Amaranthus* spp. and especially cotton. During the 1st decade of 21st century, mealybug has become a serious pest of crops and ornamentals. It has been reported from 35 different areas of the world threatening crop population. Several control and management strategies have been employed in various parts of the world to keep the pest under threshold levels. The chemical control of the cotton mealybug through Sulfoxaflor, Buprofezin, Chlorpyrifos, Profenofos, Imidacloprid, Dimethaote, Thiathoxam, Ethanol, Isopropyl alcohol, Petroleum sprays and plant based insecticides has been extensively investigated. The most efficient and suitable amongst these chemicals are Profenofos, Chlorpyrifos, Imidacloprid and Buprofezin while Imidacloprid was least toxic to friendly insects and botanical based insecticides did not harm at all. On one hand chemical control of cotton Mealybug is efficient, quick and economic whereas on the other hand it poses several environmental threats to the farmer. The climatic changes have great impact on the population dynamics of cotton Mealybug and its distribution over a wide host range. The continuous monitoring of the population abundance and dynamics of cotton Mealybug is required to avoid severe crop losses. The surveillance of the pest over large areas needs to be practiced for the development of effective management strategies.

Keywords: Cotton Mealybug; Chemical Control; Botanical Insecticides

Introduction
Cotton (*Gossypium hirsutum*) is the most important cash crop grown extensively for fibre over 83 countries with tropic and subtropical climatic conditions [1]. Pakistan stands at 4th position amongst sixty cotton growing countries of the world and third largest consumer of the cotton. Cotton as a major crop of Pakistan contributes 7.8% in value addition in agriculture, 1.6% in gross domestic product making up to 60% of the total export revenue and 55% of Pakistan's domestic cooking oil comes from cotton seeds. *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) has been the topic of contemporary research in the fields of entomology and systematics due to its invasiveness, wide spread, wide range of host plants and morphology [2]. The review of literature emphasized on the need for developing effective management of the mealybug species [2]. *P. solenopsis* has been described as a serious and invasive pest of cotton in Pakistan and India [2, 3].
The cotton production is heavily dependent on the insect pest outbreaks which threat the crop every year. Cotton crop is attacked by bollworms, aphids, mites, thrips, jassids, leaf roller, bugs, whiteflies, termites and leaf miner bollworms and armyworms [4]. Since 2005 Mealybug has proved itself as the biggest menace to the cotton crop having potential to destroy the crop over its whole range resulting in complete failure of the crop. It destroyed the crop during 2007 and caused a loss of Rs.159 crore in Pakistan; in several districts of Punjab and Sindh [3, 5, 6]. The control strategies are employed to suppress these pest populations under tolerable limits. There are several control options are available but none is absolute. Chemical control of cotton Mealybug is one of the major components of cotton Mealybug. This review encompasses chemical control strategies employed to control cotton Mealybug species worldwide. This attempt would lead to understand the current chemical control of the pest.

Origin and Distribution of Mealybug
Mealybug species (*Maconellicoccus hirsutus* and *Pheanacoccus solenopsis*) during the first decade of 21st century emerged as the most devastating pest of agricultural crops and ornamentals. These species are well spread over a wide range of tropical and subtropical countries.

The success of Mealybug as a devastating pest of cotton owes to its wide range of Morphological traits and ecological adaptability [3]. The pest status of these species was first time reported from Texas, America which later on spread throughout the world [7]. *Phenacoccus solenopsis* has been reported as key pest from over 35 localities around the globe pertaining to various ecological zones [7]. Since its discovery as a pest at Texas during 1991, it has been reported from various countries as major pest of cotton crop (Table 4). The cotton Mealybug *P. solenopsis* Tinsley (Hemiptera: Pseudococcidae) reported as pest from Texas, Caribbean and Ecuador, Chile, Argentina [8], Brazil [9], Pakistan [5], India, Nigeria, Sri Lanka [10], China [11] and Australia (Table 4). Cotton Mealybug infestations in the cotton fields of Pakistan during 2005 resulted in complete crop failure mainly unavailability of control measures as none of pesticide available at that time proved successful against the pest outbreak.

Host Range

Cotton Mealybug has a wide range of host plants ranging from herbaceous weeds to woody plants. *P. solenopsis* has been recorded as pest of 154 host-plant species out of which 20 field crops, 64 weeds, 45 ornamental plants and 25 shrubs and trees, belonging to a total of 53 plant families [12] whereas Ben-Dov [7] recorded from 174 host-plants belonging to 55 families.

Description of Mealybug

The cotton mealybug belongs to new world and resembles to *P. solani* Ferris and *P. defectus* Ferris which are also native to the New World. However, live adult females of *P. solenopsis* generally possess paired dark spots or stripes on dorsal sides, whereas the other two species are uniformly white.

P. solenopsis is sexually dimorphic, having short-lived, winged males and longer-lived, wingless, larviform females [5]. It has shown sexual reproduction, producing live young ones instead of laying eggs by a phenomenon of ovoviviparity [5]. Mealybug, soft body insect, reproduces mostly parthenogenetically, female lays eggs in ovisacs containing 150-600 eggs. Hatching takes place in 3-9 days into nymphs (Crawlers) which lasts for 22-25 days finally growing into adults in 25-30 days under optimum conditions. They can produce hundreds of nymphs in one generation with the capacity to lay up to 6000 eggs per generation.

Mode of Nutrition and Symptoms of Infestations

Cotton Mealybug is a polyphaguous sucking pest with incomplete metamorphosis. It is an exotic pest with a wide host range, a waxy protective coating on the dorsal side which counter potential mortality factors, having high reproductive rate, and ability of overwintering (Egg and adult female stage) aid insect becoming a serious pest of many commercially important crops. It attacks host plants by sucking cell sap of the phloem tissue [13] and secretes honeydew which makes sooty molds on the surface of the leaves, thus, ceasing the natural process of photosynthesis, ultimately resulting in the death of plant tissues [14, 15].

The presence of large number of Mealybug individuals on various parts of host plant one of the most important clue indicating pertinent crop losses. The major signs of cotton Mealybug infestations are wrinkled leaves and shoots, distorted and bushy branches, white powdery substance on leaves, shoots and stem, presence of honey dew, less number of bolls, unopened flowers, chlorosis, stunting, deformation and death of plants [16].

Control Strategies

The management of Cotton Mealybug is crucial to save billions of dollars and control strategies seem inevitable to suppress the pest population under threshold levels. It is observed that larval stages of cotton Mealybug are more vulnerable and are most likely to be affected by both biotic and abiotic factors. By applying control measures at this stage might provide radical success [17]. The control of cotton Mealybug includes cultural practices, use of biological control agents and use of pesticides. The life cycle and structural adaptability enable the Mealybug to counter one type or other of these control strategies successfully. Integrated pest management is still one of the major strategies against mealybug.

Chemical Control

The chemical control of Mealybug provides rapid control of the pest it also threatens natural enemies of the pest and predators leaving hazardous effects for human beings. The use of conventional pesticides against Cotton Mealybug has been proved unsatisfactory and is difficult as the pest is covered with the waxy material [18]. Integrated pest management strategies are may be adopted in order to control the infestation. The use of chemicals is necessary to control Mealybug infestation as evident by the literature but the harmful aspects have also been observed as Sparks *et al.* [19] who stated that although the insecticides provide high efficiency against pest control but it may cause resistance in insects. Cotton Mealybug due to high reproductive capacities and multiple generations (15) per year are potentially capable of becoming resistant to pesticides on consistent exposures (Table 1).

Botanical Based Insecticides

To reduce toxicity within crop plant based insecticides can also be used as these work as repellent and make the targeted plants unpalatable for insect. Successful efforts were done by Nagrare *et al*. [16] using *Azadirachta indica* (Neem) tree seed extraction equally effective in pest control, industries and medicines and for others. In addition, tobacco, huing, dhatoora and Meetha neem *(Melia azadirachta*) is also considered as non-hazardous, economical and safest having no lethal effects with a high rate of efficiency against a variety of pest insects as described by Narwal *et al.* [20]. The detail of work carried out by various researchers has been summed up in Table 3. Botanicals compounds despite their environmental compatibility and non-hazardous effects safer for humankind and animals are used at quite lesser extent in comparison with other options of pest management [21] The environmental concerns posed by the use synthetic chemical compounds in pest management has lead more regulated and documented use of pesticides banning several products and thus promoting other methods of pest control including biological control agents and their products. Plant extracts are biodegradable, less toxic to a wide variety of life, cheaper and supportive to biodiversity conservation.

Biological Control Agent

The natural enemies of cotton Mealybug has been reported from various parts of the world and are thought to be one of the most important control agent in mealybug programs. Heavy infestation of cotton mealybug may result from the absence of natural enemies on this invasive pest [22]. A majority of scientist has described the predatory potential of different predators and parasitoids. It was reported that biological control measures were proved efficient and non-

hazardous to host crop. The detail description is given in the Table 2. The serious outbreaks of mealybugs results in the absence of their natural enemies and classical biological control has been considered as the most appropriate method for the management of many exotic mealybug species in different parts of the world [23, 24].

Recommendations

It is observed that once the crop is fully infested by the pest it becomes very difficult to CMB overcome the problem. Penetration of insecticide is difficult due to waxy layer of Mealybug, however to enhance the effectiveness of insecticides, some steps may be taken. Weeds should be eradicated as these provide alternate hosts for CMB. Severely damaged plants should be immediately removed with successive sprays of water and surf at a strong stream to reduce the population. Imidacloprid may be sprayed at earlier stages of infestation and profenofos and chlorpyrifos may be used at later. The insect pests have significant history of resurgence, thus, avoidance of unnecessary use of pesticides is required preserve the natural agro-ecosystem. Chemical control is so far the best remedy to be employed to control cotton Mealybug. Profenofos, chlorpyrifos and imidacloprid were utilized extensively to suppress the population and found effective. Imidacloprid showed low levels of toxicity to natural predators and crop. The review emphasized on the work pertaining to toxic effects of chemical used to destroy cotton Mealybug population. Furthermore, natural enemies of cotton Mealybug may also introduced and utilized to control the pest.

Table 1: Control of Cotton Mealybug *Phenacoccus solenopsis* by Using Different Treatments**.**

Control Measures / Dose Used	Findings	Reported By
Efficacy of Acephate 75% SP, Chlorpyriphos 20% EC, 5% NSKE, Neem oil (2.5 L ha^{-1}) + Nimra powder (0.1%), other biopesticides and biorationals was checked in Laboratory and Field conditions in India.	The insecticides, acephate and chlorpyriphos proved superior over other treatments in causing mortality of mealybug by 72.34 and 68.60% respectively.	Kumar *et al*. [59]
Laboratory and field experiments were carried out to evaluate different insecticides like Commando (97% DF), Lannate (40% SP), Confidor (20% SL), Actara (25 WG) at their recommended doses and neem oil (1.5 and 2.0% concentrations) in Pakistan.	Commando was the most effective and persisted insecticide than the rest of the tested insecticides under laboratory and field conditions with 95.2 and 80.6% mortality of *Phenacoccus solenopsis* respectively.	Mamoon-ur-Rashid *et al.* [54]
Lamdacyhalothrin (Boxer, 2.5 EC), Bifenthrin (Talstar, 10 EC), Profenophos (Craker, 50 EC), Imidacloprid (Crown, 200 SL), (Alarm, 1.8 EC), (Proclaim, 19 EC), Chlorpyriphos (Lorsban, 40 EC), Mathidathion (Supracide, 40 EC), (Advantage, 20 EC), Acetameprid (Rani, 20 EC) were tested in a Laboratory. Bioassay and then in the field.	After 72 hours Profenophos was most effective, followed by Supracide and Talstar (with mortality rates of 68.34%, 65.83% and 48.23%, respectively).	Tanwar *et al.*[33]
The Biological control by *Chrysoperla carnea,* Fierce, profenofos, neemosal Profenofos and neemosal at 0.5%	Chemical control provided best results as compared to others.	Ahmad *et al*. [25]
A field experiment was conducted to evaluate five different insecticides carbosulfan 20EC @1250ml/ha, malathion 57EC @1250ml/ha, prophenophos 50EC @2000ml/ha, Dimethoate 40EC @625ml/ha and Imidacloprid 20SL @625ml/ha against cotton mealybug in Pakistan.	Prophenophos proved to be highly effective in reducing mealybug population with 97% mortality after 7th day of post treatment interval followed by Imidacloprid and Dimethoate with 90.8 and 82% mortality respectively.	Sanghi *et al.* [60]
A study was conducted in Pakistan during 2007 in which different insecticides e.g. Supracide 40 EC (methidathion) @ 1235 ml, Mustang 380 EC @ 2964 and 1976 ml, Lorsban 40 EC (chlorpyrifos) @ 2470 ml, Curacron 50 EC (profenofos) @ 1976 ml, Lannate 40 SP (methomyl) @ 741 g per hectare were tested under field conditions.	Supracide, Lorsban, Curacron and Lannate were proved to be more effective with mortality range of 85.74 to 95.69% and 83.17 to 93.72% during 2007 and 2006, respectively	Aheer *et al.* [61]
Laboratory and field experiments were carried out in Srilanka to check the toxicity of different plant extracts vis. *Ocimum sanctum, Azadirachta indica, Nicotina tabacum, Calotropis gigantea* and *Alium sativum* at different concentrations.	Among the treated botanicals *Ocimum sanctum* was proved to be more effective at lower concentration, 0.6% which was also its $LC_{50.}$	Prishanthini and Vinobaba [62]
Neem oil, garlic extract, tobacco, surfactant, neem seed kernel, Curacron, Ethanol, Alcohal, Isopropyle. Neem oil @1%, 2% Tobacco, Surfactant @ 10%	Curacron and tobacco yielded good results than others.	Khan *et al.* [26]
A study was conducted in India during 2006-2007 to evaluate nine insecticides against cotton mealybug under laboratory and field conditions.	Among the treated insecticides, profenophos gave the highest seed cotton yield of 2759 kg/ha followed by triazophos (2679 kg/ha) and carbaryl (2644 kg/ha). Triazophos gave the highest cost benefit ratio (1: 21: 70)	Nikam *et al.* [63]
Field experiments were conducted on farmer fields in India during 2007-2009 to check out efficacy of carbaryl, chloropyriphos and buprofezin against *Phenacoccus solenopsis* on cotton.	The highly effective insecticide was Buprofezin with more than 95% decline in mealybug population After 3 days of treatment followed by carbaryl and chloropyriphos.	Patel *et al.* [64]
Profenofos, chlorpyrifos (50EC at 0.1% and 20 EC at 0.4%, respectively)	Chlorpyrifos provided better results	Jhala *et al*. [36]
Different insecticides were checked for their effictiveness e.g., spirotetramate 150 OD, spirotetramate (12%) + imidacloprid (36 %) 480 SC, imidacloprid 200 SL, profenophos 50 EC and thiodicarb 75 WP against cotton mealybug on Bt cotton in India.	Spirotetramate (12%) + imidacloprid (36 %) @ 625 ml/ ha was proved to be the most effective combination in reducing the pest infestation. Profenophos alone caused highest decline of 96.5% in mealybug infestation after 10 days of application.	Dhawan *et al.* [65]

Table 2: Biological Control Agents of Cotton Mealybug

Experiment Detail	Findings	Reported By
Worked in different zones of Sindh for surveying Mealybug and effect of ecological factors on its distribution.	A hymenopteran encyritd parasitoid known as *Aenasius bambawalei* Hayat provided natural control.	Sahito *et al*. [34]
Studied prey ability of *Brumus suturalis* (Coleoptera) on *Phenaccocus solenopsis* under both field and laboratory conditions.	High ability of searching cotton Mealybug as prey was observed.	Khuhro *et al*. [39]
Studied the effect of introducing *Cryptolaemus montrouzieri mulsant,* an exotic parasitoid on cotton Mealybug and its biology.	The predator was affected by temperature extremes but it showed efficient control over cotton Mealybug.	Solangi *et al*. [40]
Worked on predatory potential of *Cryptolaemus montrouzieri and Crysoperla carnea* on Mealybug.	Found best for biological control of cotton Mealybug.	Rashid *et al*. [41]
Studied feeding potential of *Cryptolaemus montrouzieri* on cotton Mealybug	It is a voracious feeder and a good biological control agent for cotton Mealybug.	Kaur and Virk [42]
Worked on population dynamics, biology and host range of *Aenasius bambawalei* Hayat at Tando jam.	It was proved as best bio-control agent for Mealybug.	Solangi and Mahmood [43]
Studied cotton Mealybug and its natural enemies.	*Aenasius bambawalei* Hayat and *Promuscidea unfasciativentris Girault* were good for biological control.	Tanwar *et al*. [33]
Worked on biology and feeding behaviour of *Cryptolaemus montrouzieri* on *Phenacoccuc solenopsis* and *Maconellicoccus hirsutus.*	Found that this predator has a wide range of hosts including cotton Mealybug.	Gosalwad *et al.* [44]

Table 3: Botanical Based Insecticides Used Against Mealybug Management

Botanical Extracts	Reported By
Azadirachta indica, Ocimum sanctum, Calotropis gigantea, Nicotina tabacum, Alium sativum	Prishanthini and Vinobaba [45]
Neem oil, Neem seed extract, Tobacco extract and Garlic extract)	Arain [46]
Neem oil 300ppm (0.5ml/l), Lastraw™, (5ml/L) Wood ash (10g/L)	Gowda *et al*.[47]
Tondexir (pepper extract) and palizin (eucalyptus extract) using five doses (500, 1000, 1500, 2000 and 3000 ppm) and sirinol (garlic extract) with five doses (1000, 1500, 2000, 2500 and 3500 ppm).	Ahmadi *et al*. [48]
Lemon, *Citrus limon* L.; Orange, *C. sinensis* L; Peppermint, *Mentha piperita* L. Thyme-leaved savory, *Satureja thymbra* L.; Lavender, *Lavandula angustifolia* Mill Basil, *Ocimum basilicum* L.; Paraffin Oil	Karamaouna, *et al*.[49]
Akk, Dhatura, Eucalyptus and Neem Plants	Lanjar *et al*. [50]
Khuksa (*Ficus hispida*), Chotra (*Lantana sp.*), Chirata (*Swietia chrata*), Neem (*Azadiracta indica*), Bael (Aegle marmelos), Holde-hurhuri (*Cleomp viscosa*) and Marigold (*Targetes erecta*) and seeds of Mahogany (*Swietenia mahagoni*)	Azad *et al*. [51]
Azadirachta indica; Ocimum Sanctu;Parthenium hysterophorus	Naik and Naik [52]
Azadirachta indica, Ocimum sanctum and *Parthenium hysterophorus*	Naik and Naik [53]
neem oil and other insecticides	Suresh, *et al*. [28]
(Neemosal 0.5% EC), homeo-chemical (Fierce), biological control agent (*Chrysoperla carnea*)	Ahmadi *et al*. [48]
Commando (97% DF), Confidor (20% SL), Lannate (40% SP), Actara (25 WG) and neem oil against cotton mealybug, *Phenacoccus solenopsis* Tinsley	Mamoon-ur-Rashid *et al*. [54]
(*Jatropha, Ipomoea* and *Vitex* leaf extracts (at 10% each), neem (*Azadirachta indica*) oil, pungam (*Pongamia glabra* [*P. pinnata*]) oil, madhuca (*Madhuca indica* [*M. longifolia*]) oil (at 0.3 or 3.0% each) and 30% dimethoate)	Saminathan and Jayaraj [55]
Azadirachta indica, Pongamia pinnata, Madhuca longifolia and only leaf extracts of *Lantana camara, Adathoda vasica*	Thinnaluri *et al*. [56]
Peach plant L.(Rosales: Rosaceae);Eucalyptus, L. (Myrtales: Myrtaceae), Ashok, (Magnoliids: Annonaceae), Milk thistle, (Asterales: Asteraceae), and Sow thistle, (Asterales: Asteraceae)	Roonjho, *et al*. [57]
Andrographis leaf extract; Leucas leaf extract; Neem seed kernel extract; vitex leaf extract; fish oil rosin soap; ocimum leaf extract and lawsonia leaf extract at different dose levels	Sathyaseelan and Bhaskaran [58]

Table 4: Damage Potential of Cotton Mealybug *Phenacoccus solenopsis*

Experiment Detail	Damage Potential of Pest	Reported By
A survey conducted during 2007 in Punjab, Pakistan.	Cotton mealy bug resulted in 17% yield loss during 2007.	Anon [71]
A survey was conducted on cotton growing areas of Punjab, Pakistan.	Showed 28.2% area having mealybug infestation	Anonymous [66]
The yield losses in cotton crop of Punjab, Pakistan due to *Phenacoccus solenopsis* were estimated.	Found to be almost 12% yield loss in 2006 and 40% in 2007.	Kakakhel [67]
Host Plants Distribution and Overwintering of Cotton Mealybug (*Phenacoccus Solenopsis*; Hemiptera: Pseudococcidae)	Cotton mealy bug caused 96.4% mean infestation of host plant *Hibiscus rosa-sinensis* observed in the survey of 2005-2008	Abbas *et al*. [70]
Recent outbreak of cotton mealybug in Pakistan	Resulted in 14% loss of cotton crop during 2005.	Sahito *et al*. [68]
A study conducted in Pakistan reported damage of cotton caused by cotton meatybug.	Extensive damage by *Phenacoccus solenopsis* showed cotton yield to fall below the previous three year average by almost 20% during 2007-2008.	Naqvi & Nausheen [69]
Host Plants Distribution and Overwintering of Cotton Mealybug (*Phenacoccus Solenopsis*; Hemiptera: Pseudococcidae)	44.8 % mean infestation of *Nicotiana tabacum* by *Phenacoccus Solenopsis* was observed in the survey of 2005-2008	Abbas *et al*. [70]
A study conducted in Pakistan during 2006.	Damage caused by cotton mealybug has ruined 3.1 million bales during 2006.	Anon [71]
A survey over 47 locations in nine cotton growing states of India was conducted.	Cotton mealybug *Phenacoccus Solenopsis* was found to comprise 95% of the samples examined.	Nagrare *et al.* [72]
A study was conducted during 2007 in north India.	At the end of Kharif season (June-October), the total damage was pridicted to range from US$400,000 to 500,000.	Goswami [73]

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