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Full Length Research

First report of papaya mealybug, *Paracoccus Marginatus* Williams and Granara de Willink (Hemiptera: Pseudococcidae), in Jubek State, South Sudan

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The study on occurrence of papaya mealybug (*Paracoccus Marginatus,* Hemiptera: Pseudococcidae) and its damages on papaya (*Carica papaya*L.) plants in Jubek State (part of former Central Equatoria State)was investigated between August, 2018 and July/September, 2019 for first time. The prime objective of this study was to access the distribution, damage and host range of the pest. So far, the pest (*Paracoccus Marginatus)* has been observed on more than 52 plant species in 27 families. Of these 27 families, 8 genera are from the Malvaceae e.g. *Hibiscus sabdarriffa*, kerkede; *Abelmoschus Esculentus*, okra were heavily infested followed by 4 genera from the Euphorbiaceae of which *Manihot esculenta* (cassava) was severely infested. However, amongst the wide range of host plants observed, papaya (Caricaceae), hibiscus (Malvaceae), Bullock's heart (Annonaceae), cassava (Euphorbiaceae) and guava (Anacardaceae) were amongst those heavily infested. It was observed that most of the plant hosts infested were dicots (88.5%) and monocots (11.5%) suggesting that the papaya mealybug prefer or attack dicots more than monocots. The study recommends a smart IPM (Integrated Pest Management) control (both biological and chemical control) to avert the spread of the pest. This should measures should be enforced while scaling up sound phytosanitary legislative measures which should be imposed on imports of horticultural crops or planting material (which are possible material harbouring mealybugs). Import of fruits should be thoroughly inspected before entry into the country. To date, the control of the pest including; pruning, burning, restriction of infested plants or plant parts, removal of alternative hosts, uses of biopesticides (e.g. neem extracts), soapy water, chemical pesticides (e.g. Diomethoate 30 EC, 2ml L^{-1} of water or Lufenuron/Emamectin). Furthermore, smart IPM and plant hygiene should ensure that, once detected, all infested plants or material should be collected and burned to prevent spread from areas heavy infestation to areas where no pest incidence has been reported. While this survey is a very important bench mark, more information is needed in prediction, surveillance, distribution and abundance of this pest in other states of South Sudan

Keywords: Papaya mealybug, *Paracoccus Marginatus*, occurrence and distribution, IPM, South Sudan

INTRODUCTION

The papaya mealybug, *Paracoccus Marginatus* Williams and Granara de Willink (Hemiptera: Pseudococcidae), is a small, yellowish, polyphagous sucking insect and is considered a significant pest of many tropical and subtropical fruits, vegetables, and ornamental plants (Miller *et al*., 2002). It feeds on the sap of plants by inserting its stylets into the epidermis of the leaf and into the fruit and stem. The infested leaves become crinkled, yellowish, and withered (Tanwar *et al*. 2010; Suganthy *et al.,* 2012; Kirsur*et al*., 2014; Ben-Dov, 2015). At advanced stages of infestation, sooty mold develops on honeydew excreted by this mealybug; this mould eventually covers the leaves, fruits, and stems, impeding photosynthesis and gaseous exchange. The result is chlorosis, plant stunting, leaf deformation, early dropping of the leaves and fruits, a heavy accumulation of honeydew, and finally death of the host plants. The mealybug also deposits a thick, white, waxy material that can make infested plants parts inedible (Muniappan, 2011) and infested papaya trunks and fruits show black (smoke-like colour) or black sooty appearance and candle stick symptoms.

The mealybug(*Paracoccus Marginatus*) is a significant pest of many tropical and subtropical fruits, vegetables, and ornamental plants (Miller and Miller, 2002), and it has a wide host range, including *Carica papaya* L. (papaya),*Persea Americanaa*, P. Mill. (avocado), *Citrus*spp. (citrus), *Solanum Melongenaa* L. (eggplant), *Hibiscus* spp. (hibiscus), *Plumeria* spp. (plumeria), and *Acalypha Wilkesiana* (acalypha) (Walker *et al*., 2006). *P. marginatus* was first described by Williams and Granara de Willink (1992) and redescribed by Miller and Miller (2002) and it is thought to be native to Mexico and Central America (Miller *et al.,* 1999). It is an important pest in the Caribbean Islands and has recently been introduced into the United States (Miller and Miller, 2002) and several other Pacific islands, namely, the Republic of Palau (Muniappan *et al.,* 2006), Guam (Meyerdirk *et al*., 2004), and Hawaii (Heu *et al*., 2007). The first discovery of *P. Marginatus* in the United States was in Manatee, Palm Beach, and Broward counties of Florida in 1998 (Miller and Miller, 2002). It potentially posed a threat to numerous agricultural products in Florida as well as similar crops grown in other states (Walker *et al*., 2006).This invasive exotic pest is believed to be native of Mexico and/or the Central America region (Miller *et al.*, 1999). It was later reported in Costa Rica and Mexico (Williams and Granara de Willink, 1992; Miller *et al*., 1999).

The pest was first described by Williams and Granara de Willink (1992) and later re-described by; Miller *et al*., 2002. Thereafter, it has spread to more than 15 countries worldwide (Tanwar *et al*., 2010). The papaya mealybug has never gained the status of a serious pest in its native place probably due to the presence of an endemic natural enemy complex (Cugala *et al*., 2013). However, in places where it was introduced without their native natural enemies, it is a serious threat to numerous agricultural products (Tanwar *et al*., 2010). It is an important pest in the Caribbean Islands and since then it had been recently been introduced in the United States (Miller and Miller, 2002). Over the next decade, there were additional reports from many countries in Oceania, Asia, and Africa (Meyerdirk *et al*., 2004; Muniappan *et al*., 2006, 2008, 2009; Muniappan, 2009).

In 2002, it was reported in the Pacific Islands (Meyerdirk *et al*., 2004; Muniappan *et al*., 2006), Guam (Meyerdirk *et al*., 2004), and in 2008 Southeast Asia in Indonesia, India, and Sri Lanka (Muniappan *et al.*, 2008). It was later reported from Bangladesh and the Maldives in 2009 and Cambodia, Philippines and Thailand in 2010 (Muniappan *et al.*, 2011), China (Tanwar *et al*., 2010; Ahmed *et al*., 2015).

Papaya mealybug (PM), *Paracoccus Marginatus*, was first detected on the African continent (West Africa) towards the end of 2009 where local outbreaks caused severe damage in papaya orchards near Accra, Ghana. It caused severe economic losses in 85% of all papaya farms in the papaya growing regions (Cham *et al*., 2011).Since then the occurrence of the pest was reported in many other countries of the region such as Benin, Nigeria, Togo, and Gabon, (Muniappan *et al*., 2009; IITA, 2015). In Eastern and Southern Africa, it was recorded in Mauritius, Reunion, Seychelles, and Tanzania (Muniappan *et al*., 2009; IITA, 2015), Mozambique in Memba-Cabo Delgado (Cugala *et al*., 2013), Kenya in Mwale and Mombasa (2016),and Malawi (2017).

Since papaya is a major export fruit and mayor producing countries being Mexico, Brazil (1,450,000 Mt), Nigeria (748,000 Mt), India (644,000 Mt), (612,910 Mt), and Congo DR (213,000 Mt)(FAO, 2001), there is a danger if this invasive pest unabatedly spread to these major producing countries, the horticultural industry would be seriously threatened or paralysed.

In general, pawpaw crops have shown a continuous and stable growth and importers are confident of the future of this market. However, occurrence of such devastating pest poses a potential threat to papaya production worldwide.

The main consumer markets are usually supplied by one major supplier; in the case of the US markets, most of the fruit is supplied by Mexico, whereas for Europe, Brazil is the main exporter, and Japan's demands are covered by the US via Hawaii (Mejía, 2003).

Just after Brazil, India is the second world producer with 40,000 hectares (ha) and a total production of 400,000 metric tonnes (MT) and a yield of 11.25 Tonnes/ha. Other important producers include: Indonesia with 336,068 MT, China with 149, 163 MT and Philippines with 67,000 MT ((Medinilla, 2000).

Nigeria is the main producer in the African continent with 751,000 MT, with a 90,000 ha devoted to the crop, and together with South Africa, Mozambique and Congo are the most important producers, however, none of them have reported any exports of the crop (Mejía, 2003).

In South Sudan, the mealybug insect *per se* is not a stranger to the country as it is common in cassava plants. Of recent, the pest was spotted in Somba Luri in 2013 in cassava fields barely 25 km from Juba Town. However, the scale with which the outbreak of this invasive and devastating pest is spreading among major horticultural, agricultural and wild species including weeds warrant a thorough investigation into the distribution, the population dynamics and economic losses inflicted by the pest under investigation.

In this study, we provide the first report of its occurrence in former Central Equatoria State with particular focus on Jubek State and its implications on the livelihoods of small scale farmers.

MATERIALS AND METHODS

Study area

The study on the occurrence of papaya mealybug (*Paracoccus Marginatus***,** Hemiptera: Pseudococcidae) and its damages on papaya (*Carica papaya* L.) plants were investigated in Jubek State (formerly Central Equatoria State) between August 2018 and July/September, 2019. Jubek State is administratively divided into seven (7) counties namely Juba, Kator, Rejaf, Luri, Gondokoro, Lokiliri, and Mongalla (Fig.1). Study areas included HaiMalakal, MTC (Mechanical Training Centre), HaiJalaba and Hai Cinema (Juba County), Nyaying and Gabat (Gondokoro County), Gumbo (Rejaf County), Kator and Konyokonyo (Kator County), Gu'dele (Block 5 and 8) and Munuki (Munuki County), Gurei and Kapuri (Luri County), In one of field excursions, the heavy mealybug were observed on cassava plant in a farm about 25 Km NW of Juba Town in LuriSomba in 2013.

Sample collection

Pawpaw stems, leaves and fruits and adjacent weed plants, as mentioned earlier, were carefully examined for symptoms of infestation and clustering of insect colonies. The morphological and taxonomical characters of the pests were confirmed according to Miller and Miller (2002).

Damage and infestation assessment

Infestation of papaya by mealybug (Paracoccus Marginatus, Hemiptera: Pseudococcidae) and its damage on papaya (Carica papaya L.) plants were assessed by scoring on a scale of 1 to 5 (where 1= no infestation or negligible, 2= infestation restricted to the growing points only; 3= moderately severe infestation of most leaves; 4= severe infestations and appearance of sooty moulds on leaves; 5= very severe infestation of leaves, heavy sooty molds, and appearance of candle stick symptoms and dead plants). Where infested papaya plants were spotted, adjacent plants including annual and perennial weed species were also inspected for possible infestation.

Figure 1: Study area on the occurrence of papaya mealybug (Paracoccus Marginatus, Hemiptera: Pseudococcidae)

Symptoms of infestation

Symptoms of infestation were scored as very severe (5), severe (4), mild (3), less severe (2) or negligible (1) on both cultivated and wild plants. Heavy infestation and masses of mealybugs on the aerial parts and the mealybugs on papaya plants are shown in Fig 2 (C). And, light infestations on the fruits and leaves are shown in Fig. 2 (D & E). In severe infections the insects were found on infected portions, while the leaves and fruits produce milky sap (Fig. 2). In heavily infested plants, leaves and fruits withered, decayed include chlorosis, distortion, early leaf and death of the plant.

Phylogenetic analysis

Phylogenetic analysis of families/species infested by PM was performed based on Ward's method (Ward, 1963). Ward's method, one clustering methods, for tree building of the general categories, is a method used for constructing phylogenetic trees based on hierarchical clustering. Here, we used to the two classes; Dicotyledonae and Monocotyledonae to interpret how they differ based on preference of pest infestation where the leaves in the dendrogram represent families

Figure 2: Mealybug (sooty mold) on papaya fruits (A), cotton plant infested with pest (B), papaya tree shoot almost wilting (C), bullock's heart fruit infested (D) and heavily infested papaya leaf (E)

Table 1: Number of plant species with their scientific and local names, family, severity or symptoms of infestation and location of areas surveyed.

S/n	Scientific name	Common/local name (type)	Family name	Location	*Symptom/severity
1.	*Abutilon figarianum*	Indianmallow, velvetleaf (W)	Malvaceae	Hai Gonya (Ministries)	4
2.	*Annona reticulata*	Bullock's heart (F)	Annonaceace	MTC, Gu'dele (8)	3
3.	*Adansonia digitata*	Boabob (Gungules) (NP/F)	Malvaceae	Hai Malakal, UofJ, Gu'dele (B)	2
4.	*Bidens pilosa*	Black jack (W)	Asteraceae	Mina (Juba River Port)	3
5.	*Cajanus cajan*	Pigeon pea (Burukusu) (P/L)	Fabaceae	Gu'dele (8)	3
6.	*Carica papaya*	Papaya (Payipayi) (F)	Caricaceae	All areas surveyed	4
7.	*Cassia tora*	Sickle senna (Nyagwa) (W/NP	Caesalpiniaceae	Mina (River Port), Ministries	3
8.	*Cadaba farinose*	Kokuri (W)	Capparaceae	Gumbo, Mission (ECSS)	2
9.	*Calotropis procera*	Apple of Sodom (Usher) (W)	Apocynaceae	Hai Gonya (Ministries)	1
10.	*Cnidoscolus aconifolius*	Chaya/tree spinach (V/M)	Euphorbiaceae	UofJ	2
11.	*Ceiba pentandra*	Silk cotton tree	Bombacaceae	UofJ	2
11.	*Cordium variegatum*	Codium (O)	Euphorbiaceae	Nyokuron West	2
12.	*Commelina benghalensis*	Spiderwort (Lo'bulutat) (W)	Commelinaceae	Mission(ECSS)	2
13.	*Corochorus oliterus*	Jew's Mallow (Gudura) (V/W)	Malvaceae	Mina (Juba River Port)	3
14.	*Citrus lemon*	Lemon (F)	Rutaceae	Gu'dele (8)	2
15.	*Datura stranonium*	Jimsonweed, Devil's snare	Solanaceae	UofJ	2
16.	*Dieffenbachia aurantica*	Mother-in-law's tongue (O)	Araceae	UofJ	2
17.	*Dioscorea rotundata* L.	Yam (T/V)	Dioscoreaceae	Gu'dele	1
18.	*Duranta erecta* L.	Duranta (OH)	Verbenaceae	Gu'dele, UofJ	2
19.	*Euphorbia tithymaloides*	Pedilathus (O)	Euphorbiaceae	Gu'dele (8), Munuki	1
20.	*Euphorbia spp.*	Slipper spurge (O)	Euphorbiaceae	Gu'dele (5 &8)	1
21.	*Gossypium hirsutum* L.	Cotton (Gutun) (FC)	Malvaceae	Gu'dele (8)	2
22.	*Hibiscus sabdariffa*	Hibiscus(Kerkede) (B/M/V)	Malvaceae	Mina (Juba River Port), Ministries	4
23.	*Hibiscus cannabinus*	Wild kenaf (Pala) (FC/W)	Malvaceae	Juba Teaching Hospital (JTH)	2
24.	*Hibiscus esculentus*	Okra (Bamia) (V)	Malvaceae	Mina (Juba River Port), Ministries	2
25.	*Ipomea spp.*	Awiir (V)	Convolvulaceae	MTC, Ministries	2
26.	*Ipomeae batata*	Sweet potato (T/V)	Convolvulaceae	MTC, Ministries	2
27.	*Jatropha curcas*	Jatropha (Khiruwa((M)	Euphorbiaceae	Gu'dele (5)	2
28.	*Lanctana camara*	Common lantana (O/W)	Verbenaceae	Hai Malakal, Mission (ECSS)	2
29.	*Leonotis mollissimo*	Christmas candlestick	Lamiaceae	MTC, UoJ	1
30.	*Leucas aspera*	(W)	Lamiaceae	MTC	2
31.	*Luffa 5ylindrical.*	Luffa (Lifa) (W)	Cucurbitaceae	MTC, Gu'dele (8)	3
32.	*Mangifera indica*	Mango (Manga) (F)	Anacardaceae	Mina (Juba River Port),Gu'dele (8)	5
33.	*Manihot esculenta*	Cassava (Bafura) (T/V)	Euphorbiaceae	Ministries (Hai Gonya)	5

34.	*Momordica spp.*	NA (W)	Cucurbitaceae	Hai Malakal, Mission (ECS)	2
35.	*Ocimum basilicum*	Sweet basil (Lomureju) (M)	Labiateae	Mina (Juba River Port)	3
36.	*Passiflora edulis*	Passion fruit (F)	Passifloraceae	Atlabara C	2
37.	*Periploca nigrescens*	'Periploca' (O/W)	Asclepiadaceae	UofJ	2
38.	*Phaseolus spp.*	Dungwo (PL)	Fabaceae	Gu'dele (8)	2
39.	*Phoenix dactylifera*	Balah (F)	Arecaceae	Gu'dele (Bowaba)	1
40.	*Pithecellobium dulce*	Thomr Hindi (NP/F)	Fabaceae	Gu'dele (Buwaba)	2
41.	*Psidium guajava*	Guava (F)	Anacaridaceae	Hai Malakal, Mission, Gu'dele (8), Munuki	4
42.	*Sesamum indicum*	Sesame (simsim) (OS)	Pedaliaceae	Atlabara C	2
43.	*Solanum dubium*	Guli (W)	Solanaceae	Juba Teaching Hospital(JTH)	4
44.	*Solanum melongena* L	Eggplant (Asuwat) (V)	Solanaceae	Hai Gonya (Ministries)	4
45.	*Senna siamea*	Siamea (M)	Fabaceae	Hai Jalaba, Gu'dele (8)	1
46.	*Starchypheta cayennesis*	Snake weed, rat tail (W)	Astraceae	Hai Malakal, Mission (ECSS)	2
47.	*Sida alba*	Broom (Lugbare) (W)	Malvaceae	Hai Malakal	2
48.	*Spathodea campanulata*	African tulip tree (O)	Bignoniaceae	Hai Jalaba	2
49.	*Tectona grandis*	Teak (Tik) (F/TW)	Lamiaceae	Gu'dele (8), Munuki	2
50.	*Urtica herba*	Sting nettle (W)	Verbenaceae	Mission (ECSS)	2
51.	*Xanthium stranarium*	Shilnimaak (W)	Asteraceae	Mina, MTC, Ministries	3
52.	*Zizihpus spina-christi* L.	Christ's thorn (Nabak) (NP/F)	Rhamnaceae	Gu'dele (8)	3

Key: *Symptoms of infestation was scored as very severe (5), severe (4), mild (3), less severe (2), none (1); locations: ECSS (Episcopal Church of South Sudan), MTC (Mechanical Training Centre), and JTH (Juba Teaching Hospital; UofJ (University of Juba), Gu'dele (5 & 8 are Block 5 & 8, respectively); Scientific names (synonyms),*Cassia tora* (syn. *Senna tora*), *Commelina comminus (11), Abelmoschus esculentus (Hibiscus esculentus)* (22),*G. barbandus* (19), *Pedilanthus tithymaloides* (17), *Luffa aegyptiaca* (28), *Laportea aestuans* (37) (syn. *Fleurya aestuans,* Urticaceae)(Bown, 2013); Type/use: B/M/V= beverage/medicinal & vegetable, F= fruit, FC/W = fiber crop/wild, FC= fiber crop, F/TW= forest/timber (wood), M= medicinal plant, NP/F = neglected plant/fruit, O=ornamental plant, OH = ornamental hedge, OS= oilseed, O/W= ornamental or wild plant, PL=pulse/legume, T/V= tuber & vegetable, W= weed or wild plant, V= vegetable, V/W= vegetable/weed, NA, not available

Table 2: Various host families of cultivated and wild species and number of genera infested within the family.

	Family	Number of Genera	Group (Class in Eukaryota Domain)
1.	Anacardaceae	2	Dicotyledon (Dicot)
2.	Annonaceace	1	Dicotyledon (Dicot)
3.	Apocynaceae	1	Dicotyledon (Dicot)
4.	Araceae	1	Monocotyledon (Monocot)
4.	Arecaceae	1	Monocotyledon (Monocot)
5	Asclepiadaceae	1	Dicotyledon (Dicot)
6.	Asteraceae	2	Dicotyledon (Dicot)
7.	Bignoniaceae	1	Dicotyledon (Dicot)
8.	Bombacaceae	1	Dicotyledon (Dicot)
9.	Caesalpiniaceae	2	Dicotyledon (Dicot)
10.	Capparaceae	1	Dicotyledon (Dicot)
11.	Caricaceae	1	Dicotyledon (Dicot)
12.	Commelinacease	1	Monocotyledon (Monocot)
13.	Convolvulaceae	2	Dicotyledon (Dicot)
14.	Cucurbitaceae	2	Dicotyledon (Dicot)
15.	Euphorbiaceae	5	Dicotyledon (Dicot)
16.	Dioscoreaceae	1	Dicotyledon (Dicot)
17.	Fabaceae	4	Dicotyledon (Dicot)
18.	Labiateae	2	Dicotyledon (Dicot)
19.	Lamiaceae	2	Dicotyledon (Dicot)
20.	Malvaceae	8	Dicotyledon (Dicot)
21.	Passifloraceae	1	Dicotyledon (Dicot)
22.	Pedaliaceae	1	Dicotyledon (Dicot)
23.	Rhamnaceae	1	Dicotyledon (Dicot)
24.	Rutaceae	1	Dicotyledon (Dicot)
25.	Solanaceae	3	Dicotyledon (Dicot)
26.	Verbenaceae	2	Dicotyledon (Dicot)

Table 3: *Survey of the worldwide invasion (from native origin to the tropics) of *Paracoccus marginatus* since the first reports of its invasiveness

First reported	Location	Region	Origin	References
1992	Belize	South/Central America	Native	Williams & de Willink, 1992; Miller *et al*., 1999; Pollard, 1999; Miller & Miller, 2002
1992	Costa Rica	South/Central America	Native	Williams & de Willink, 1992; Miller *et al*., 1999; Pollard 1999; Miller & Miller, 2002;
1992	Guatemala	South/Central America	Native	Williams & de Willink, 1992; Miller *et al*. 1999; Pollard, 1999; Miller & Miller, 2002
1992	Mexico	South/Central America	Native	Williams & de Willink, 1992; Miller *et al*., 1999; Pollard, 1999; Miller & Miller, 2002
1994	Antigua	Caribbean	Introduced	Muniappan, 2009
1994	Dominican Republic	Caribbean	Introduced	Pollard, 1999; Muniappan, 2009
1994	Grenada	Caribbean	Introduced	Muniappan, 2008
1994	U.S. Virgin Islands	Caribbean	Introduced	Pollard, 1999; Muniappan, 2009
1996	British Virgin Islands	Caribbean	Introduced	Muniappan, 2008
1996	Saint Martin	Caribbean	introduced	Pollard, 1999; Muniappan, 2009; Muniappan *et al*., 2009
1998	Barbuda	Caribbean	Introduced	Pollard, 1999
1998	Guadeloupe	Caribbean	Introduced	Matile-Ferrero & Etienne, 1998; Muniappan, 2009
1998	Haiti	Caribbean	Introduced	Pollard, 1999; Muniappan, 2009
1998	Manatee and Broward counties, Florida, USA	North America	Introduced	Miller *et al*., 1999; Pollard, 1999; Miller & Miller, 2002; Muniappan, 2009
1998	Saint-Barthelemy	Caribbean	Introduced	Muniappan ,2009
1998	St. Kitts and Nevis	Caribbean	Introduced	Pollard, 1999; Muniappan, 2009
1999	Cuba	Caribbean	Introduced	Muniappan, 2008
1999	French Guyana	Caribbean	Introduced	Matile-Ferrero *et al*., 2000; Muniappan, 2008
1999	Netherlands Antilles	Caribbean	Introduced	Pollard, 1999
1999	Puerto Rico	Caribbean	Introduced	Pollard, 1999; Muniappan, 2009
2000	Barbados	Caribbean	Introduced	Muniappan, 2009
2000	Cayman Islands	Caribbean	Introduced	Muniappan, 2009
2000	Montserrat	Caribbean	Introduced	Muniappan, 2009
2000	Bahamas	Caribbean	Introduced	Muniappan, 2009
2002	Guam	Oceania		Meyerdirk *et al*., 2004; Muniappan, 2009
2003	Palau	Oceania	Introduced	Muniappan *et al*., 2006; Muniappan, 2009
2004	Hawaii, USA	North America	Introduced	Heu *et al*., 2007; Muniappan, 2009
2005	northern Mariana Islands	Oceania	Introduced	Muniappan, 2009; Muniappan *et al*., 2009
2008	Java, Bali, and Sulawesi Islands, Indonesia	Asia (Southeast Asia)	Introduced	Muniappan, 2009; Muniappan *et al*., 2009
2008	Luzon, Philippines	Asia	Introduced	Muniappan, 2009; Muniappan *et al*., 2009
2008	Saint Lucia	Caribbean	Introduced	Jn Pierre, 2008

2008	Sri Lanka	Asia	Introduced	Muniappan, 2009; Muniappan *et al*., 2009; Galanihe *et al*., 2010
2008	Tamil Nadu, India	Asia	Introduced	Muniappan, 2009; Muniappan *et al*., 2009; Ayyasamy & Regupathy, 2010; Suresh *et al*., 2010
2008	Bangkok, Thailand	Asia	Introduced	Muniappan, 2009; Muniappan *et al*., 2009
2008	Joydebpur, Bangladesh	Asia	Introduced	Muniappan *et al*., 2008
2009	Jammu, India	Asia (Indian Subcont.)	Introduced	Sharma *et al*., 2013
2009	Joydebpur, Bangladesh	Asia	Introduced	Muniappan, 2009; Muniappan *et al*., 2009
2009	Kerala, India	Asia (Indian Subcontinent)	Introduced	Krishnakumar & Rajan, 2009; Lyla & Philip, 2010
2009	Malaysia	Asia	Introduced	Mastoi *et al*., 2011
2009	Maldives	Asia	Introduced	Muniappan, 2009; Muniappan *et al*., 2009
2009	NsawamKede, Ghana	Africa (West Africa)	Introduced	Muniappan, 2009; Muniappan *et al*., 2009; Cham *et al*., 2011.
2009	Hilacondji, Benin	Africa (West Africa)	Introduced	Muniappan, 2009; Muniappan *et al*., 2009
2009	Lomé, Togo	Africa (West Africa)	Introduced	Muniappan, 2009; Muniappan *et al*., 2009
2009	Siem Reap, Cambodia	Asia (Southeast Asia)	Introduced	Muniappan, 2009; Muniappan *et al*., 2009
2009	Thailand	Asia	Introduced	Muniappan, 2009; Muniappan *et al*., 2009
2010	Réunion	Africa (Southeast Africa)	Introduced	Germain*et al*., 2010
2010	Pune region of Western Maharashtra , India	Asia (Indian Subcont.)	Introduced	Pokharkar *et al*., 2011; Mundale and Nakat, 2011; Chandale *et al*., 2011; Nakat *et al*., 2011
2011	Karnataka, India	Asia (Indian Subcont.)	Introduced	Shekhar *et al*., 2011
2011	Oman	Asia, Middle East (Arabia Peninsula)	Introduced	CABI unpublished data; Muniappan, 2011
2011	Taiwan	Asia	Introduced	Chen *et al*., 2011
2012	Assam, India	Asia	Introduced	Sarma, 2013
2012	Rajasthan, India	Asia	Introduced	Mani *et al*., 2012
2013	Memba-Cabo Delgado, Mozambique	Africa (Southern Africa)	Introduced	Cugala *et al*., 2013
2014	Guangzhou, China	Asia	Introduced	Ahmed *et al*., 2015
2014	Mauritius	Africa	Introduced	Germain *et al*., 2014
2014	Yunnan, China	Asia	Introduced	Ahmed *et al*., 2015
2015	Tanzania	Africa (East Africa)	Introduced	Muniappan *et al*., 2009; IITA, 2015
2016	Mwale and Mombasa	Africa (East Africa)	Introduced	This study (2016)
2017	Lilongwe, Malawi	Africa (Southern Africa)	Introduced	www.malawi24.com
2018	Juba, South Sudan	Africa (East Africa)	Introduced	This study (2018)
2019	Juba, South Sudan	Africa (East Africa)	Introduced	This study (2019)

Key: *Modified from Ahmed *et al*. (2015); South. African (Southern African region), W. Africa (West Africa), SE Asia (Southeast Asia), ME (Middle East), Subcont. (Subcontinent)

RESULTS AND DISCUSSION

This study has tentatively recorded the presence of Paracoccus. marginatus in 7 counties of Jubek State (part of former Central Equatoria State: Juba County, Kator County, Rejaf County, Luri County, Munuki County, and Gondokoro County (Fig. 1). The specimens collected (Table 1.) showed that Paracoccus Marginatus occurred widely and was recorded on more than 52 host plant species from 26 families namely; Anacardaceae (Mangifera Indica, mango), Annonaceace (Annona reticulata, Bullock's heart;A. Cherimoya, A. muricata, A. squamousa), apple of Sodom/ushar), Asteraceae (Xanthium brasillicum, X. stranarium, Shilnimaak),Arecaceae(Phoenix dactylifera,Balah), Bignoniaceae (Spathodea Campanulata, African tulip tree), Caesalpiniaceae (Sennasiamea, siamea and Cassia tora, nyagwa), Capparaceae (Calatropisprocera, apple of Sodom/ushar), Caricaceae (Carica papaya, pawpaw), Commelinaceae (Commelina Communis, C. bengalensis), Convolvulaceae (Ipomeabatata, Ipomeaspp,), Cucurbitaceae (Luffacylindrica, L.aegyptiaca, Momordica spp.), Euphorbiaceae (Manihot esculenta, cassava),Dioscoreaceae (Dioscorea rotundata L., yam), Fabiaceae, Labiateae (Ocimum basilicum, rihan), Lamiaceae (Tectona Grandis, teak), Malvaceae (Gossypium Hirsutum, G. barbadens, cotton; Hibiscus sabdariffa, Kerkede; H.cannabinus, wild kenaf; Abelmoschus Esculentus, okra), Rhamnaceae (Zizihpusspina-christi, nabak), Rutaceae (Citus lemon, lemon), Solanaceae (Solanum Melongenaa, eggplant, and S. dubium, guli, Lycopersicumlycopersicon, tomato), and Verbenaceae (Lantana camara, common lantana, Urticaherba, sting nettle) and several species (Table 1). During one field excursions, a heavy mealybug infestation was observed on cassava plants in a farm about 25 Km North West of Juba Town in Luri Somba in 2013. Based on our observations, it is probable that this pest might have been introduced into South Sudan through planting materials which later spread to papaya until it reached this devastating infestation levels that is being reported here. Alternatively, a new pest might have been introduced through the southeast African route where it was recorded in Mozambique (2013), Tanzania (2015), and Kenya (2016),Malawi (2017). Initially, the route of entry of the pest given the trend of the spread and distribution, two (2) possible routes could be identified that is; the West African route and Southeast African route. Nevertheless, given that the mealybugh as a wide host range and is therefore capable of attacking several plant species including vegetables such as okra, Jew's mallow, cash crops (hibiscus, cotton) ornamental plants (slipper spurge, Euphorbia sp., African tulip tree (Spathodea Campanulata, Bignoniaceae) and other economically important fruits (papaya, lemon, mango, and guava)and ornamentals (Codiaeum Variegatum, Garden croton) etc.

The question is now why is the mealybug spreading very fast and invading new territories? This is not only a challenging problem, butit implies that in the presentstatus quomore research into the biology and population dynamics of this pest be conducted to fully elucidate all associated characteristics. Currently, the wealth of data available on this invasive pest isunravelling to better understand the nature of its adaptability and distribution. Also, study on the effect of temperature on the life history of the mealybug (Paracoccus Marginatus Williams & Granara de Willink, Hemiptera: Pseudococcidae) was investigated and this in the revealed thatP. marginatus was able to develop and complete its life cycle at 18, 20, 25, and 30±1°C suggesting that Paracoccoushas the ability to develop, survive, and reproduce at temperatures 18, 20, 25, and 30°C (Amarasekare et al., 2008).Therefore, the ability ofP. Marginatusto develop, survive, and reproduce successfully between 18 and 30°Calso suggests that it has the capability to develop and establish in areas within this temperature range (Amarasekare et al., 2008).This information would also be helpful in development of management options targeting the susceptible stages of P. Marginatusat different environmental temperatures, for instance, an extended development time of eggs and the immature stages of P. Marginatusat low temperatures may increase their exposure to natural enemies and insecticides (Amarasekare et al., 2008). Furthermore, early-instar mealybugs are easier to control than late instars (Townsend et al., 2000). Amarasekare et al. (2008) also indicated that at high temperatures of (25 and 30°C)P. Marginatus Nymph develop rapidly and become adults 2-3times sooner than atlow temperatures (18 and 20°C), which may reduce exposure time to natural enemies and insecticides. Hence, the ability of an insect to develop at different temperatures is an important adaptation to survive in various climatic conditions (tropical, subtropical, and temperate), which is important in predicting insect pest outbreaks (Mizell and Nebeker, 1978). Temperature is therefore, one of the most important and critical to abiotic factors that can affect insect development as well as influence the population dynamics of insect pests and their natural

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enemies' alike (Huffaker et al., 1999). The rate of insect development is affected by the temperature to which the insects are exposed (Campbell et al., 1974). Insects require a certain amount of heat units(degree-days) to develop from one life stage to the next (Gordan, 1999). Therefore, it could be suggested that the reason why the papaya mealybug (PM) is spreading very fast and invading new territories (Table 3.) may be attributed to (1) absence of natural enemies, (2) adaptability and ability to survive at different environmental conditions. The rate of the insect development is affected by temperature to which the insects are exposed (Campbell et al., 1974). Although their findings were unable to address other factors despite the data available as to whether certain external factors contributed to the rapid spread ofP. marginatus populations across Asia (Ahmed et. al., 2015), another report suggests trade of ornamental flowers could have facilitated the invasion of virgin territories (Qian et al., 2007). However, the mealybug itself was reported to have high biological adaptability, ecological adjustability, temperature tolerance, and a wide range of host plants that may help it to establish quickly in newly invaded places (Arifet al., 2009; Hodgson, 2009; Vennila et al., 2011, 2013; Xin et al,.2011). This rapid spread suggests that current quarantine measures have failed to stop the invasion of P. marginatus into other countries, for instance, China and other neighbouring countries.

So far, in South Sudan the pest (Paracoccus Marginatus) has been observed in more than 27 families and more than 52 plant species. In Africa,P. marginatus was first recorded in Ghana (West Africa) in 2009, where it caused economic losses in 85% of all papaya farms in papaya growing regions (Cham et al., 2011). Since then the occurrence of the pest was reported in other countries (Table 3.) of the region such as Benin, Nigeria, Togo, and Gabon, (Muniappanet al., 2009; IITA, 2015). In Eastern and Southern Africa, it recorded in Mauritius, Reunion, Seychelles, and Tanzania (Muniappan et al., 2009; IITA, 2015), (Mozambique in Memba-Cabo Delgado (Cugalaet al., 2013), Kenya in Mwale and Mombasa (2016),and Malawi (2017).

Of the 27 families, 8 genera from the Malvaceae were infested and Hibiscus sabdarriffa (hibiscus, kerkede) and Abelmoschus Esculentus (okra) were heavily infested. So to speak, of all the wide range of hosts observed, it was found that papaya (Caricaceae), kerkede (Malvaceae), cassava (Euphorbiaceae), Bullock's heat (Annonaceae), guava (Anacardaceae) and other wild plant species were heavily infested. A largenumber of economically important fruits, vegetables,and ornamental plants are grown in southern California including citrus, avocado, beans, hibiscus, andplumeria (Amarasekare et al., 2008) And citrus is one of the host plants of P. Marginatus (Walkeret al., 2006).

It was observed that most of the plant hosts infested were dicots (88%) and monocots (12%) suggesting that the papaya mealybug prefer or attack dicots more than the monocots (Fig. 4).The disparity among the two classes (Monocotyledonae and Dicotyledonae) were analysed by phylogenetic (clustering) analysis (Ward, 1963) and it was observed that the monocots were less preferred by the pest (*Paracoccus Marginatus*).

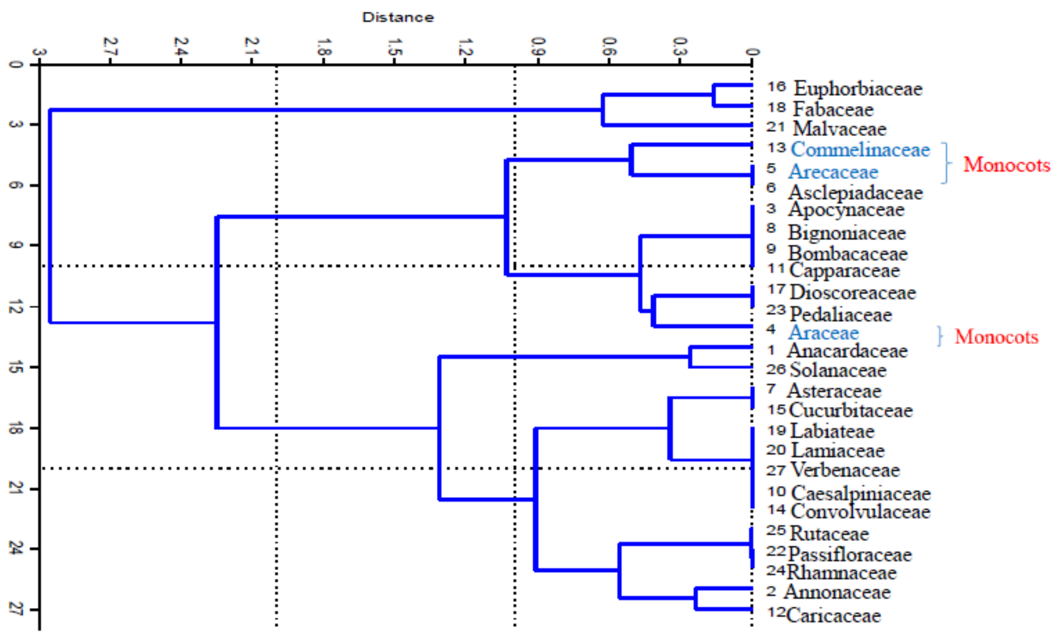

Figure 3: Phylogenetic analysis of plant families and severity infestation by papaya mealybug (PM) [*Paracoccus Marginatus Hemiptera*: Pseudococcidae] showing the disparities between Eukaryota domain as in the two classes: monocots (12%) and dicots (88%). Constrained phylogenetic tree was constructed according to Ward's method (Ward, 1963) (cophenetic correlation Coefficient = 0.753). The values presented here were standardized and transformed using square root √ x +0.5 transformation system

There are several explanations to the later disparity in the two classes. On one hand, it was found that potato and tomato leaves synthesize protein ease inhibitor I & II in response to insect attack, a response illustrating the unique aspects of some plant signal transduction pathways (Palme, 1990; Pearce *et al*., 1991; Fosket, 1994). On the other hand, however, physiologically, active secondary metabolites (e.g. alkaloids) participate in plant chemical defences (Buchanan *et al*., 2000). Moreover, various alkaloids are toxic to insects or function as feeding deterrents (Buchanan *et al*., 2000).

In nature, plants possess a considerable diversity of resistance strategies and produce complex chemical reactions after experiencing mechanical damage or attacks by herbivores (Green and Ryan, 1972). The signal transduction pathways related to plant defence includes the ethylene (ET) pathway, jasmonic acid (JA) pathway, and salicylic acid (SA) pathway. The JA and ET pathway are induced against necrotrophic pathogens, chewing herbivores and cell-content feeders (Thaler*et al*., 2012; Godinho *et al*., 2016). However, the SA signalling pathway is primarily induced by bio-trophic pathogens and piercing-sucking herbivores, resulting in minimal tissue damage (Arena *et al*., 2016). Simultaneously, insects adapt to plant defence strategies by evolving their feeding patterns and feeding behaviour (Hogenhout and Bos, 2011).Differences in morphology and pathogen-host specificities between dicots (Arabidopsis) and monocots suggest that JA biosynthetic or signalling components particular to economically important cereal crops may exist (Lyons *et al*., 2013).

Nevertheless, papaya, which is a very susceptible hostplant, like elsewhere, is the second most important fruit crop afterpineapple, and Hawaii currently has ≈ 864 ha of papaya in production (USDA-NASS, 2007).Some studies have shown that papaya mealybug affects many pawpaw fruits and the damage was serious on the fruits than the leaves and stems(Akpabio and Oboho, 2016). This may influence the quality and nutritional properties of pawpaw with consequent socioeconomic impact. Similar observations were seen on mango trees where floral buds and fruits were more infested than leaves. No sooty moldor waxy growths were detected on both sides of the leaf blade suggesting that plant morphological features can help deter the pest.

Survey of the global invasion of *Paracoccus Marginatus* since the first reports of its invasiveness revealed that this invasive pest is spreading to new territories crossing continents, breaching international boundaries and spreading within country unless a robust control measures are enforced. A similar pest (cassava mealybug, *Search Results* Mat.-Ferr., Homoptera:

Pseudococcidae) was accidently introduced into Africa from the New World in the early 1970's and became the most severe pest on cassava (Neuenschwander, 1994).Fortunately, the results of strategies applied on cassava mealybug could help in tackling the papaya mealybug outbreak. During the Africa-wide Biological Control Project, the neotropical parasitoid *Epidinocarsis Lopezii* (De Santis) (Hymenopteria: Encyrtidae) was established in 26 African countries, causing satisfactory reduction in the population density of cassava mealybug *Search Results*Mat.-Ferr. (Homoptera: Pseudococcidae) in most farmers' fields (Neuenschwander, 1994).

In regard to control of the mealybug, farmers rely on uses of plant extracts, either ashes or concoction of other plant extracts. So far, insecticides failed to give adequate control of *P. Marginatus*becauseit is'hard to kill pest' with conventional insecticides because of cryptic habit and waxy coating over the body (Mani *et al*., 2012).However, uses of predators such as larvae of lady bird beetles and parasitoids, physical control by directing a powerful set of water at infested plant parts have been recommended to reduce the activities of *Paracoccus Marginatus* in the tropics. An integrated pest management (IPM)approach involving cultural practices, legal, chemicaland biological control is advisable.

CONCLUSION AND RECOMMENDATION

This study has revealed that papaya mealybug affects many horticultural fruits including papaya fruits in Jubek State and other peripheral areas. The infestation is devastating on the fruits than the leaves and stems. This may compromise with the marketable quality and nutritional properties of papaya with consequent socioeconomic impact on small scale farmers. To avert the spread of the pest, a smart IPM control (both biological and chemical control) measures should be enforced while scaling up sound phytosanitary legislative measures and should be imposed on imports of horticultural crops, planting material (which are possible material harbouring mealybugs. Import of fruits should be thoroughly inspected before entry to the country. Plant hygiene should ensure that, once detected, all infested plants are collected and burned to prevent spread from areas heavily to area where no pest was been reported. Therefore, an integrated pest management (IPM)approach involving cultural practices, legal, chemical and biological control is advisable. While this survey is very important more information is needed in predicting distribution and abundance of this pest in other states of South Sudan

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