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Review

A Review on White Mango Scale Biology, Ecology, Distribution and Management

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Abstract: The white mango scale (WMS) insect, *Aulacaspis tubercularis* (Hemiptera: Diaspididae), is a polyphagous, multivoltine pest which is a serious threat to qualitative mango production and export. The WMS insect sucks sap from leaves, branches and fruits. The heavy infestation of this pest may cause the falling of young leaves, drying up of twigs, poor flowering, and, finally, reduce the quality of fruits by producing pink spots on fruits' surface. This review paper was written to provide comprehensive information about pest biology, ecology and management in different parts of the world. WMS was first reported on the island of Formosa on *Mangifera indica* in 1929 and later on in the Caribbean Islands, India and Brazil. Now it is found in almost 69 mango-producing countries of the world. The thermal regime may affect the population of pests. In Australia, the life cycle is completed in 35–40 days in summer and 70–85 days in winter. Variety, age of plants, number of trees per acre, canopy size and sunlight penetration affect the density of WMS. Different *Coccinellid* beetles and parasitoid *Encarsia femorosa* feed on WMS; however, farmers most commonly use insecticides to get rid of this pest. In Pakistan, WMS is a growing threat to the export of mangoes; hence IPM plan is needed to reduce the pest numbers and enhance qualitative mango production.

Keywords: *Aulacaspis tubercularis*; environmental variables; damage; cultural control; chemical control and biological control

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1. Introduction

Mango (*Mangifera indica* Linn. Family: Anacardiace), the so-called "King of fruits", is an important fruit crop throughout the world, including Pakistan. Mango fruits are popular because they are delicious and rich in vitamins A and C. Good flavor and taste add further value to this fruit. In recent years, mango production has been decreased by multiple factors, viz., nutrients deficiency, flood, drought, thermal regimes, improper management practices (ploughing and intercropping) [1,2], and biotic factors (insect pests and diseases) [3,4]. The most prevalent insect pests in Pakistan are scales (*Aulacaspis tubercularis* (Newstead)), mango hopper (*Idioscopus clypealis* (Lethierry)), midges (*Dasineura amaramanjarae* (Grover)), mealybug (*Droschia mangiferae*), fruit fly (*Bacrtrocera dorsalis* (Hendel) and *Bactrocera zonata* (Saunders)), thrips (*Scirtothrips dorsalis* (Hood)), and bark beetle (*Hypocryphalus mangiferae* (Stebbing)) [5,6].

In recent years, white mango scale (*Aulacaspis tubercularis* Newstead; Diaspididae; Hemiptera) has increased to the extent that it is now regarded as an important economically destructive and potential export risk in different parts of the world [7,8] including south-east Asia. This pest was first reported on the island of Formosa on *Mangifera indica* in 1929, and later on in the Caribbean Islands (2012), India and Brazil (2021) [9]. *A. tubercularis* originated from Asia [9] and later on it was observed in South Africa [10,11], Australia, East and West Africa, North and South America and the Caribbean Islands [12]. Now it is found in almost 69 mango-producing countries of the world, and being polyphagous in nature, this pest attacks several crops. The damage of the pest is always variable depending upon the climate and mango variety. This sucking insect pest can be observed on different parts of mango plants, including shoots, twigs, leaves, branches and fruits (Figure 1).

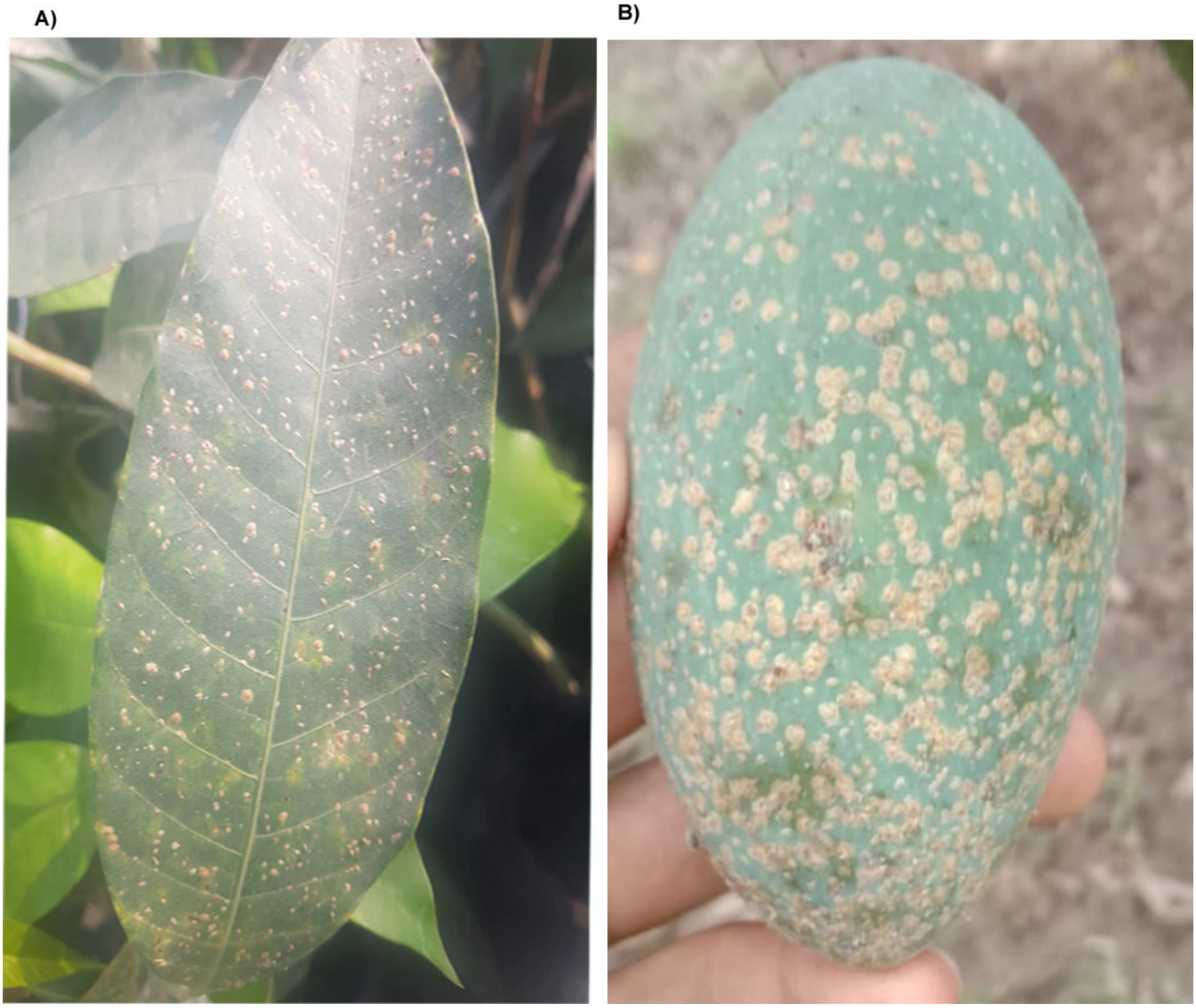

Figure 1. White mango scale insect on leaves and fruit in farmer orchards in Pakistan. (**A**) WMS population on leaves. (**B**) WMS population on fruit.

Its severe infestation may result in poor blossoming or effecting commercial value of mango fruits particularly in late varieties. In the South Pacific region, strict quarantine procedures are implemented to reduce WMS spread, being a serious pest on mangoes [13]. In Pakistan, WMS infestation has been observed on almost all varieties of mango specially the late mango varieties, i.e., Sufaid Chaunsa (a leading exportable variety of Pakistan). It is an extreme need to develop an integrated pest management plan based on pest ecology and biology to reduce its infestation in farmer fields in Pakistan.

2. Occurrence

WMS (*A. tubercularis*) had been considered a native to the Asian continent; however, later on, it was distributed in other mango-producing countries through infested plant material [14]. WMS infestation has been reported in more than 60 mango-growing countries, including Africa, Asia, Oceania, South and Central America, parts of Europe and the 80 Caribbean islands (Table 1) [15].

In Mexico, this pest was first detected in 1999 on 300 acres, and later on, due to extensive damage caused by the pest, it has been regarded as the second most important mango pest after fruit flies (*Anastrepha* sp.; Diptera: Tephritidae) [16]. Morsi et al. [17] observed WMS in Minia (Egypt); later on, the pest was observed in all mango-growing areas of Egypt. In Ethiopia, WMS infestation was first reported in 2010 [18]. Late on, it became a serious threat to mango productivity in western Ethiopia [19,20]. In Spain and Andalusia, WMS caused extensive damage to mango production during 2010 (Málaga and Granada provinces) [21].

In 1947, WMS was observed in South Africa on a few mango cultivars; later on, the pest was also observed feeding on avocados in South Africa [22]. WMS moved from South Asia to Ethiopia through the import of mango seedlings in 2010 [18] and further dispersed 100 km west of the original site within a year in the same way [19]. Global dispersal of this devastating insect pest was observed through the movement of infested material.

North Atlantic Plant Protection Organization (NAPPO) [23] considered this as an important pest and put it on the alert list, but European countries, EPPO, although considering it as an important pest, did not place it on the threat list [21]. WMS is considered an important pest in the Mediterranean basin, and strict quarantine measures are implemented to restrict its dispersal.

Table 1. Geographical dispersal of white mango scale insects in different countries of the world.

Region	Country	State (Sub-National Level)	Infesting Plant Parts	References
Asia	India	Bihar, Andaman and Nicobar Islands, Andhra Pardesh, Himachal Pardesh, Karnatka, Kerala, UP, Gujrat, Haryana, Sikkim, tamil Nadu, West Bengal,	Mango Fruits, leaves and branches	Kansci et al. [24]; García et al. [15]; CABI [25]; EPPO (online); Bragard et al. [26]
	Pakistan	Punjab and Sindh	Mango Fruits, leaves and branches	Mohyuddin and Mahmood [5]; CABI [25]
	China	Guangdong, Hainan, Sichuan, Hong Kong, (Xianggang)	Mango Fruits, leaves and branches	EPPO (online); Bragard et al. [26]
	Malaysia	West Peninsular Malaysia, Sabah, Sarawak, Malaya	Mango Fruits, leaves and branches	EPPO (online); Bragard et al. [26]; CABI [25]
	Indonesia, Nepal	Java, Borneo	Mango Fruits, leaves and branches	EPPO (online); Bragard et al. [26]; CABI [25]
	Philippines, Sri Lanka, Taiwan, Thailand, Japan, Iraq,	Further details on sub-national level regarding pest occurrence in these countries are not available	Although reported but no further details are available	EPPO (online); Bragard et al. [26]; CABI [25]
	Russia	Further details on sub-national level regarding pest occurrence in these countries are not available	Not reported on mangoes, reported on other crops	Borchsenius [27]
Middle East	Egypt	Sharkia Governorate, Qaliobiya Governorate, Qualubia,	Mango fruits, leaves and canopy	El-Metwally et al. [28]; Nabil et al. [29]
	Israel	Reported but no further details regarding pest colonization in different states are available	Present, but no further details regarding host crop are available	EPPO (online) Bragard et al. [26];
Western Africa	Western Ethiopia	All parts of country	Mango canopy, leaves and fruits	Ofgaa et al. [30]; Fita [19];
	Ghana, Benin, Cote d Ivoire, Gambia, Liberia, Malawi, Mauritius, Reunion, Seychelles, Sierra, Leone, Togo, Zambia	No further details regarding subnational level are available	Although reported to be present in these countries, no further details are available regarding host crops, etc.	Bragard et al. [26]; EPPO (online)

Table 1. *Cont.*

Region	Country	State (Sub-National Level)	Infesting Plant Parts	References
East Africa	Ethiopia	Central Rift valley	Mangoes all parts of plants	Bragard et al. [26], Ayalew et al. [31], Annecke [32]
	Kenya	Murang, Taveta	Mango plant parts	Bragard et al. [26]; Otieno [33]
	Mozambique	Mazoe	Mango plant parts	Bragard et al. [26]; Ayalew et al. [31], Annecke [32]; Otieno [33]
	Tanzania	No further details regarding subnational level are available	Mango plant parts	Bragard et al. [26]; Otieno [33]; EPPO (online)
	Uganda	No further details regarding subnational level are available	Mango plant parts	Bragard et al. [26]; CABI [25], Otieno [33]; EPPO (Online)
South Africa	South Africa	Kaapmuiden and Nelspruit are present in all mango-growing parts of South Africa	Mango plant parts	Labuschagne et al. [34]; Le Lagadec et al. [35]; Otieno [33]; Bragard et al. [26];
	Madagascar	No further details regarding subnational level are available	Mango plant parts	Bragard et al. [26]; Otieno [33]; EPPO (online)
	Zimbabwe	No further details regarding subnational level are available	Mango plant parts	Bragard et al. [26]; Otieno [33]; EPPO (online)
Oceania	Australia	No further details regarding subnational level are available	Mango canopy leaves, fruits	Peña et al. [12]; Otieno [33]; CABI [25], Bragard et al. [26]
South America	Brazil	Espírito Santo, Goiás, Maranhão, Minas Gerais, Rio de Janeiro, Rio Grande do Sul, São Paulo, Bahia, Pernambuco	Mango leaves, twigs and fruits	Peña et al. [12]; da Costa-Lima et al. [36]; García et al. [15]; Bragard et al. [26]; EPPO (online)
	Chile, Argentina, Colombia, Guyana, Suriname, Venezuela	No further details regarding subnational level are available	Reported on mangoes, but no details are available	EPPO (online); Bragard et al. [26]; García et al. [15]
Americas	Caribbean Islands	Antigua Barbuda, Aruba, Barbados, Dominican Republic, Grenada, Guadeloupe, Haiti, Jamaica, Martinique, Puerto Rico, Saint Lucia, Trinidad and Tobago, Virgin Islands (British), Virgin Islands US	Mango plants	EPPO (online); Bragard et al. [26]; Murray [37]; García et al. [15]
Europe	Italy	Sicilia, Liguria	Ornamental plants and citrus fruits	Mazzeo et al. [23]. EPPO (online); Bragard et al. [26];
	Portugal	Madeira	Mango plant parts	del Pino et al. [38]; EPPO (online); Bragard et al. [26]
	Spain	Canary Islands	Mango plant parts	del Pino et al. [38], Arteaga et al. [39]; EPPO (online); Bragard et al. [26];
North America	United States	Florida	Present on all parts of mango plants	Germain et al. [8]; García et al. [15]; EPPO (online); Bragard et al. [26];
	Canada	No further details regarding subnational level are available	Potential threat.	García et al. [15]; EPPO (online); Bragard et al. [26];
	Mexico	Niyarit	Present on all parts of mango plants	Germain et al. [8]; García et al. [15]; EPPO (online); Bragard et al. [26]; García-Álvarez et al. [40]
	Bermuda	Further details on sub-national level regarding pest occurrence in these countries are not available	Potential threat.	Germain et al. [8]; García et al. [15]; EPPO (online); Bragard et al. [26];
Central America	El Salvador		Present	CABI [25]

3. Epidemiological Requirement

Climatic factors, viz., temperature, relative humidity, hurricane, and wind, affect the abundance of WMS [41]. The population of WMS, insect physiology and insect behavior were also affected by environmental factors [42,43], host plants, competitors and natural enemies [30,44]. Temperature can even affect the male-female ratio. Females were most abundant between 18–22 °C and 73–78% RH while males were abundant at temperatures between 25–28 °C and 66–71% RH [45]. At times of peak abundance, 1:20 female to male was observed [45].

WMS (*A. tubercularis*) males cluster in the lower canopy of trees [45]. Although females are homogeneously distributed in trees, when the temperature increases, they migrate to lower plant canopy [45]. After emergence, males cluster around new virgin females and copulate. Males survive 1–2 days after emergence and do not feed. First, instar nymphs can travel and disperse through winds to the new tree. After reaching there, they establish a colony. However, infested plant material movement from one place to another place for export, movement through birds carrying food in claws, wind and irrigation water can spread the pest in the whole orchard or distant orchards as well.

4. Damage

WMS is a cosmopolitan, highly fecundate and polyphagous pest (feeding on crops belonging to more than 30 different genera and over 18 families [15,46,47]. The pest was abundant on host plants belonging to four families, i.e., Anacardiaceae, Lauraceae, Palmae, and Rutaceae, particularly mangoes and cinnamon [48,49].

WMS is a serious pest of mangoes [50] in Argentina [51], Australia [52], Brazil [53], China [54], Colombia [55], Ecuador [56], Egypt [28], Ethiopia [57], India [54], Kenya [58], Mexico [59], Pakistan [54], South Africa [60], Spain [21] and many other countries [15].

The losses caused by this pest on mangoes varied based on the prevailing climate, variety and pest population. For example, in Kenya, it was not considered an important pest by the mango community as its impact was less serious [58], while in other countries such as Ethiopia [20], Egypt [61] and South Africa [62], the pest threatened production.

WMS feeds on plant parts, including fruits, through sucking cell sap. The infestation of WMS results in deformations which ultimately affect plant yield (Videos S1 and S2). WMS, during feeding, releases toxic saliva that affects the commercial value of fruits and their export. Greater damage was noticed in late mango cultivars [29,63] due to the abundance of scales on fruits and quantitative and qualitative damage produced [64,65].

The less mobile nature of the pest, the presence of chlorotic spots on the leaves and twigs, and less conspicuous blemishes on fruit skin might have been overlooked by farming communities in some countries (for example, in Kenya) [66,67]. Leaf loss and death of twigs were common in young trees, especially during hot and dry weather [28]. Small mango plants in nurseries could die because of heavy infestation of pests at the juvenile stage [66,68]. Mild infestation of WMS in the nursery may delay mango growth in the nursery, particularly during hot, dry seasons [69]. Due to the infestation of WMS, the plant photosynthesis process is affected; hence the leaves change color from green to pale yellow [70] (Figure 2).

The conspicuous blemishes on mango fruit skin not only reduce the export of mango fruits but also enhance the economic losses to farmers as well as to exporters [71]. The volatiles and odors emitted from ripening fruits might have attracted WMS because the fruits are filled with sugars on which insects feed [72]. More than 50% of losses in exports of mango fruits have been recorded due to the presence of chlorotic spots on the epidermis [54,59,62].

When the pest is abundant in mango crops, it is observed on all plant parts, including leaves, twigs, and fruits [73]. The odors released by ripening fruits attract the female WMS; hence they are highly abundant on the fruit at the ripening stage [20,73]. However, less acidic, viscous and sweet ripened mangoes may be more attractive compared to the immature ones due to their biochemical composition [24,74,75].

A B

Figure 2. White mango scale damage on leaves and fruit in farmer orchards in Pakistan. (**A**) Chlorosis on leaves due to WMS infestation (**B**) Chlorotic spots on fruits due to WMS infestation in Pakistan.

The management costs and economic losses caused by soft-scale infestations throughout the world have reached greater than one billion US dollars annually [76]. In Kenya, farmers spend about 13% of the mango orchard income on the management of WMS [58]. In Germany, 97% and 67% of mango fruits were rejected due to scales insect infestation on cultivar Sensation and Fascell, respectively [52].

About four–five *A. tubercularis* per fruit had caused up to 50% loss in commercial orchards in Spain due to the downgrading of mango fruits' cosmetic value. However, the susceptibility of mango cultivars to WMS infestation varies based on different characteristics. In this regard, a study was conducted in Puerto Rico, where it was concluded that the Haden, Edward and David Haden cultivars were most susceptible to scale insects infestation, while the Irwin and Keitt cultivars were less susceptible and Palmer was the most resistant [77]. Mango scale insect infestation in mango orchards of small farmers resulted in less production and reduced quality as well [19].

Due to severe infestation of WMS on citrus and fern, chlorotic spots were produced [78]. WMS was reported on citrus in Egypt [79]. An increase in one WMS per mango leaf decreased fruit yields by up to 4.28 kg per tree per year [69].

5. Life Cycle

White mango scale (WMS) tiny-shelled insects have more than 300 species [41,80]. For mass rearing of this pest, optimum growth conditions were 25 °C and 70% relative humidity, respectively [81]. However, 24–35 °C and relative humidity of 70–95% have been regarded as ideal environmental conditions for an increase in the population of WMS in field conditions [82]. Both types of reproduction, sexual and asexual, were observed in WMS [83].

5.1. Adult

The adult female is similar to nymphs without legs and wings [84]; a circular scale made up of wax 2 mm in diameter, having three longitudinal ridges and an exuviae terminal covering the body [38,54,85]. The exposed body of the gravid female is 1.5–2.0 mm long and brownish in color. Both forms of reproduction, ovipary and vivipary, were observed in scale insects [86].

The adult male WMS is usually small, slender, and winged [87]. Males bear vestigial mouthparts, hence are short-lived. Adult males were yellow to orange colored, about 0.53 mm long, and were unable to feed due to vestigial mouthparts. Adult males soon after emergence mate and die within 1–2 days [52]. Adult females excrete sex pheromones to attract male-scale insects [88]. Adult WMS vary in size (1.5–25 mm), shape and color [85,89]. Males usually cluster around females, while females usually occur singly [76].

5.2. Eggs

A female lays 80–200 eggs [90]. The eggs are 0.17 mm long, oval, and initially reddish brown in color, which later on become purple-colored depending upon maturity [89]. However, egg-laying fecundity is dependent upon the weather conditions as well, as in Australia, 50 eggs per female *A. tubercularis* were recorded. In South Africa, during summer, spring and winter conditions, about 203, 261 and 82 eggs per female were recorded, respectively. However, under semi-field conditions (27.5 °C and 81% R.H, 65), Gutierrez [84] observed 98.55 eggs per female [52]. At 27 °C and 81% RH, the incubation period was 8 days [84].

5.3. Hatching

After fertilization, the eggs hatch in 8 days [45]. Oviparous and viviparous reproduction was observed in scale insects population [73]. In sexual dimorphism, the female lays eggs. From these eggs, nymphs develop. Four stages (nymph stage 1, nymph stage 2, pre-pupa and pupa) were observed in the male population, while there are two female instars (nymph stage 1 and nymph stage 2) [38,52] in the female WMS population.

5.4. 1st Instar

The first instar nymphs emerge from eggs, settle down onto the tender part of the plant and suck the plant nutrients. Newly emerged first instar nymphs settle down within 24 h after hatching. Magsig-Castillo et al. [91] described that to find a good place for a feeding site, the first instar nymph can travel a distance of less than one meter. Once occupying some specific place, they insert their stylets, which ultimately form a food canal within the plant parts; hence they suck the sap from areas of colonization, either leaves, fruits or developing tissues [92]. After that, filaments of thread made up of wax were produced, which ultimately covered the upper epidermis [85]. Female crawlers often uniformly distribute within plant parts, while male crawlers settle near female crawlers in the form of groups. Although instar nymphs settle in groups, their population can be dispersed by various factors [50,93]. First, the instar male WMS colonizes near the adult female [84,85]. A study showed that about 10–80 males group near emerging adult female insects.

Nymphal instars and the male adults can move [52], but the movement of female crawlers through wings, bird claws or any other means is very important to initiate the infestation in a new tree or orchard [94]. In winter (7 and 23 °C), spring (13 and 26 °C), and summer (18 and 29 °C), the female first instar stage may last from 11.1–17.1 days [52] while at 27 °C and 81% R.H, the first female and male instar last 10 and 9 days, respectively [84]. In further development, about 80% of crawlers become males [90].

5.5. 2nd Instar

The second instar female WMS varies in size. In female WMS, the scale developed on the epidermis of the WMS was 3–4 mm, rectangular and developed from waxy filaments. The second instar female antennae were ovoid, translucent yellow colored and bear very small antennae [38]. The second instar male develops under the scale protective sheath bearing three longitudinal ridges [38]. In winter, spring and summer simulated conditions, the duration of the second female instar ranges from 11.1–25.3 days [52], while at 27 °C and 81% relative humidity, the second female and male instars may last for 5–8 days, respectively [84].

5.6. Pre-Pupa to Pupa

No change takes place in the size of WMS males from pre-pupae to pupae [38]. The pre-pupa and pupa stages may last for 3–5 days, respectively [84]. The pupal stage is found only in the case of males.

Life cycle period:

Environmental conditions and climate affect the life cycle of WMS [20]. In Australia, during summer, the WMS life cycle is completed in 35–40 days. In Winter, the life cycle is completed in 70–85 days [67,95]. A Female's WMS completes life in 52 days, while a male's only lasts 36 days [67]. The life cycle of WMS was completed in 68.9 in winter, 52.5 in spring and 42.7 days in summer [52].

This pest has 3–4 overlapping generations in a year [48,96]. There may be 5–6 generations per year, at 26 °C daytime temperature and 13 °C nocturnal temperature [70]. WMS has three generations in Mexico [41,66] and Egypt [28,48,68]. This is an important pest of mangoes in Egypt [97].

In Spain, it has three–four overlapping generations in a year [20,38,98], and in Southern Spain, it has two generations (spring and autumn) [38]. The ecological studies on pest resting behavior revealed that pest colonizes on the south sides of the tree in two locations (Kaapmuiden and Nelspruit, South Africa) [34].

5.7. Feeding Mechanism

In the WMS population, the adult male insects have vestigial mouthparts and hence live for only a few hours. A female WMS normally feeds and lives longer [99]. A male, after emergence, mates and dies within 1–2 days. WMS has piercing and sucking mouthparts. This chitinous tube is composed of four stylets, two maxillae and two mandibles [92]. During feeding, the female WMS obtains nutrients by pushing mouthparts into the parenchymatous tissues [100–103].

Histological studies show that the WMS scratches the interior of leaf tissue, including vascular bundles [104]. WMS, during feeding, not only punctures the parenchymatous tissues, but the lignified materials of the xylem are also punctured to obtain food. The pest secretes phenolic acid, which leaves a reddish scar [92].

6. Alternate Host Plants of WMS

Various plants belonging to 23 families and 37 genera act as the alternate host of WMS (Table 2). Cultivated and uncultivated wild plants can harbor the WMS population in the tropics and subtropics. Plants belonging to the families Anacardiaceae, Arecaceae, Burseraceae, Callophyllaceae, Cucubitaceae, Fabaceae, Iridaceae, Lauraceae, Myrtaceae, Pentaphylaceae, Rhizophoraceae, Rosaceae, Rutaceae, Spindaceae, Zingiberaceae, Annonaceae, Acerceae, Diptercarpaceae, and Escallonoaceae were reported as the alternate host plants of WMS [15,33].

Table 2. Alternate host plants of *Aulacaspis tubercularis*.

Common Name	Technical Name	Family	Reference	Country Where Reported
Kawakami maple	*Acer kawakamii*	Aceraceae	García et al. [15]	United States
Yellow meranti	*Shorea laxa*	Dipterocarpaceae	García et al. [15]	Borneo
Featherwood	*Polyosma*	Escalloniaceae	García et al. [15]	Taiwan
African Iris	*Dietes prolongata*	Iridaceae	García et al. [15], Peterson et al. [105]	Malaysia
Mango	*Mangifera*	Anacardiaceae	García et al. [15], Danzig and Pellizzari [106]	Hungary
Mango	*Mangifera indica*	Anacardiaceae	García et al. [15], da Costa-Lima et al. [36], Malumphy [47]	Brazil, Saint Lucia, Formosa
Coconut	*Cocos*	Burseraceae	García et al. [15], Miller and Davidson [70]	New York, USA
Coconut palm	*Cocos nucifera*	Callophyllaceae	García et al. [15], Cohic [107]	France
Chinese olive, Java almond	*Canarium*	Burseraceae	García et al. [15], Williams and Miller [108]	Karakatoa, Indonesia
Alexandrian laurel	*Callophyllum inophyllum*	Cucurbitaceae	García et al. [15], Williams and Miller [107]	Karakatoa, Indonesia
Cucumber	*Cucumis*	Cucurbitaceae	García et al. [15], Miller and Davidson [70], Williams and Miller [108]	Karakatoa, Indonesia, New York, USA
Squash	*Cucubita*	Cucurbitaceae	García et al. [15], Miller and Davidson [70]	New York, USA
Acorn squash	*Cucurbita pipo*	Cucurbitaceae	García et al. [15], Miller and Davidson [70]	New York, USA
Sponge guard	*Luffa*	Cucurbitaceae	García et al. [15], Miller and Davidson [70]	New York, USA
Wattles	*Acacia*	Fabaceae	García et al. [15], Thu et al. [109]	Vietnam
Earleaf acacia	*Acacia auriculiformis*	Fabaceae	García et al. [15], Thu et al. [109]	Vietnam
Silver wattle, lancewood	*Acacia managium*	Fabaceae	García et al. [15], Thu et al. [109]	Vietnam
Wood iris	*Dietes*	Iridaceae	García et al. [15], Miller and Davidson [70]	New York, USA
African iris	*Dietes iridioides*	Iridiaceae	García et al. [15], Miller and Davidson [70]	New York, USA
Dalchini	*Cinnamomum*	Lauraceae	García et al. [15], Munting [110]	South Africa
Camphor laurel	*Cinnamomum camphora*	Lauraceae	García et al. [15]	China
Cassia or Chinese cinnamon	*Cinnamomum cassia*	Lauraceae	García et al. [15], Thu et al. [109]	Vietnam
Selasian wood	*Cinnamomum parthenoxylon*	Lauraceae	García et al. [15], Martin and Lau [111]	Hong Kong, China
Cinnamon	*Cinnamomum verum*	Lauraceae	García et al. [15], Newstead [112], Varshney [113]	Western Africa, South East Asia
Bay laurel	*Laurus*	Lauraceae	García et al. [15], Miller and Davidson [70], Varshney [113]	New York, USA
Bay laurel	*Laurus nobilis*	Lauraceae	García et al. [15]	Taiwan
Soft bollygum	*Listea*	Lauraceae	García et al. [15], Miller and Davidson [70]	New york
Soft bollygum	*Listea glutinosa*	Lauraceae	García et al. [15,114]	Japan
Avocado	*Persea*	Lauraceae	García et al. [15], Miller and Davidson [70]	New York, USA, Taiwan
Avocado	*Persea americana*	Lauraceae	García et al. [15], Miller and Davidson [70]	New York, USA, Taiwan

Table 2. *Cont.*

Common Name	Technical Name	Family	Reference	Country Where Reported
Priyango	*Aglaia*	Meliaceae	García et al. [15], Miller and Davidson [70]	New York, USA
Nyireh bunga	*Xylocarpus granatum*	Meliaceae	García et al. [15]	Taiwan
Guava	*Psidium*	Myrtaceae	García et al. [15], Miller and Davidson [70]	United States
Mock orange	*Pittosporum*	Pittosporaceae	García et al. [15], Chen [115]	China
Cheese wood	*Pittosporum glabratum*	Pittosporaceae	García et al. [15], Chen [115]	China
Upriver orange mangrove	*Bruguiera sexangula*	Rhizophoraceae	García et al. [15]	Taiwan
Talt stilt mangrove	*Rhizophora apiculata*	Rhizophoraceae	García et al. [15]	Taiwan
Pulm	*Prunus*	Rosaeceae	García et al. [15], Miller and Davidson [70]	United States
Citrus, mandarin	*Citrus*	Rutaceae	García et al. [15], Borkhsenius [27]	Moscow
Longan	*Dimocarpus*	Saprindaceae	García et al. [15], Miller and Davidson [70]	United States
Lychee	*Litchi*	Saprindaceae	García et al. [15], Miller and Davidson [70]	United States
Lychee	*Litchi Chinensis*	Saprindaceae	García et al. [15,70]	United States
Group of plants belonging to this genus	*Nephalium*	Saprindaceae	García et al. [15], Miller and Davidson [70]	United States
	Illicium cambodianum	Schiandraceae	García et al. [15]	Taiwan
Common ginger	*Zingibar officinale*	Zingiberaceae	García et al. [15], Watson [87]	Present in numerous countries
Huru iris	*Actinodaphane sphaerocarpa*	Lauraceae	García et al. [15]	
True cinnamon tree	*Cinnamomum ceyaniam*	Lauraceae	Otieno [33]	
Spicewood, spicebush, benjamin bush	*Lindera*	Lauraceae	García et al. [15]	Taiwan
Lindera	*Lindera macusua*	Lauraceae	García et al. [15]	Taiwan
	Lindera pericarpa	Lauraceae	García et al. [15]	Taiwan
Himalayan spicebush	*Lindera pulcherrima*	Lauraceae	García et al. [15]	Taiwan
Soalu	*Listea monopetala*	Lauraceae	García et al. [15], Kuwana [114]	Japan
	Listea pungens	Lauraceae	García et al. [15], Tang [116]	China
Japanese bay tree	*Machilus*	Lauraceae	García et al. [15]	Taiwan and United States
A specie of avocado	*Machilus wangchiana*	Lauraceae	García et al. [15], Martin and Lau [111]	Hong kong China
No common name	*Neolistea launginosa*	Lauraceae	García et al. [15]	Taiwan
Gaiadendron	*Gaiadendron*	Loranthaceae	García et al. [15]	United States
Kawakami maple	*Acer caudatifolium*	Sapindaceae	García et al. [15]	United States

7. Management

A variety of management methods have been used in the past to control WMS populations [31,68,69,117].

7.1. Cultural Control

For the control of WMS populations, different cultural control practices such as pruning (cutting of plant branches to make them open for aeration and reduce humidity), smoking, area clearing (removal of infested plant material from the orchard), application of homemade oils and soaps [118,119] have been recommended. Certain cultural control measures have been adopted in the mango-growing orchards to make unfavorable conditions for *A. tubercularis*.

Post-harvest pruning can increase light penetration in the tree, hence would decrease the shady environment. This practice makes the environment less favorable for WMS on leaves, twigs, and new flushes [45,120]. Through pruning, the penetration of chemical sprays into the interior of trees was better, which ultimately reduced scale insects population [121].

Usually, WMS prefers a shaded environment. For controlling scale insects' population, pruning after harvest can improve aeration, hence making the environment less favorable for the pest. Farmers in Ethiopia practice clearing the infested tree parts, pruning after harvest, and smoking to control WMS [19]. Farmers in Eastern Kenya practice regular and cyclical pruning to reduce the WMS population in mango orchards [58,122].

Agronomic practices can increase or decrease the pest population, for example, excessive use of nitrogenous fertilizer and irrigation, while a few practices, such as the application of organic manure, may enhance plant resistance against pests [123]. *WMS* population was higher in organic orchards compared to conventionally managed orchards. The authors suggested that this increase in population might be due to the excessive use of nitrogenous and phosphorous fertilizers [124]. A higher population of WMS was observed in late-maturing cultivars in Mexico [66,120]. In South Africa, late-maturing mango varieties had higher WMS infestation [125]. The number of generations of WMS increased to 12 in hanging mango fruits [125].

Plant resistance contributed to a decrease in the WMS population. Cultivars with dense foliage and bigger tree size provided a shady environment for the growth of WMS; hence the population of *A. tubercularis* increased [41]. The chemical composition of fruits (sugar contents, acidity) contributes to the susceptibility of mango cultivars against WMS [126].

Fruit bagging protects mangoes from damage due to insect pests (fruit fly and scale insects), mechanical damage (scars and scratching produced during harvesting) and exposure to the sun, and diseases (anthracnose, stem end rot, etc.) [127–129]. Further research on bagging documented that due to bagging, the damage is reduced by up to 9%, while un-bagged fruits were 36% damaged due to multiple factors, including scales [130].

7.2. Biological Control

A wide range of biological control agents were observed feeding on WMS in different parts of the world. *Coccinellid* beetles, though famous for controlling hemipteran insects' populations, were not effective against WMS [79]. *Rhyzobius lophanthae* Blaisdell (Coleoptera: Coccinellidae) and *Chilocorus nigrita* (Fabricius) (Coleoptera: Coccinellidae) were observed in South Africa feeding on WMS [79]. *Encarsia* sp. (Hymenoptera: Aphelinidae) parasitoids also feed on *A. tubercularis* in South Africa; the rate of parasitism was 17.7% on the mango crop [131].

Ladybird beetle *Chilocorus* sp. (Coleoptera: Coccinellidae) larvae feed on WMS at all stages. The studies concluded that the scale on WMS does not interfere with the feeding of *Chilocorus,* sp. Larvae were able to reach the body of the scale and chew it [58]. WMS population was greatly reduced by this predaceous larva [58].

Aphelinidae and Encyrtidae wasps were also observed feeding on WMS [63,68,132]. However, the distribution of these parasitoids varied differently in various mango-growing countries [133]. In South Africa, Egypt and Mexico, *Encarsia citrina* Crawford (Hymenoptera: Aphelinidae) was observed feeding and parasitizing on WMS [29,48,60,67,69,131,132,134], but the control was below ETL. The percentage of parasitism by *E. citrina* increased to 80% at some times of the year [60,69]. *E. citrina* was also observed in WMS populations in Andalusia, Spain [135]. *E. citrina* has also been regarded as the most effective endo parasitoid of WMS [135]. Being an effective parasitoid in controlling WMS, the *E. citrina* was introduced in various countries to control the pest population [136]. Ecto-parasitoid *Aphytis* sp. (Hymenoptera: Aphelinidae) was observed feeding on WMS in Australia [121] and Egypt [48,68].

Pteroptrix koebelei is an indigenous natural biocontrol agent against WMS. It can reduce up to 90% population of WMS in India [137]. Along with *P. koebelei*, various arthropod predators were found with *WMS* in mango fields. These predators belonged to different orders, e.g., Neuroptera (Chrysopidae), Coleoptera (Coccinellidae and Cybocephalidae), Thysanoptera (Phlaeothripidae), and Diptera (Cecidomyiidae). Some mites (Cheyletidae and Stigmaeidae) were also reported to feed on WMS. Among them, *Cybocephalids* beetles were observed feeding on Diaspidid scales [138], while *Cybocephalids* beetles were also observed feeding on WMS in mango orchards [139].

Among the predators, *Cybocephalus rufifrons* flaviceps Reitter was observed as a major predator, responsible for 35% of predation, followed by *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) (25.5%) and *Chilocorus bipustulatus* (L.) (Coleoptera: Coccinellidae) (21.4%), while predation by mites was lease abundant, i.e., 11.8% [63]. Moreover, different lady beetle species of the genus *Chilocorus* sp. (Coleoptera: Coccinellidae) were found feeding on *A. tubercularis* on mango trees in South Africa [60], Australia [121], India [137], Egypt [63,68], Mexico [140] and Ethiopia [58]. A thrips species, *Aleurodothrips fasciapennis,* was observed predating on WMS [34,52,60], while in South Africa, *Cecidomyiidae* were observed feeding on WMS.

In Spain, *Cybocephalus nipponicus, Stethorus pusillus* (Herbst), *Chrysoperla* sp. and Cecidomyiidae were observed feeding on WMS [21]. Among these, *C. nipponicus* was predominant, but control was insufficient and below ETL [141]. Inundation release of *C. nipponicus* was practiced, and it was concluded that the release of 50–100 beetles per orchard reduced the infestation to 2–3%; however, complete eradication of the pest population could not be achieved.

In South Africa, Coccinellid *Chilocorus nigritus* (Fabricius) was observed feeding on *A. tubercularis*; however, the control was insufficient [34,131,134,142]. Another example of introduction and inundative release was *C. nipponicus* imported from the USA in Ecuador from New Jersey (USA) to control *A. tubercularis* [67]. A specie of mite, *Hemisarcoptes malus* Schimer (Hemisarcoptidae), was also observed feeding on the scale [143–145].

7.3. Chemical Management

Various conventional broad-spectrum insecticides belonging to different groups (organophosphates, pyrethroids and neonicotinoids) are used to control WMS populations in different parts of the world [69,146,147]. However, soil drenching has been recommended as an effective method to control WMS [148].

Fenvalerate controlled 85.3% of WMS populations [149]. However, an early stage of scales can be effectively controlled with the sprays of dimethoate, monocrotophos, neem oil, and quinolphos [137]. The pyrethroids group insecticide deltamethrin had been used in Kenya to control WMS [150]. However, Thiamethoxam application through drip irrigation was the most effective insecticide for the control of WMS on mangos in South Africa [62].

Thiamethoxam 25% WG application at a rate of 6 g/tree and 12 g/tree suppressed scale insect population efficiently; however, the results were not significantly different [151]. Excessive use of neonicotinoids did not increase WMS mortality. Moreover, the neonicotinoid may cause CCD (colony collapse disorder) in honey bees [151,152]. In Ethiopia, Ayalew [31] reported that about 30–90% mortality rate of white mango scale insect was observed from Movento chemical application against this insect pest. In Ethiopia, research proved that April to June was the best time to control WMS on mangoes because this was the time when the crawlers were abundant on mango leaves and twigs in Ethiopia [58].

The highest mortality was observed through the application of Folimat [153]. Diazinon and Dimethoate were found to reduce the damage caused by this pest [57]. Application of mineral oil caused 98% mortality of WMS [154]. However, laboratory studies conducted on the evaluation of toxicity of organophosphates, pyrethroids and neonicotinoid insecticides recommended against WMS showing that these insecticides were highly toxic against parasitoids *E. citrina* and predator *C. nipponicus* [138,155]; hence irregular use of these broad-spectrum insecticides would cause population resurgence due to mortality of predators and parasitoids in the ecosystem [60,134].

Pruning of plants, along with the application of insecticide thiamethoxam, resulted in good control of the WMS population [156]. The timing of the application of insecticide/mineral oil is very important for efficient pest control. An experiment conducted in this regard demonstrated that incorrect application of mineral oils led to adverse effects such as fruit drop; hence the population of WMS should be controlled before they move towards fruits [157]. However, integrated use of pruning, biocontrol agents and chemicals can significantly reduce WMS.

8. Discussion

The white mango scale (WMS) is a serious threat to the quantitative and qualitative production of mangoes in the world. The chlorotic spots produced on mango fruits due to insects feeding make the fruit unmarketable even in local domestic markets within developing countries. This causes huge economic losses to the mango growers.

Abate and Dechassa [158] pointed out future research challenges for suppressing the WMS population in Ethiopia. They pointed out that in Ethiopia, laboratories should be established to devise the rearing protocols of biocontrol agents that will eventually suppress the pest population in the field. Cultural practices' role in reducing the WMS population in Ethiopia should be understood. The effect of insecticides on natural enemies and the pest population should be determined. Insecticide residues should be understood to devise the best control technology against white mango scales. Exotic natural enemies should be brought and introduced into Africa to suppress the pest population. An integrated pest management program should be developed to decrease the pest population in farmer fields.

For the European Union, WMS is regarded as a quarantine pest [26]. The European Union has put strict quarantine measures to restrict the entry of this pest. Physical inspection application of different treatments has been recommended on consignments of fresh plant material imported from other countries. Due to the small size of this pest, it can move from the infected plants in Andulasia to other uninfected zones through wind, birds or other insects [26].

In Pakistan and India, very little information is available on pest dynamics. Peña et al. [12] determined that WMS is a serious pest to mango cultivation in different countries, including Pakistan. These WMS transfer the toxic saliva into the fruits, as a result of which chlorotic lesions are produced. WMS had been observed on leaves and fruits. The mango shield scale has been reported in Asia, Africa, Australia, Israel, and the Americas as well.

The population dynamics of the pest was affected by weather conditions as well. In Pakistan, mangoes are grown in the provinces of Punjab and Sindh. Both provinces vary in climatic conditions and topography. The climate in Sindh is hot and humid, while in Punjab, dry and hot weather prevails. Due to the hot and humid weather in Sindh, mango matures about one month prior to Punjab. In Sindh, mango is cultivated in the districts of Hyderabad, Kotri, Rohri, Mirpur Khas, and Sadiqabad. In Punjab, most mangos are cultivated. In Punjab, mangos are grown in the districts of Khanewal, Rahim Yar Khan, Vehari, Muzaffar Garh, and Bahawalpur. However, some mangos are also cultivated in upper Punjab Lahore and Murree Hills. The weather in Murree Hills is cold and humid. Hence, it is extremely important to understand when the population of scales develops in Pakistan when it reaches its peak and what weather conditions limit the population of scales. Understanding the role of weather factors would help scientists to devise strategies against the pest.

Although much work has been done in different cities of the world about insecticide efficacy, pesticide residues against the pest, and MRL of the pesticide, such information is not available with reference to Pakistan. The pesticides should be screened out against scales, and MRL of these insecticides should be shared with the local community so that they are aware that pesticide is a toxic chemical and its judicious use will decrease pest abundance.

An integrated pest management model should be developed in Pakistan to control the WMS population efficiently.

9. Conclusions

The white mango scale insect (WMS), *A. tubercularis* (Hemiptera: Diaspididae), is a polyphagous, multivoltine pest which is a serious threat to qualitative and quantitative mango production. The fruits infested with WMS develop pink blemishes, hence are not marketable. Although the local community may consume these fruits, farmer profit is considerably reduced. In Kenya, mango growers spend about 13% of the total income generated from mango sales on chemical management of this pest. In Germany, the percentage of fruit rejected in the unsprayed controls was 97% and 67% on variety Sensation and Fascell, respectively. About four–five *A. tubercularis* per fruit caused up to 50% loss in commercial orchards in Spain due to the downgrading of mango fruits' cosmetic value. Hence farmers must be advised to control the pest outbreak in all mango-growing countries because the pest is cosmopolitan, being present in all mango-growing regions of the world. Late varieties were prone to heavy infestation because of pest colonization. Cultural practices such as pruning after harvest, smoking, cleaning of infested plant material, bagging of fruits not infested with mango scale insects, and application of insecticides along with mineral oil may reduce the pest numbers to a greater extent. Insecticides such as Fenveralerate, dimethoate, pyrethroids, thiamethoxam, imidacloprid, and movento, may reduce the pest numbers to a greater extent. However, care should be taken because the higher application of insecticide may increase mortality of biological control agents as well; hence a natural balance may be disturbed. *Coccinellid* predators, viz., *Rhyzobius lophanthae*, *Chilocorus* sp, and *Chrysoperla carnea*, can reduce the pest numbers to a greater extent. Parasitoids of Aphelinidae and Encyrtidae may reduce 80% of the population of WMS. Hence combined use of insecticide along with pruning may reduce the pest population and would cause the least damage to the biological control agents. Integrated pest management programs are extremely needed in mango growing regions to enhance farmer knowledge and decrease the overall losses due to WMS.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agriculture13091770/s1, Video S1: Damage caused by WMS, pest colonization tree, canopy leaves and twigs. Video S2: White mango scale insect on fruits.

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