Scale Insects (Hemiptera: Coccomorpha) on Jackfruit (Moraceae) in Nayarit, Mexico[1]

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Abstract Jackfruit, *Artocarpus heterophyllus* Lam. (Rosales: Moraceae), was only recently introduced into Mexico, and the state of Nayarit has become its main source of production. Information on its management, development, and production in Mexico is scarce. In this study, we identified four species of scale insects on jackfruit belonging to the families Coccidae (one species), Diaspididae (two species), and Pseudococcidae (one species) from Coccomorpha. We found one species of a parasitic wasp (Hymenoptera: Aphelinidae) and two ant species (Hymenoptera: Formicidae) associated with the mango shield scale, *Milviscutulus mangiferae* (Green) (Coccidae). Three species of aphelinid parasitoids and one coccinellid species (Coleoptera: Coccinellidae) were found attacking the lesser snow scale, *Pinnaspis strachani* (Cooley) (Diaspididae). The lesser snow scale and the mango shield scale were the most frequent scales insect species encountered in jackfruit orchards in Nayarit. Therefore, attention should be paid to the populations of these two scale insects, as well as to the type of interaction between ants and the mango shield scale, to design more efficient management of these pests.

Key Words ants, jackfruit, parasitism, scale insects

Jackfruit, *Artocarpus heterophyllus* Lam. (Rosales: Moraceae), is a plant that is native to southeastern Asia and widely distributed in several tropical countries globally (Abreu and Rodrigues 2010, Prakash et al. 2009). In recent years, cultivation of this fruit has expanded into tropical areas of Mexico (SIAP 2018), and it is now cultivated on 1,750 ha with an annual production of 21,767 metric tons. The state of Nayarit is the main producer in Mexico, with 1,626 ha and 20,252 metric tons. Approximately 90% of production in Mexico is for the export market, mainly to the United States (Luna-Esquivel et al. 2013, SIAP 2017).

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As an introduced and expanding crop, jackfruit is susceptible to potential insect pest species that adapt to the new crop and use it as a potential source of food, shelter, and ovipositional sites. This can cause pest problems and yield losses in production and therefore have an economic impact on producers.

Scale insects (Hemiptera: Coccomorpha) are of concern in jackfruit production. Of the approximately 8,000 species (Miller et al. 2014), the greatest number of species are in the families Diaspididae, Pseudococcidae, and Coccidae, in respective order (Ouvrard et al. 2013, Williams and Granara de Willink 1992). Some species of these families are important agricultural pests and potential invasive species meriting survey and management studies on jackfruit (Miller et al. 2005, Ouvrard et al. 2013).

Ants may exhibit mutualistic relationships with scale insects (Delabie 2001, González-Hernández et al. 1999), while there are a number of parasitic and predatory species that attack scales. These include the hymenopteran parasitoids of the families Encyrtidae, Aphelinidae, and Signiphoridae (Anis 2011) that are found in most habitats and are considered important biological control agents (Rehmat et al. 2011).

Knowledge of the diversity of scale species associated with jackfruit cultivation and their interactions with potential natural enemies is important in designing integrated pest management strategies. Therefore, the objective of this study was to identify the Coccomorpha species feeding on jackfruit, their natural enemies, and associated mutualistic ants in the states of Nayarit and Colima where this fruit is primarily produced in Mexico.

Materials and Methods

The study was conducted in commercial jackfruit plantings in Nayarit, Mexico, in June, July, and October 2018, and August and September 2019. The sampling sites were located at different altitudes to have a representation of the climatic conditions where jackfruit orchards are located (Table 1).

Following the technique of Southwood (2000), sampling was performed directly on foliage, fruits, branches, and trunks at each cardinal point of the tree. When scale insects were found, the area of the plant tissue or section of the infested fruit was excised. From each sample, some specimens were preserved in 1.5-ml Eppendorf tubes containing 70% ethyl alcohol. The remainder of the samples were stored individually in Ziploc® bags for further laboratory processing. Ants that showed an association (mutualist) with scale insects, mainly with species of Coccidae and Pseudococcidae, were preserved in ethyl alcohol under the same conditions as the scale insects. Samples of plant tissue with scale insects were transported to the Pest Management Laboratory of the Colegio de Postgraduados, Montecillo Campus, Texcoco, State of Mexico, Mexico, where they were separated and maintained in petri dishes (27 $\pm$ 2°C; 60 $\pm$ 5% relative humidity, and 12:12 h light:dark) to obtain adult parasitoids emerging from scale insects.

Some specimens of scale insects were processed for identification following the methods of Kosztarab (1963) with some modifications. The scale insects in Eppendorf tubes containing 10% KOH were placed into a thermoblock (AccuBlock, Labnet International, Edison, NJ) at a temperature of 80°C for 10 to 15 min.

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Table 1. Scale insects associated with jackfruit orchards in Nayarit, Mexico in 2018 and 2019.

Taxon	Plant Part	Natural Enemies	Associated Ant	Locality	Coordinates	Altitude (m above sea level)
Diaspididae						
Pinnaspis strachani (Cooley)	Fruits	*Encarsia* sp. *Eretmocerus* sp.		Las Varas, Compostela, Nayarit	N 21°07′12″, W 105°10′23″	34
	Fruits and branches	*Aphytis* sp.		Las Varas, Compostela, Nayarit	N 21°10′24″, W 105°10′27″	34
	Fruits, branches and trunks	*Pentilia* sp.		Las Varas, Compostela, Nayarit	N 21°10′33″, W 105°10′24″	9
	Fruits			Huicicita, Compostela, Nayarit	N 21°27′58″, W 105°10′79″	62
	Branches			Arocha, Compostela, Nayarit	N 21°25′99″, W 105°06′46″	154
	Leaves			Huerto 2, Altavista, Compostela, Nayarit	N 21°17′49″, W 105°17′42″	33
	Fruits			Huerto 3, Altavista, Compostela, Nayarit	N 21°11′69″, W 105°17′14″	46
	Fruits, leaves and branches			El Crucero, El Capomo, Compostela, Nayarit	N 21°06′55″, W 105°10′17″	26
	Branches			Las Calbazas, El Capomo, Compostela, Nayarit	N 21°07′09″, W 105°10′14″	47

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Table 1. Continued.

Taxon	Plant Part	Natural Enemies	Associated Ant	Locality	Coordinates	Altitude (m above sea level)
	Leaves and branches			Tecuitata, San Blas, Nayarit	N 21°26′22″, W 105°08′51″	228
	Fruits			El Llano, San Blas, Nayarit	N 21°25′16″, W 105°10′50″	19
	Fruits and branches			El Llano, San Blas, Nayarit	N 21°25′16″, W 105°10′49″	30
	Fruits			Jacocotán, San Blas, Nayarit	N 21°29′39″, W 105°45′90″	545
	Fruits, branches and trunks			Jalcocotan, San Blas, Nayarit	N 21°45′57″, W 105°18′73″	829
	Fruits, branches and trunks			Tecuitata, San Blas, Nayarit	N 21°26′28″, W 105°85′80″	243
	Leaves and branches			Ejido Brasiles, Bahía de Banderas, Nayarit	N 20°76′20″, W 105°29′55″	30
	Fruits, leaves and branches			Rancho Pitahaya, Brasiles; Bahía de Banderas, Nay	N 20°45′39″, W 105°17′44″	19
	Fruits and leaves			Valle de Banderas, Zona urbana, Bahía de Banderas, Nayarit	N 20°47′10″, W 105°13′51″	22

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Table 1. Continued.

Taxon	Plant Part	Natural Enemies	Associated Ant	Locality	Coordinates	Altitude (m above sea level)
Pseudischnaspis bowreyi (Cockerell)	Leaves			El Porvenir, Zona Urbana, Bahía de Banderas, Nayarit	N 20°45′80″, W 105°14′38″	5
Coccidae						
Milviscutulus mangiferae (Green)	Leaves		*Crematogaster crinosa* (Mayr)	Ejido Las Ardillas, Las Varas, Compostela, Nayarit	N 21°17′69″, W 105°17′40″	27
	Leaves			San Isidro, Compostela, Nayarit	N 21°28′08″, W 105°15′93″	27
	Fruits and leaves		*C. crinosa*	Huerto 1, El Capomo, Altavista, Compostela, Nayarit	N 21°11′71″, W 105°16′88″	51
	Leaves	*Coccophagus bimaculatus* Myartseva	*Ectatomma ruidum* (Roger)	El Crucero, El Capomo, Compostela, Nayarit	N 21°06′55″, W 105°10′17″	26
	Branches			Huerto 4, Altavista, Compostela, Nayarit	N 21°07′11″, W 105°15′78″	211
	Leaves			Altavista, Compostela, Nayarit	N 21°06′13″, W 105°10′35″	103
	Leaves		*C. crinosa*	Tecuitata, San Blas, Nayarit	N 21°26′28″, W 105°85′80″	243

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Table 1. Continued.

Taxon	Plant Part	Natural Enemies	Associated Ant	Locality	Coordinates	Altitude (m above sea level)
	Leaves			Santa Cruz de Miramar, San Blas, Nayarit	N 21°45′57″, W 105°18′73″	24
	Leaves			Rancho Pitahaya, Brasiles; Bahía de Banderas, Nayarit	N 20°45′39″, W 105°17′44″	19
Pseudococcidae						
Ferrisia virgata (Cockerell)	Leaves			San Vicente, Zona Urbana, Bahía de Banderas, Nayarit	N 20°45′40″, W 105°15′20″	24
	Leaves and buds			El Crucero, El Capomo, Compostela, Nayarit	N 21°06′55″, W 105°10′17″	26

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Subsequently, the material was processed as follows: (a) 10 min in acetic acid + alcohol, (b) 10 min in fuchsin acid to stain sclerosed structures, (c) 10 min in each concentration of ethyl alcohol (80, 96, and 100%) for dehydration, (d) immersion of the specimens in clove oil, and (e) permanent mounting on microscopic slides with Canadian balsam. The scale insect specimen identifications were made by the fourth author (H.G.-H.) using the keys of Ferris (1942) for Diaspididae (*Pseudischnaspis*), Hamon and Williams (1984) for Coccidae, Williams and Granara de Willink (1992) for Pseudococcidae: *Ferrisia* spp., Kaydan and Gullan 2012 for *Ferrisia* spp., Ramos-Portilla and Caballero (2017) for *Pinnaspis*, and Abd-Rabou and Evans (2018) for *Milviscutulus*.

The collected ants were mounted on cardboard triangles with pins and identified by Dr. Juan Manuel Vanegas Rico (Colegio de Postgraduados, Campus Montecillo, Texcoco, State of Mexico, Mexico) and Dr. Karla Yolanda Flores Maldonado (Universidad Autónoma de Tamaulipas, Victoria, Tamaulipas, Mexico). The taxonomic keys Olivero-G et al. (2009) and Longino (2013) were used to identify species of Ectatomminae and *Crematogaster*, respectively.

The coccinellid collected in the study was identified by Antonio Marín Jarillo (Instituto Nacional de Investigaciones Forestales, Agricolas y Pecuarias, Celaya, Guanajuato, Mexico). Specimens were dissected following the methods of González et al. (2019), which briefly consisted on softening a specimen in hot water, placing the abdomen in potassium hydroxide until muscle and fat are removed, rinsing the abdomen and genital structures in clear water, and placing the cleaned structures in glycerin for examination. Taxonomic keys of González et al. (2019) were used to identify to genus level.

Rearing and collection of parasitoids that emerged from scales were by methods of Noyes (1982). The obtained parasitoids were mounted on microscopic slides, following the method of Myartseva et al. (2011). Specimens were identified by the sixth author (J.R.L.-F.) using the keys of Myartseva et al. (2012).

All the mounted and identified entomological material was deposited in the Insect Collection at the Colegio de Postgraduados, Campus Montecillo, Texcoco, State of Mexico, Mexico. All images (except 1.B) were taken with a digital camera (Canon Ds126211, Canada) fitted to a Zeiss Discovery V.2. stereoscopic microscope (Zeiss, Jena, Germany).

Results and Discussion

Our study yielded four scale insect species (Coccomorpha) infesting jackfruit trees (Table 1). These included lesser snow scale, *Pinnaspis strachani* (Cooley) (Hemiptera: Diaspididae) (Figs. 1A, B), the bowrey scale, *Pseudischnaspis bowreyi* (Cockerell) (Hemiptera: Diaspididae) (Fig. 1C), the mango shield scale, *Milviscutulus mangiferae* (Green) (Hemiptera: Coccidae) (Fig. 1D), and the striped mealybug, *Ferrisia virgata* (Cockerell) (Hemiptera: Pseudococcidae) (Fig. 1E). In addition, we found and identified two species of ants (Hymenoptera: Formicidae), one beetle species (Coleoptera: Coccinellidae), and four parasitoid species (Hymenoptera: Aphelinidae) associated with those scale insects (Table 1).

Pinnaspis strachani was the most widely distributed scale in jackfruit orchards of Nayarit. Although it was detected on leaves, branches, and tree trunks, it mainly

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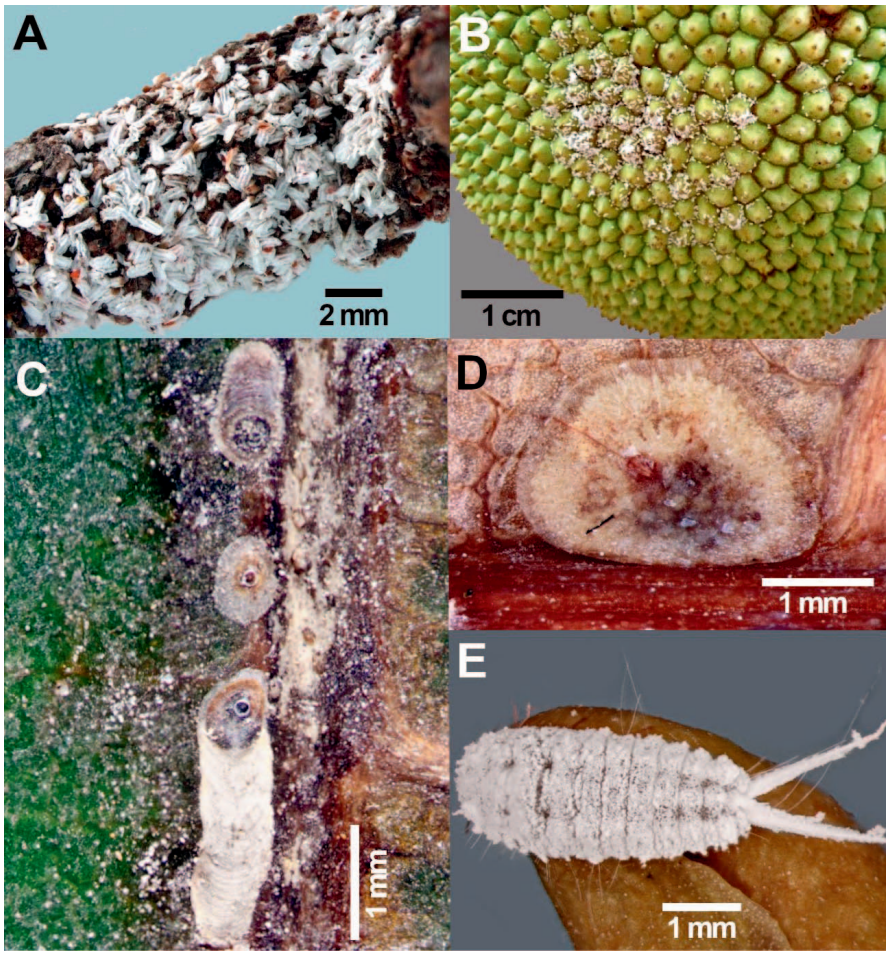

Fig. 1. Lesser snow scale, *Pinnaspis strachani,* on jackfruit branch (A) and on fruit of jackfruit (B); bowrey scale, *Pseudischnaspis bowreyi*, on jackfruit leaves (C); mango shield scales, *Milviscutulus mangiferae,* on jackfruit leaves (D); striped mealybug, *Ferrisia virgata*, on bud of jackfruit (E).

affects fruits causing mostly cosmetic type damage (Fig. 1B). It is reported from 111 countries with hosts representing at least 244 genera belonging to 74 botanical families, including the Anacardiaceae, Annonaceae, Arecadeae, Asparagaceae, Cucurbitaceae, Fabaceae, Lauraceae, Malvaceae, Poacea, Rosaceae, Moraceae, and Solanaceae (García Morales et al. 2016). It is considered an important pest of *Citrus*, *Hibiscus*, palm, coconut, mango, grapefruit, cassava, and banana (Watson 2002) and a major pest of jackfruit in China (Tao 1999) and India (Rajkumar et al. 2018). In Mexico, *P. strachani* has been detected on citrus fruits, although it is not a major pest (González Hernández and Atkinson 1984). Likewise, its presence has

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been reported on different hosts in the states of Baja California Sur, Oaxaca, Sinaloa, and Veracruz (Ferris and Prabhaker 1947, Myartseva and Ruiz-Cancino 2000). In Mexico, *P. strachani* can now be considered an important pest in jackfruit orchards, infesting fruits and affecting their aesthetic quality. Moreover, it is difficult to eliminate the scales during the packaging process.

The parasitoids *Aphytis* sp. (Hymenoptera: Aphelinidae), *Encarsia* sp. (Hymenoptera: Aphelinidae), and *Eretmocerus* sp. (Hymenoptera: Aphelinidae) emerged from *P. strachani* scale insects. The predator *Pentilia* sp. (Coccinellidae) was detected feeding on *P. strachani* colonies on jackfruit in the locality of Las Varas, Compostela, Nayarit. Of the four species of scales, the largest number of Aphelinidae parasitoids emerged from *P. strachani*. Ahmad and Ghani (1972) recorded *Aphytis* spp. (Hymenoptera: Aphelinidae) on *P. strachani* in Pakistan. Likewise, Sankaran (1984) reported *Encarsia* Förster on *P. strachani* in southern India. Myartseva and Evans (2007) reported *Encarsia gaonae* (Myartseva & Evans) and *Encarsia citrina* (Craw) parasitizing *P. strachani* that was infesting *Amyris madrensis* S. Watson (Rutaceae) in Tamaulipas and *Citrus* spp. in Veracruz. There are several reports of parasitoids associated with *P. strachani*: 13 species of Aphelinidae, 5 of Encyrtidae, 4 of Signiphoridae, and 1 Eupelmidae, as well as 7 species of ladybeetle predators (Coleoptera: Coccinellidae) (García Morales et al. 2016). *Pentilia* spp. predators have been detected attacking the white mango scale, *Aulacaspis tubercularis* Newstead (Diaspididae), on mangos in San Blas, Nayarit, where this coccinellid and other predator species (lacewings and other coccinellids) are important natural regulatory factors of this scale pest on mangos (Urías-López et al. 2019).

The bowrey scale, *Pseudischnaspis bowreyi,* was collected only once on the leaves of jackfruit in a backyard in Bahía de Banderas, Nayarit. This scale has been collected on agave in Jamaica, on mango in Frontera, Tabasco, Mexico (Miller et al. 1984), and on Arecaceae in Rio Frio, Tamaulipas, Mexico (Normark et al. 2019). Other reports include Michoacán and Yucatan in Mexico, Florida in the United States (with no records of the hosts) (Miller 1996), Argentina, Barbados, Bermuda, Bolivia, Brazil, Colombia, Cuba, Dominican Republic, Ecuador, Peru, Puerto Rico, St. Thomas, Trinidad, and Venezuela, often on bromeliads (Nakahara 1982).

Milvisctulus mangiferae was detected in the municipalities of Bahía de Banderas, Compostela, and San Blas, Nayarit. This species was observed causing light infestations on foliage, branches, and fruits, along with the development of sooty mold. The mango shield scale is a cosmopolitan polyphagous species that has been reported on 83 genera representing 42 families (García Morales et al. 2016). Hamon and Williams (1984) reported *M. mangiferae* (as *Protopulvinaria mangiferae*) attacking jackfruit and as an important pest of mango in Florida. According to Ben-Dov et al. (1975), the mango shield scale is distributed mainly in subtropical and tropical areas in almost all mango-producing countries. In Mexico, there are reports of mango shield scale in the states of Baja California, Chiapas, Colima, Guerrero, Jalisco, Morelos, Sinaloa, and Tamaulipas (Arriola-Padilla et al. 2016, Carrillo Sánchez et al. 1996, Miller 1996). The parasitoid *Coccophagus bimaculatus* Myartseva (Hymenoptera: Aphelinidae) emerged from this soft scale collected on leaves of jackfruit in the locality El Crucero, El Capomo, Compostela, Nayarit. *Coccophagus scutellaris* (Dalman) has been reported parasitizing *M. mangiferae* in Mexico (Myartseva et al. 2012), whereas, in Israel, *Coccophagus*

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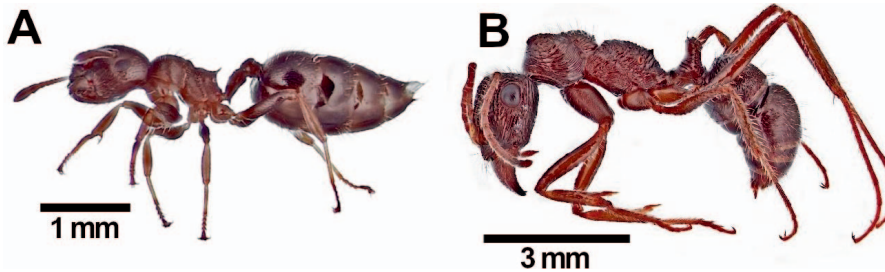

Fig. 2. Ants associated with the mango shield scale: *Crematogaster crinosa* (Formicidae: Myrmicinae) (A) and *Ectatomma ruidum* (Formicidae: Ectatomminae) (B).

lycimnia (Walker), *Coccophagus eritraensis* Compere, *C. scutellaris*, *Coccophagus bivittatus* Compere (Hymenoptera: Aphelinidae), *Diversinervus elegans* Silvestri, and *Microterys nietneri* (Motschulsky) (=*Microterys flavus*) (Hymenoptera: Encyrtidae) have been recorded parasitizing *M. mangiferae* (Avidov and Zaitzov 1960, Gerson and Applebaum 2019, Wysoki et al. 1993). *Milviscutulus mangiferae* was observed associated with *Crematogaster crinosa* Mayr (Hymenoptera: Formicidae) (Fig. 2A) and *Ectatomma ruidum* (Roger) (Hymenoptera: Formicidae) (Fig. 2B). *Milviscutulus mangiferae* individuals may be found on leaf buds and leaves and are attended by ants such as *C. crinosa* or *E. ruidum*, which can defend the scale against natural enemies. In our study, *M. mangiferae* was observed sporadically feeding on jackfruit leaves, branches and, in few cases, fruits in Nayarit. Regarding ants, *C. crinosa* had the widest distribution and association with species of soft scales. According to Vázquez-Bolaños (2015), *C. crinosa* is widely distributed in Mexico, recorded in 14 states, while *E. ruidum* is distributed in nine states. However, there is no record of distribution of *E. ruidum* in the state of Nayarit, Mexico. Gullan (1997) and Styrsky and Eubanks (2007) mentioned that species of the genus *Crematogaster* have an association with scale insects, mainly in tropical regions. Morrison (1929) reported species of *Crematogaster*, among others, attending colonies of coccids and pseudococcids in Panama.

The activity of these ant species that attend scale insects generally affects the scales natural enemies (Reimer et al. 1993, Way 1963). However, it is necessary to determine whether any of these species of ants have a mutualistic relationship with some soft scales, for example, whether they exploit the soft scales' honeydew in return for protection from natural enemies. Moreover, these sugary excretions can cause the growth of sooty mold on foliage and fruits. On foliage, this can affect the photosynthetic activity of the leaves (Abd-Rabou and Evans 2018) and on fruits their cosmetic value. Therefore, when there are sugary excretions on fruits, it should be eliminated in postharvest handling in the packing line.

The striped mealybug, *F. virgata,* was collected on jackfruit leaves and leaf buds in a commercial orchard in El Capomo, municipalities of Compostela, Nayarit, and on leaves of a tree in a backyard of the urban area of Ejido San Vicente, municipality of Bahía de Banderas, Nayarit. *Ferrisia virgata* is a polyphagous cosmopolitan species detected in 102 countries (García Morales et al. 2016). In

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México, it occurs in the states of Chiapas, Guerrero, Michoacán, Nuevo León, Morelos, and Tamaulipas (Arriola Padilla et al. 2016, Carrillo Sánchez et al. 1966, Gaona García et al. 2006, Solís Aguilar et al. 1992). The striped mealybug has been collected in heavy infestations on soursop fruits in commercial orchards in Compostela, Nayarit, and on guava tree trunks in commercial orchards in Calvillo, Aguascalientes (H.G.-H., unpubl. data; Arriola Padilla 2009). The encyrtid parasitoids *Anusioptera* sp. and *Chiloneurus* sp. have been reported on *F. virgata* in Tamaulipas, Mexico (Gaona García et al. 2006).

Recently, Rajkumar et al. (2018) reported the following species of scale insects associated with jackfruit in India: *Drosicha mangiferae* (Stebbing) (Hemiptera: Monophlebidae), the armored scale *Aspidiotus destructor* Signoret (Hemiptera: Diaspididae), the soft scales *M. mangiferae* and *Ceroplastes rubens* Maskell (Hemiptera: Coccidae), and the mealybugs *Nipaecoccus viridis* (Newstead) and *Planococcus lilacinus* (Cockerell) (Hemiptera: Pseudococcidae). In south India, Kallekkattil et al. (2020) reported the pseudococcids *Coccidohystrix insolita* (Green), *F. virgata*, *N. viridis*, *Paracoccus marginatus* Williams & Granara de Willink, and *Planococcus citri* (Risso) infesting tender shoots, leaves, and fruits of jackfruit. Most of these scale insects reported on jackfruit are cosmopolitan and polyphagous.

These results demonstrate that jackfruit production in Nayarit, Mexico, may be impacted by infestations of at least four species of scale insects. Of those four species, the lesser snow scale was the most widely distributed and appeared to be of greatest concern for economic impact on production. Infestations of this scale can affect the aesthetic quality of fruits destined for the export market. Further research should explore methods of managing this pest and its damage to jackfruit grown in Mexico.

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