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Host plant-mealybug (*Phenacoccus solenopsis*) interaction: A review

Muhammad Rafiq Shahid[1*], Farrukh Ilahi[2], Tatheer e Zahra[3], Hafiz Saeed Ur Rehman[4], Muhammad Mubashir Qureshi[5], Sadia Kanwal[1], Naveeda Anjum[6], Khalida Hamid Abbasi[6] and Muhammad Aqeel Feroze[6]

[1]Cotton Research Institute, Multan, Pakistan
[2]Cotton Research Station Faisalabad, Pakistan
[3]Baha Ud Din Zakria University, Multan, Pakistan
[4]Soil and Water Testing Laboratory, Bahawalpur, Pakistan
[5]Soil and water testing Laboratory, Multan, Pakistan
[6] Barani Agricultural Research Institute (BARI), Chakwal, Pakistan

*****Corresponding author: Muhammad Rafiq Shahid (shahid1364@yahoo.com)

Abstract

One of the most significant insect pests of cotton is the cotton mealybug, technically known as *Phenacoccus solenopsis*. Up to 14% of Pakistan's economy was thought to have suffered in 2005 as a result of cotton mealybug. It is now believed to be widespread around the globe, although during the months of September and October when temperatures are mild, its population increases. It feeds in a polyphagous manner. The environmental factors and CMB's predilection for particular host plant species determine its biological properties. Under conditions of severe CMB infestation, the attacked plants show signs of leaf defoliation and seem to have been sprayed with a defoliant. The majority of farmers now use pesticides to maintain their crops. Integrated Pest Management is the most suitable option and host plant resistance is the basic component for the management of insect pests. It is a safe way to manage mealybug without the harmful effect of pesticides on the environment and non-targeted beneficial fauna. Plants protect themselves from insect pest herbivory due to host plant resistance mechanisms. This invasive species has the ability to grow farther and can increase its host range due to the variety of hosts it can find under various climatic conditions. In this work, the relationship between plants and mealybugs has been described in detail.

Keywords: Benefits of host plant resistance (HPR), Cotton mealybug, Limitations of chemical control, Mode of damage, Polyphagous, *P. solenopsis*

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Introduction

Commercial impact of *P. solenopsis*

The level of biotic and abiotic stressors in Pakistan and, eventually, cotton production is related. About 8.2% of cotton is added value in the agricultural sector, and cotton accounts for 2% of the nation's GDP. In Pakistan, the cotton mealybug caused a drop of 1.3 million bales, resulting in very large economic losses (Hameed et al., 2012).

Geographical distribution of *P. solenopsis*

Due to its discovery in the Galapagos Islands in 2001 (Causton et al., 2006) and in Argentina, including Cuba, Ecuador, and Mexico, in 2003, P. solenopsis has historically been found all over the world (Williams & Willink, 1992). This invasive species has the potential to spread further and can grow, as evidenced by its occurrences in a rice field (Granara, 2003), during 2002 in Brazil (Muniappan, 2009) and from Chile during 2007, from Ghana (Muniappan, 2009), during 2008 from China (Muniappan, 2009), from Colombia (Granara et al., 2007), during 2005 from Pakistan (Arif et al., 2007).

Population dynamics of *P. solenopsis*

Scale insect epidemics were observed in all cotton growing areas of Sindh and all cotton growing areas of Punjab (Sahito et al., 2011). Cotton scale insects were abundant during the Brazilian cotton season in the semi-arid cotton growing areas of Bahia, Agrette, and Paraiba, according to Silva (2012). Arif et al. (2009) investigated the cotton cultivation area in the southern part of Punjab and observed cotton scale insect host plants. There have been 154 plant species discovered, including a wide variety of fruits, vegetables, decorative plants, weeds, and crops. Sunflowers, tubular roses, cotton, eggplant, okra, tomatoes, sesame seeds, and all of these produce lose money. Abbas et al. (2010) reported a method for bringing the host plant to the laboratory and confirming the relationship between the host and the pest if the invasion in the field could not be confirmed. Under ideal laboratory conditions, adult female cotton scale insects should be bred on the target host plant. If the pest completes its life cycle and produces a crawler sac in the host plant, the host plant should be documented as the pest scale insect's host. If a young plant does not mature or reproduce, it should be designated as a non-host plant. *P. solenopsis* (Tinsley) population dynamics were higher in cotton (*Gossypium hirsutum* L.) and okra (*Abelmoschus esculentus* L.) in India in October. In February, they discovered mealybugs in tomatoes (*Lycopersicon esculentum* L.) and potatoes (*Solanum tuberosum* L.). Scale insect populations correlated positively with high temperatures but negatively with low temperatures and humidity.

Polyphagous feeding and Invasiveness nature

Phenacoccus solenopsis can multiply on various host plants. It was first observed on vail weeds in the United States. It was found on Brazilian tomatoes (Culik and Gullan, 2005), Pakistani cotton, and Indian cotton (Charleston et al., 2010), *Hibiscus rosasinensis* (Moghaddam and Bagheri 2010) in Australia, Nigeria, Iran, and Africa, Thai vegetables (Bambawale, 2008). Deshpande (2009) recorded that *P. solenopsis* introduction in Asia might be as a result of an illegal introduction of Bt cotton by a progressive grower in the United States (Deshpande, 2009). This exotic pest species is introduced through plant material (Jansen, 2004) trade (Tanwar et al., 2007) through international ports and greenhouses outside the range of native species due to the promotion of international trade around the world (Nagrare et al., 2009). Other factors contributing to *P. solenopsis*'s invasiveness include its polyphagous feeding style, reproductive rate, potential to acclimate to different climates, and body covered in mealy powder and wax, which inhibits pesticides from reaching the target location and facilitates simple spread (Hodgson et al., 2008).

Nature of damage of *Phenacoccus solenopsis*

Cotton plants infested by mealybug insects remain stunted, with small-sized bolls, yellow leaves that eventually fall from plants (Mark and Gullan, 2005). *P. solenopsis*, was reported on both Bt and non-Bt varieties (Dutt 2007). Highly damaged plants appear to have been sprayed by defoliants (Arif et al., 2007). The protein and sugar content of mealybug-infested leaves is significantly higher than that of normal leaves. Jagadish et al. (2009) also described the decrease in phenol levels in sunflower plants following cotton mealybug infestation.

Life history parameters

Female CMBs have an ovoviviparous reproductive pattern composed of wax stranded ovisac. Under laboratory conditions maintained at (23 to 30 ° C and 49 to 92 percent relative humidity), the first, second, and third instar periods were 3.9, 5.1, and 4.2 days, respectively. Male and female mealybugs lived 1.5 and 42.4 days, respectively, with a breeding period of 30.2 days (Vennila et al., 2010). According to Hanchinal et al. (2010), *P. solenopsis* spawning usually lasts for 9-12 days. According to Joshi et al. (2010) depending upon the climatic conditions *Phenacoccus solenopsis* has an average life cycle of 25 to 38 days.

They also found that male of *P. solenopsis* due to extra pupal stage had a longer developmental period than females. It was explained that female of *P. solenopsis* can produce 128-812 crawlers and complete 15 generations per year (Vinnila et al., 2010). *P. solenopsis* first-age crawlers are dispersed and settle primarily on cotton buds' leaves, petioles, stems, and bracts (Ben-Dov, 2010). After moulting at the third instar in females and the fourth instar in males, larvae mature into adults (Miller, 2005).

Host plants of cotton mealybug in Pakistan

P. solenopsis has a diverse range of host plants due to its polyphagous feeding habits. The ICAC Recorder (2008) categorized 22; Hodgson et al. 2008 recorded 55 alternate hosts in 18 families, Arif et al. (2009) reported 154 host plants from Pakistan.

Fig. 1 depicts the spread of *P. solenopsis* amongst alternative host plants. In Fig. 1 infestation of cotton mealybug has been shown on different host plants belonging to the family Solanaceae. Susceptible host plants included *melongena, Lycopersicon esculentum, Cestrum diarrhoea, Solanum nigrum, Withania somnifera, and Capsicum annum* (Fig. 1). Plants belonging to the family Malvaceae affected by cotton mealybug have been shown in Fig. 2. Most susceptible host plants are *Abelmoschus esculentus, Gossypium hirsutum, Hibiscus rosasinensis,* and Abutilon indicum (Fig. 2). In Fig. 3 various host plants affected by cotton mealybug belonging to the family Asteraceae have been shown but the most susceptible ones are *Helianthus annuus, Silver ragwort, Parthenium hysterophorus* and *Xanthium strumarium.* families. In Fig. 4 susceptible host plant of cotton mealybug was *Euphorbia prostrate* and Tribulus terrestris was from the Zygophyllaceae family. All of these plants are the primary hosts of cotton mealybug. Fig. 1 depicts the distribution and population of cotton mealybug insects on various host plants.

Alternative host plants of cotton mealybug

List of host plants belonging to different families are shown in the Fig. 1 given below:

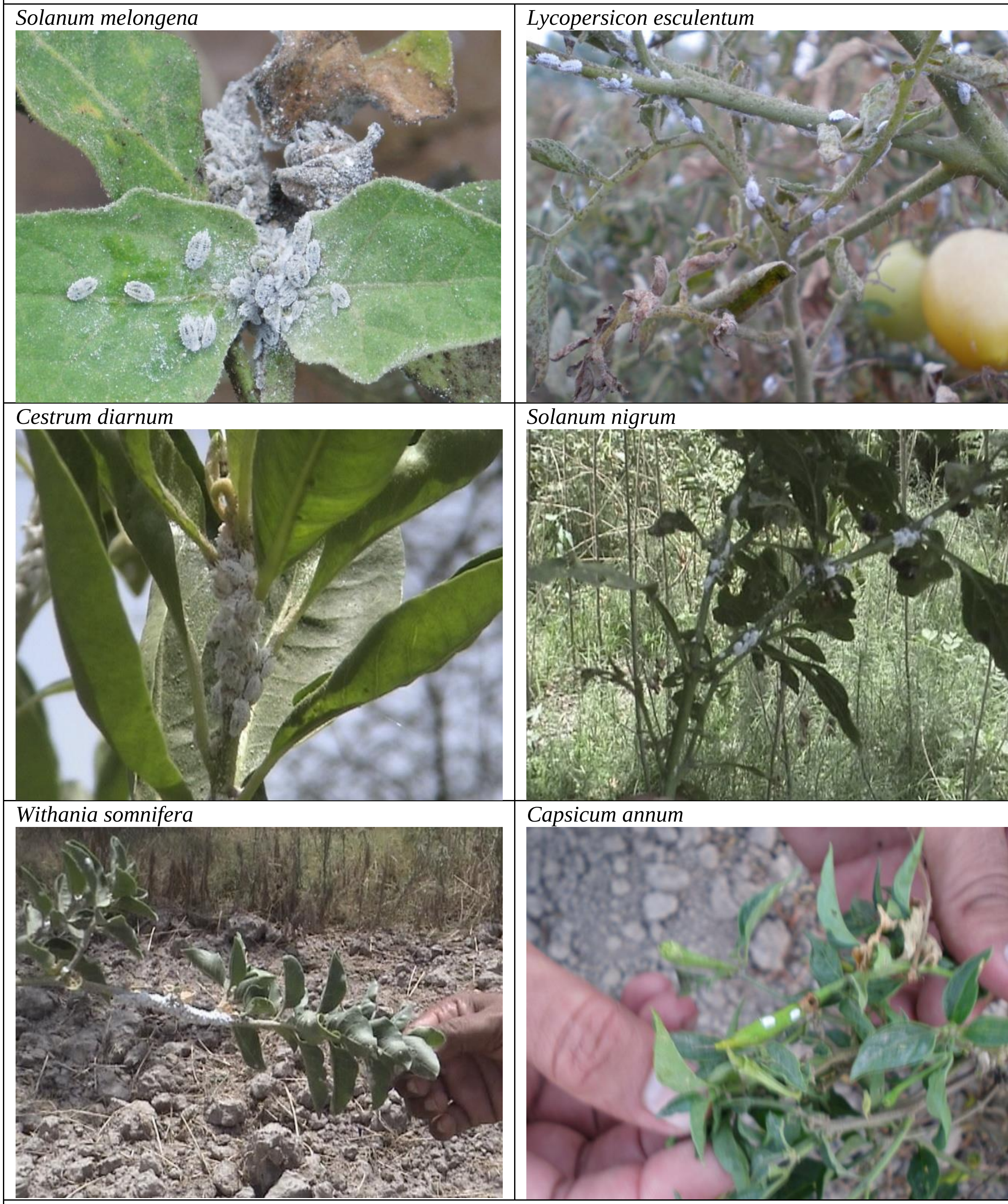


Fig. 1 Infestation of cotton mealybug on different host plants belonging to family Solanaceae

Abelmoschus esculentus

Gossypium hirsutum

Hibiscus rosasinensis

Abutilon indicum

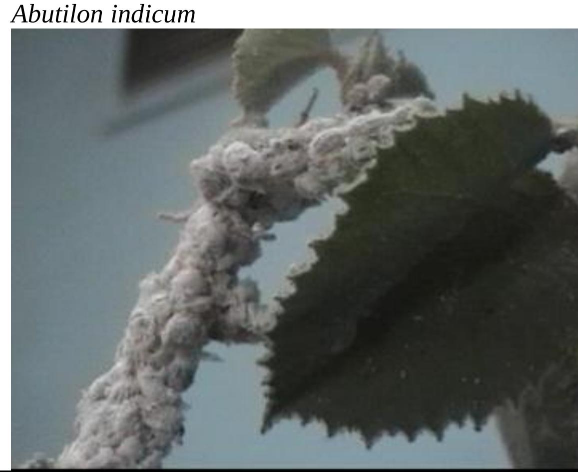


Fig. 2 Infestation of Cotton mealybug on different host plants belonging to family Malvaceae

Helianthus annus

Silver ragwort

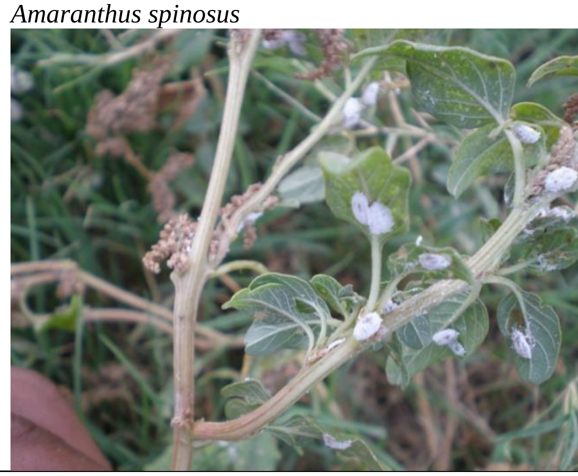
Parthenium hysterophorus

Xanthium strumarium

Fig. 3 Infestation of cotton mealybug on different host plants belonging to family Asteraceae

Chenopodium album

Amaranthus spinosus



Chenopodium morale

Trianthema portulastrum

Fig. 4 Infestation of cotton mealybug on different host plants belonging to family Chenopodiaceae

Limitation and harmful effect of chemical use against *P. solenopsis*

The effectiveness of chemical control is not up to the mark due to wax body coated of cotton mealybug and thus insecticide faces difficulties in approaching the target site. Contrarily, repeated use of conventional pesticides harms the environment and natural enemies, leads to pesticide resistance in the targeted arthropods, has hazardous effects on unintended animals, and renders produce unfit for human consumption (Walton et al., 2006).

Importance of host plant resistance

The use of host plant resistance is an important method to manage economic cotton mealybug insects while avoiding the harmful effects of pesticides. Resistant plants defend themselves against pest herbivores by developing a resistance mechanism. Plant resistance is founded on biophysical and biochemical properties (Bernays and Chapman, 1994). Several glandular and non-glandular trichomes cover the plant's surface. Non-glandular trichomes prevent feeding and oviposition, and glandular trichomes, in particular, expel volatile exudates that repel insects and drive them away from the plant's surface and alters the behaviour of herbivorous insects in this way due to the antixenosis mechanism of plant resistance (Mierziak et al., 2014). Sap of plants contains a variety of nutritive and non- nutritive contents that not only affect plant activity and development, but can also change the quality of food sources for harmful insects (Goncalves-Alvim et al., 2004). Similar to how oxygen supports the production of chloroplasts and protein molecules, nitrogen also encourages the accumulation of chlorophyll in plants, making them more succulent (Amaliotis et al., 2004). Sucking harmful insects are frequently drawn to tender plants with more chlorophyll (Slocombe et al., 2008). Because of the pest's quantitative and qualitative dietary requirements for food, the chemistry of vegetative plants also plays an important role in pest feeding suitability (Liu et al., 2004). It also has an impact on insect performance. Structure and composition of the host plant specifically toughness, nutrient and secondary metabolites are the major of source of host plant resistance. Young leaves due to softness and more nitrogen are more nutritious than mature leaves (Coley and Barone, 1996). This change is positively associated with leaf turgidity and softness (Kursar and Coley, 2003). If the leaves are soft, rapid swelling shortens the window of fragility, but rapid swelling requires high concentrations of nitrogen associated with the growth process (Kursar and Coley, 1992). Furthermore, due to its rapid expansion, resources are involved in everything from defence to growth. As a result, the high nitrogen content and low chemical defence effect can explain the high incidence of herbivores in fast expanders (Coley et al. 2005). Decisions about oviposition and insect nutrition depend heavily on these plant traits (Shahid et al., 2012). Demand for host plant resistance is growing in practical applications (Mierziak et al., 2014).

Mechanisms of host plant resistance

In an integrated pest management approach, understanding the mechanism of host plant resistance is extremely beneficial. There are three types of resistance mechanisms. In other words, antixenosis, antibiosis, and tolerance mechanisms. All these mechanisms alter insect feeding and fecundity behaviour, as well as their growth, survival, reproduction, and life history parameters of the target insect pest (Cook and Smith, 1988). When tested against various pests, different genotypes have distinct resistance mechanisms. Some of them might be immune to antixenosis, antibiotics, herbivorous pests, or any combination of these.

Food preference

Herbivorous pests' chemoreceptive behaviour is primarily responsible for host plant selection (Jeremy and Szentesi, 2003). This includes the stages of host, host recognition, host acceptance, and host adaptation. Such plant traits allow insect pests to distinguish between host plants that are favourable or unfavourable for harmful insects, as well as their spawning preferences, due to the availability of sensory organs in their bodies (Anderson et al., 1989). Herbivorous pests reject or accept food sources based on physical and chemical properties of the plant (Renwick, 2002).

Morphological characteristics are classified as physical or epiphylactic factors, while chemical characteristics are classified as internal protection studies or endophylactic / biochemical factors (Stadler, 2000). Color, shape, size, cell wall thickness, hardness, trichomes, mineral content accumulation in cuticles (such as silicon), and surface waxes are all epiphylactic factors (Hirota and Kato, 2001). They further reported that crop stage alters the physiological and behavioural reactions of arthropods to plants and has a considerable impact on plant resistance to insects. Endophylaxis is the production of phenols, tannins, and secondary metabolites, which are volatile forms of a plant's glandular exudates and serve to repel hazardous organisms or render food unsuitable for insects' nutritional needs (Goncalves-Alvim et al., 2004). Epiphylaxis factors influence insect pest feeding and oviposition. Endophylaxis factors influence the herbivorous insect pest's biological or life history parameters (Dhaliwal and Arora, 2003). A same plant or group of plant traits in any host can provide resistance to many insect pests. Trichomes conferred avoidance to Maruca testulalis, Clavigralla tomentosicollis, as well as to Callosobruchus maculatus in vigna crop (Oghiakhe, 1997). Likewise, a same plant can confer avoidance towards one or to a group of harmful insects. Genotypes can provide resistance to the weevil, pink bollworm, and various other insect pests of cotton (Ahmad et al., 1987). Descamps and Chopa (2011) reported that barley is the preferred food of Rhopalosiphum padi, and barley pests have a higher inherent natural growth rate (0.309 female^{-1}d^{-1}) than all other grains. The mortality rate was low (22.2%), and the doubling time was short (2.24). Therefore, the study of how plants and insects interact focuses on the biochemicals, proteins, and physical traits that have developed in the processes of host plant resistance (Schoonhoven et al. 2005).

Antixenosis mechanism

Feeding, protection, spawning and colonisation of harmful pests are all recognized as non-priority mechanisms of resistance (Dhaliwal and Alora., 2003). By providing this mechanism, insects exhibit evasive behaviour from that specific plant, rendering it ineffective or of poor quality against insect invasion (Schoonhoven et al., 1998). Due to its resistant antixenosis mechanism, the spawning of Ceratapion basicorne was comparatively higher in its preferred plant species than among non-preferred species (Smith, 2012). Plant morphological and biochemical properties also play an important role in the tolerance mechanism. The leaves' epicuticular wax content served as a mechanical hindrance for many harmful insects including Phyllotreta spp., Eurydema ventrale, and Thrips tabaci (Znidarcic et al. 2008). The provision of a specific aromon, a lack of some chiromon, or an imbalance between aromon and chiromon also improves plant resistance to pests (Panda and Khush, 1995). There are different levels of pest resistance among plant species, which have a plant resistance mechanism (Rangasamy et al., 2006). The number of rhizomes and turf density rose as the turfgrass established a resistance mechanism through the alteration of plant proteins and oxidases. Along with nutritional impacts, plant characteristics also affect pest performance (Schoonhoven et al., 2005). Injurious sucking insects are very selective feeders who pick their feeding host plants based on mechanical, chemical, and visual cues (Bernays 1998). Plant preference or rejection by pests is determined by the composition of volatile chemicals released from the plant, plant wax, cell wall, and phloem content, and other factors (Caillaud and Via2000). Chemical texture and structure vary depending on plant type and its organ of the same plant (Schoonhoven et al., 2005).

Antibiotic mechanism

Herbivorous pests' physiological function is harmed by the antibiotic resistance mechanism (Felkl et al., 2005). Insect consumption of plants can cause symptoms of a variety of antibiotics, ranging from acute or lethal to subchronic or mild. Early death at youngone stage, irregular growth rate, size, and weight loss are the most common insect pest symptoms. Larva or nymph, larval extension Period, pupation failure, failure of adult emergence from pupae, inability to concentrate on food stock, subsequent diapause failure, abnormal adults, decreased fertility, decreased childbirth, restlessness and abnormal behaviour, sucking Pests' honeydew secretion has been reduced (Pedigo, 1996). Herbivorous pests' physiological function is harmed by the antibiotic resistance mechanism (Felkl et al., 2005). Consumption of plants by insects can result in a range of antibiotic-related symptoms, from acute or fatal to subchronic or moderate.

The most typical insect pest signs include early death of young, abnormal growth rate, size, and weight loss. larval extension, nymph, or both Period, pupation failure, adult emergence failure, inability to focus on food supply, failure of the ensuing diapause, abnormal adults, decreased fertility, decreased childbirth, restlessness and abnormal behaviour, and a decrease in the amount of honeydew secreted by pests when they are sucking (Pedigo, 1996).The physiological status of the pest, such as age, feeding status, mating status, and egg mass, influences the specificity and motivation for spawning of the host plant (Jallow and Zalucki, 1998).

The presence of gossypol glands and phenolic compounds that are resistant to some cotton pests is a well-known example (Dhaliwal et al., 1993). These individuals. It is possible that the plant's body shape characteristics provide resistance against harmful pests or affect their metabolic activity (Hirota and Kato, 2001; Goncalves). Pest activity is influenced by nutritional changes (Chau et al. 2005). Chemicals both inorganic, primary and intermediate and secondary substances, are also known to avoid a wide range of harmful organisms (Stadler, 2000). (Goncalves-Alvim et al., 2004). Dhaliwal and Arora, 2003 are examples). There are various volatile and non-volatile compounds on the surface of plant parts that produce specific stimuli (Baur et al., 1996). These stimuli are perceived by the insect via its sensory organs and mediate the insect's behaviour from host recognition to host acceptance (Goncalves-Alvim et al., 2004). According to Shahid et al. (2016), biochemical content is important in host plant resistance to scale insects.

Inorganic primary, intermediate and secondary metabolites (Dhaliwal and Arora, 2003) are examples of these compounds, which are classified as nutrients and allelochemicals. Secondary metabolites are allelochemicals that do not take part in vital photosynthesis as well as other metabolic activities of plant development, and reproduction of living things. These are organic contents that are frequently created as byproducts of the primary metabolic pathway. As a result of synergistic interactions. Herbivorous pests choose between volatile and non-volatile compounds when deciding which plant to feed on. Tannins and phenols, which are classified as secondary metabolites affect insect relation with plants (Schoonhoven et al., 1998), and their working against feeding pests varies (Wang et al., 2009). Although dietary contents were previously considered to have little effect on plant resistance as they were thought to be used for plant growth and development, nutrients are now important in the process of selecting host plants for insects. It has been acknowledged to play an important role (Jansen, 2004). Insect damage to plants may be related to nutrients rather than secondary metabolites (Chapman, 2001). (Louda and Mole, 1991). Secondary metabolites, collectively known as anti-herbivorous compounds, are vital for recognising suitable sites for offspring (Karban et al., 1997) and for the feeding behaviour of specialised insects for major insect susceptibility to nutrients (Renwick et al., 2001; Stadler et al., 1995).

Previously, dietary nutrients were considered to have minimal effect on host plant resistance as they were thought to be used for plant growth and development; however, nutrients used in the process of selecting an insect host plant grew in significance. Recognized to play a significant role (recognised to play a significant role) (Jansen, 2004). Plant insect damage is linked to nutrients rather than secondary plant metabolites. Secondary plant substances / metabolites collectively known as anti-herbivorous compounds, to recognise suitable locations for offspring (Karban et al., 1997) and special insect feeding behaviours to the susceptibility of major insects to nutrients (Du. et al., 1995) and secondary metabolites consist of Terpenoids, phenolic compounds, flavonoids, and their glucosides, alkaloids, methyl ketones, salicylic acid all differ among plant species (Goncalves-Alvim et al., 2004).

In most cases, insect pest attacks result in the production of phenols in plants (Somssich et al. 1996). According to Bi et al. (1997), damage to cotton leaves (Gossypium hirsutum L.) increased oxidase activity. They also stated that there is a link between oxidases and phenolic peroxides and lipid peroxides. Tannins are found in higher concentrations in woody than in herbaceous plants. They are a common feeding deterrent, so they are important in plant ecology and insect protection. Plant flavonoids influence insect behaviour, development, and growth. Gossypol is an allelochemical (sesquiterpenoid phenol aldehyde) that reduces herbivore digestibility through cotton's plant-resistant antibiotic mechanism (Syed et al., 2003). Antibiotic or non-preferential behaviour has been observed in pest species groups (Syed et al. 2003; Leghari et al., 2001). P. invasive mealybug insect Tomatoes (Solanum lycopersicun), Hibiscus rosa-sinensis, and cotton were all affected by solenopsis at all stages (Gossypium sp.). The weight of scale insects varies greatly depending on their developmental stage of *P. solenopsis* on lycopersicum excreted significantly more honeydew than H. rosa-sinensis and G. hirsutum (Zhou et al., 2013).

Tolerance system

Tolerance is the host plant's ability to recover/withstand herbivorous pest damage as a result of it there is compensation in produce yield and quality (Ierusalimov, 1998; Tiffin, 2000). Many physical and biochemical changes occur when the host plant tissue is physically damaged. Plants possess defensive ability inbuilt naturally. Stotz et al. (2000) reported that after physical injury, phenols accumulate in the epidermis and phloem of the stem. This means that the production of physiological factors, as well as plant resistance, increases the number of physical barriers and biochemical defences especially phenols and terpenoids against arthropod attacks (Frankenstein et al., 2006).

Resistance is unlikely to provide high levels of resistance but may be beneficial when combined with other resistance mechanisms (Stowe et al., 2000). Plants undergo compensatory growth and repair in response to pest attacks, as well as restoration of biochemical contents that are resistant to insect invasion by providing various types of compensatory processes/ mechanisms (Gogi et al., 2010). Sarmah et al. (2011), reported that the nitrogen and crude protein content of the leaves had a significant impact on the weight of larvae and cocoons. Infected plants undergo morphological and wax deposit changes as a result of herbivorous arthropod attacks, including changes in the leaf area, total leaves, leaf dry weight, photosynthetic activity, chlorophyll content, starch, water uptake effect, protein level, and wax accumulation. Physiological changes (Hopkins and Huner, 2004). Barrier), proline accumulation, oxidation, and lipid peroxidase activity (Hussain et al., 2014), macronutrient and micronutrient intake.

Total biomass, reducing sugars, non-reducing sugars, proteins, ash, and nitrogen contents were positively correlated with the spread of mealy bugs, but crude fibre, fibre fraction, lipids, silica content, waxes, calcium level, phenolic compounds, tannin quantity and flavonoids were correlated negatively (Eid et al., 2011). Cotton mealybug invasion increased the contents of lignin, cellulose, and hemicellulose, as well as the protective biochemicals in cotton. The enzymes polyphenol oxidase, and peroxidase increased after feeding the scale insects (Shafique et al., 2014). All of these differences in endemic plants result in plant resistance mechanisms. The first *P. solenopsis* epidemic had no effect on chlorophyll content or light utilisation efficiency, which could be attributed to tolerance (Huang et al., 2013).

Plant resistance towards biological parameters of Phenacoccus solenopsis

Food and spawning preferences of *P. solenopsis* were influenced by host plants, because duration of 1st, 2nd, and 3rd instar nymphs, as well as the lifespan of its females differ between host plant species. There are a lot of studies that plant influenced the biological parameters of *P. solenospsis* (Mamoon-ul-Rasheed et al., 2012; Abro and Sahito 2012).
Rose, Jatropha, mango, and *Bougainvillea spp* showed resistance to Cotton Mealy Bug. The mortality rate of the first instar ranked the highest (70-90%) and the fertility of CMB was reduced to (100-200 eggs) on *R. indica*, the lifespan of *P. solenopsis* on discussed plants were also extended by 20-23 days compared with susceptible plants i.e., cotton, shoe flowers, and silvery plants (Sana-Ullah et al., 2011; Zhou et al., 2013).

Conclusion

Instead of chemical control, use of host plant resistance is a safe way to manage mealybug. The safest method of managing mealybug is to use host plant resistance. It has no harmful effects on the environment or unintended beneficial wildlife. *P. solenopsis* being an invasive species has the ability to grow farther and can increase its host range due to the variety of hosts it can find under various climatic conditions. In this work, the interaction between plants and mealybugs has been thoroughly discussed. This information would be very helpful for the appropriate and comprehensive management of *P. solenopsis* on economically viable crops in the future.

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