Research articles

DOI 10.55278/OKCN2453

Current status of cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Pseudococcidae) and its indigenous natural enemies observed under field conditions in Namakkal district of Tamil Nadu, India

Thimmegowda P R.*, M. Ayyamperumal, S. Sivarama krishnan, S. N. Shivakumar, C. Elangovan, J. Raju, N. Vasu, M. Karunakaran, D.K. Nagaraju, Om Prakash Verma and J. P. Singh

Directorate of Plant Protection, Quarantine and Storage, Ministry of Agriculture & Farmers Welfare, Department of Agriculture & Farmers Welfare, *Government of India, NH-IV, Faridabad, Haryana -121001.*

Corresponding author: tgowda123@gmail.com

Abstract

The cassava mealybug *Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Pseudococcidae) is one of the most severe pest of cassava in the world. It causes severe damage by stunting the growth points of cassava plants, sometimes totally defoliating the plants and storage root yield loss up to 84 % have been reported from Congo- Central Africa and hence present study was undertaken to assess the current status of invasive pest with respect to its incidence and yield loss. The cassava growing area of nearly 120 ha was surveyed during July and August 2021 in ten number of blocks of Namakkal district of Tamil Nadu. The crop age varied from six to eight months, level of infestation varied from 30 to 100 per cent and yield loss ranges from 30 to 90 per cent. It was observed that, crops namely groundnut, banana and sugarcane were found adjacent to cassava were not infested by the mealybug. *Parthenium hysterophorus, Corchorus olitorius* and *Digera arvensis* were some of weeds found infested by mealybug. Two hemipteran predators' viz., nymphs of reduviid bugs and anthocorid bugs, three ladybird beetles namely, *Scymnus coccivora, Cheilomenes sexmaculata* and *Hyperaspis maindroni* (Coleoptera: Coccinellidae), two neuropteran *Mallada* sp., *Chrysoperla* sp., both grubs and adults were found to be predating on the cassava mealybug.

Keywords: Cassava mealybug, *Phenacoccus manihoti, natural enemies, incidence, invasive pest impact.*

Introduction

Cassava (*Manihot esculenta* Crantz) also known commonly as Tapioca, is an important industrial crop native to North-East Brazil and it is continuing to be a crop of food security for the millions of people especially in the developing countries of the globe. It is an important alternate source of energy to meet the demands of increasing population. Cassava is a good source of dietary fiber as well as vitamin C, thiamin, folic acid, manganese, and potassium. Cassava was introduced into India by the Portuguese when they landed in the Malabar region, presently part of Kerala state during the 17th century, from Brazil (Edison *et al*., 2013). Cassava crop is cultivated predominantly in the southern states, of which Tamil Nadu and Kerala accounts for 51.9 per cent and 31.7 per cent of area with a production of 57.8 per cent and 34.9 per cent respectively. It is also grown in Andhra Pradesh, Karnataka, Madhya Pradesh, Northeastern states and to some extent in Pondicherry and Andaman and Nicobar group of Islands (Sampath kumar *et al.*, 2021).

The cassava mealybug *Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Pseudococcidae) is one of the most severe pest of cassava in the world (Yonow *et al.*, 2017). *Phenacoccus manihoti* is indigenous to South America, where it is found in Argentina, Bolivia, Brazil, Colombia, Guyana and Paraguay. It was accidentally introduced from South America to the Congo Republic in 1973 (Herren and Neuenschwander, 1991). It has spread in Africa to practically all countries where cassava is grown, in a broad belt from West through to East Africa and down to the eastern edge of South Africa.

Phenacoccus manihoti causes severe damage by stunting the growth points of cassava plants, sometimes totally defoliating the plants and storage root yield losses up to 84 % have been reported from Congo- Central Africa (Nwanze *et al*., 1982a). *Phenacoccus manihoti* was first detected in Thailand in 2008 (Winotai *et al*., 2010; Muniappan *et al.,* 2009) and remains a threat to the cassava cultivating areas of southern Asia. Further, its expansion in Asian distribution was also detected at Vietnam, Cambodia, Myanmar and threatens to engulf the cassava growing areas of southern China, Indonesia and Philippines (Wu and Wang, 2011; Parsa *et al.,* 2012). This exotic pest has a wide host range. However, damage and reproduction potential of mealybug is high in cassava compared to other host species. The host range is likely to expand as the species becomes more established and now it has spread into Tamil Nadu.

In India, *P. manihoti* infestation was first reported from Kerala in a students' experimental plots at the Department of Agronomy, College of Horticulture, Kerala Agricultural University, Vellanikkara, Thrissur, Kerala (Joshi *et al*., 2020). Later infestations of cassava mealybug were

reported from Salem, Namakkal, Erode and Dharmapuri districts of Tamil Nadu (Sampathkumar *et al*., 2021). It is likely that the pest has gained entry into the country through trade in tuber crops. For the effective pest management of this exotic pest, identifying exotic or indigenous natural enemies of *P. manihoti* is very essential. Hence, the surveys were undertaken by Central Integrated Pest Management Centre during July and August 2021 to record per cent infestation levels, to estimate the approximate yield losses incurred by the farmers and to identify naturally occurring enemies of cassava mealybug under field conditions.

Material and Methods

The cassava growing area of nearly 120 ha was surveyed during July and August 2021 in ten blocks of Namakkal district of Tamil Nadu. Blocks surveyed were Elachipalayam, Thiruchengode, Kabilarmalai, Mohanur, Namakkal, Erumapatti, Mallasamudram, Vennandur, Rasipuram and Paramathi. Per cent infestation of cassava mealybug was assessed by using parameters namely the number of plants showing Rosette symptoms in a fixed area 100 sq. m at different fields divided by total plants was used. Scoring and per cent infestation level was calculated as described by Nwanze, 1982b. Cassava mealybug specimens and its natural enemies found in the field were carefully collected from the mealybug infested plants using camel brush and transferred into 70% ethyl alcohol. The samples thus, collected were brought to the laboratory at Central Integrated Pest Management Centre (CIPMC), Tiruchirapalli for further studies and identification. The cassava mealybug infested plant parts were also removed from the plant along with mealybug with help of a sharp knife and placed in to polythene bags (25 x15cm) which were sealed with rubber bands and labelled with date and locality of the collection and kept for parasitoids emergence.

Results and Discussion

During the survey, the infestation of mealybug, *Phenacoccus manihoti* in Cassava with all the stages such as ovisacs, nymphs and adults were observed (Figure1.) in all the inspected blocks of Namakkal District of Tamil Nadu. The symptoms such as stunted growth (rosette like appearance), bunched terminal shoots, honey dew excretion with sooty mould (Figure 2.), curling and distortion of leaf shape were observed (Figure 3). Finally the severely affected cassava plants get stunted (Figure 4.) and dried (Figure 5), exhibited less number of tubers with reduced tuber length (Figure 6). As a result, some of the farmers destroyed the severely affected cassava fields by ploughing the soil and burying the affected plants into the soil (Figure 7.). There were no fields which were free from cassava mealybug infestation and all most all the fields were infested. However, there were crops adjacent to cassava fields such as groundnut, banana and sugarcane which was non-infested by *P. manihoti.* There are no authorized nurseries for supplying planting material; hence, farmers

usually collect the propagative material from the cassava plants from the previous season and through these setts mealybug eggs may enter into the new crop as unnoticed. Overall infestation level varies from 30 to 95 per cent and yield loss is raging from 30 to 90 per cent in different blocks of Namakkal district of Tamil Nadu in the month of August 2021 (Table 1).

The natural enemies observed under field conditions were two hemipteran predators' viz., reduviid bug nymphs and anthocorid bugs; three ladybird beetles namely, *Scymnus coccivora* Ayyar, *Cheilomenes sexmaculata* (Fabricius) and *Hyperaspis maindroni* Sicard (Coleoptera: Coccinellidae) Figure 8a. (*Hyperaspismaindroni* **grubs feeds on ovisacs)**, Figure 8b (pu**pa**) and Figure 8c (Adult); two neuropteran predators were *Mallada* sp. and *Chrysoperla* sp., both grubs and adults were found feeding on the cassava mealybug in the infested fields.

Invasive pests such as papaya mealybug, *Paracoccus marginatus Williams and Granara de Willink (Hemiptea: Pseudococcidae)* introduced during 2002 was successfully controlled by encyrtid parasitoid, *Acerophagus papayae Noyes & Schauff* (Hymenoptera: Encyrtidae) in the initial stage of the invasion. This was one of the biggest milestone of classical biological control in India. Likewise, an effective natural enemy, *Anagyrus lopezi* (De Santis) (Hymenoptera: Encyrtidae) of cassava mealybug was recorded in South America (Lohr *et al*., 1990). This host specific parasitoid was then introduced in to West Africa for biological control of the mealybug (Herren and Neuenschwander, 1991). This biological control program was very successful using *A. lopezi* and has provided good control of the cassava mealybug pest in Africa (Zeddies *et al.,* 2001).

Factors responsible for high infestation of cassava mealybug.

a. **Drought:** High infestation level of cassava mealy bug was observed in those plots, where cassava is being grown under rainfed conditions. Here, due to the water stress coupled with high temperature the crop was already under stress and hence, cassava plants may not be able to withstand the infestation of mealybugs. Whereas, flood irrigated or drip irrigated cassava plots are not under water stress and thus these plots could be able to sustain the effect of cassava mealybug better than the crops grown under rainfed condition.

Outbreaks of natural populations of cassava mealybugs occur on cassava every year during the dry season in Africa and South America. In drought-stressed cassava, nutrients such as sucrose and amino acids are either more concentrated or better balanced, such plants are more suitable for the development and reproduction of mealybugs. This has been demonstrated with *Phenacoccus herreni* Cox and Williams. Simultaneously, it

has been demonstrated with *P. manihoti* that, the partial resistance of cassava (both antixenosis and antibiosis) decreases during the dry season. All the above-mentioned conditions were combined to ensure that, the drought-stressed plants are physiologically more favourable for infestation by the cassava mealybugs, and serve to enhance mealybug infestation build up during long dry seasons in the field (Paul-Andre Calatayud and Bruno Le Ru., 2006).

b. **Planting time:** High level of infestation was observed in late planted cassava plots (during November) than the early planted cassava plants (Mar-April). This could be due to the weather conditions and rainfall because the setts which are planted in November 2020 to January 2021 were found severely infested during summer period (March to June). Whereas, setts planted in the months of March to April had low infestation levels. This is due to the rainfall, most of the mealybug population would get washed off due to rain splashes and this could lead to low infestation level. Similar observations were also recorded by Sampathkumar *et al*., 2021.

c. **Type of variety or host resistance:** The cassava variety Mulluvadi released by Tamil Nadu Agricultural University is highly susceptible than the white Thailand variety. Among these two varieties, Mulluvadi was most predominantly grown variety because of its drought resistant character. Since *P. manihoti* is a newly introduced and invasive pest, there have been no resistant varieties available as of now and efforts are needed in this regard to identify resistant or tolerant varieties for Cassava mealybug.

d. **Irrigation and Plant Nutrition:** Irrigated fields with balanced nutrition and well maintained fields recorded low infestation levels compared to the crop grown under rainfed conditions and poorly nourished cassava fields. Infestation by *P. manihoti* is rarely observed in forest regions and in soils which are rich in organic elements (Neuenschwander *et al.*, 1989; 1990). The impact of improved soil fertility in diminishing cassava infestation by *P. manihoti* has been reported also by Schulthess and colleagues (1997), and this finding has been supported by the evidence of Tertuliano and colleagues (1999). Mulching and manures are the best fertilizers in enhancing cassava resistance to *P. manihoti,* as shown by a higher defensive response (*i.e.* the increase of rutin level in leaves after infestation).

e. Natural enemies: Even though *Hyperaspis maindroni* Sicard (Coleoptera: Coccinellidae) and two neuropteran predators *Mallada* sp. and *Chrysoperla* sp., were found feeding on the cassava mealybug in the unsprayed fields, their population in the field conditions were

very low when compared to population density of mealybug. In addition to this, the biocontrol potential of *H maindroni* was severely hampered due to parasitization by a parasitoid, *Homalotylus turkmenicus* Myartseva (Hymenoptera: Encyrtidae) as mentioned in the earlier studies conducted by Gupta *et al*., 2020.

f. **Field sanitation and crop hygiene:** The cassava fields which are not maintained well were most severely infested when compared to fields with good sanitary practices like free from weeds and other alternate host of the pest. Some of the weeds like ***Parthenium hysterophorus*** **(Figure 9),** ***Corchorus olitorius*** **(Figure 10) and** *Digera arvensis* **(Figure 11) were found infested with cassava mealybug** *Phenacoccus manihoti*. These weeds may act as alternate hosts for the survival of mealybug during off season or between two cropping periods. Further, systematic investigations are needed to find out whether the pest can survive and complete all its growth stages on these weeds is the question. Although, it has been collected on plants in various families, such as citrus and tomato, there is no evidence that it can survive for more than one generation on plants other than Manihot and perhaps certain other Euphorbiaceae (Williams and Granara de Willink, 1992).

g. Pesticide sprayed v/s non sprayed fields: The cassava fields which are sprayed with Profenophos 50% EC had low infestation level when compared to fields sprayed with other pesticides. At present there are no label claim pesticides available in the market for the control of mealybugs.

Cassava mealybug had spread across the width of Africa in a period of 16 years. Its accidental introduction damaged a staple crop that is particularly important in times of drought, leading to famine. At present, *P. manihoti* poses a threat to other cassava growing states of India as the invasive pest is reported only from Kerala and Tamil Nadu. Accidental introduction to new territories is possible through the movement of infested living cassava material for propagative purposes through shipping, air transport or by road. *Anagyrus lopezi* (De Santis) (Hymenoptera: Encyrtidae), a parasitoid native to Central America, is being used for the management of cassava mealybug in African and other Asian countries. *Anagyrus lopezi* is host-specific, and environmentally-adaptable (Wyckhuys *et al*., 2018a) it has attained maximum parasitism levels of 97% (in late dry season), which greatly surpass the 33–36% established threshold (of maximum parasitism rate) for successful biological control (Wyckhuys *et al*., 2017). Host specificity studies conducted in different countries indicated that *A. lopezi* could develop only on cassava mealybug (Wyckhuys *et al*., 2018b). In a combined effort of International Institute of Tropical Agriculture (IITA), CABI, Inter-African phytosanitary council (IAPSC) and

other agencies, *Anagyrus lopezi* (De Santis) was shipped to Africa, mass reared and released in the field trials. This was successful throughout sub-Saharan Africa, thus cassava mealybug is now under control and no longer possess threat to cassava production (Cock *et al*., 2009). This indicates that internal collaborations and free exchange of biocontol agents would bring solutions to this invasive pest. Thus in the event of non-availability of effective biocontrol agents, it may be advisable to regulate the trade and movement of propagative material in fresh planting material of cassava from these two southern states (Kerala and Tamil Nadu) to other states of the country. Planting material should be inspected in the growing season previous to shipment and should be free from infestation. Use of certified planting materials might help in restricting or delaying the further spread of the invasive pest.

Figure 1. Nymphs and adults of *Phenococcus manihoti*

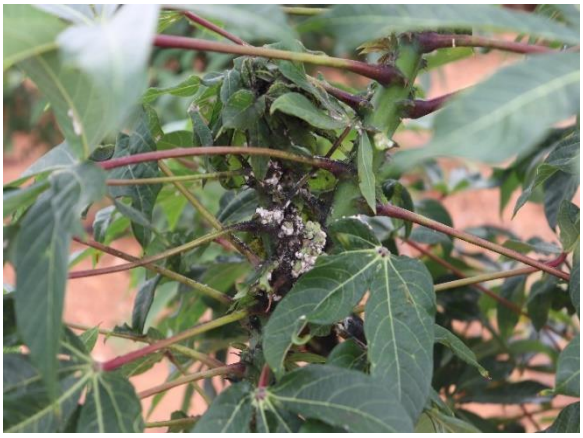

Figure 2. Bunched terminal shoot, honeydew secretion with sooty mold.

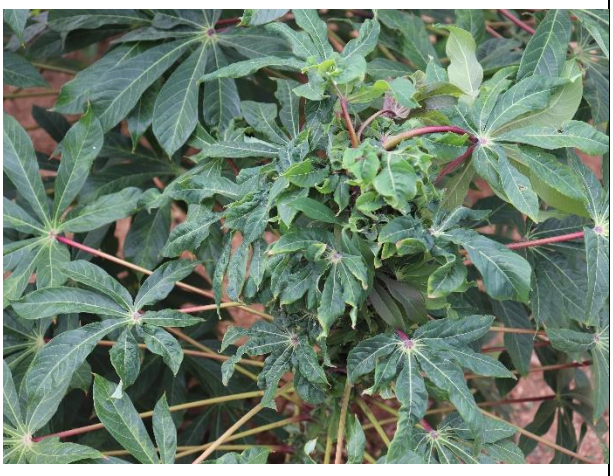

Figure 3a. Curling (rosette appearance) of infested leaves

Figure 3b. Distortion of leaves.

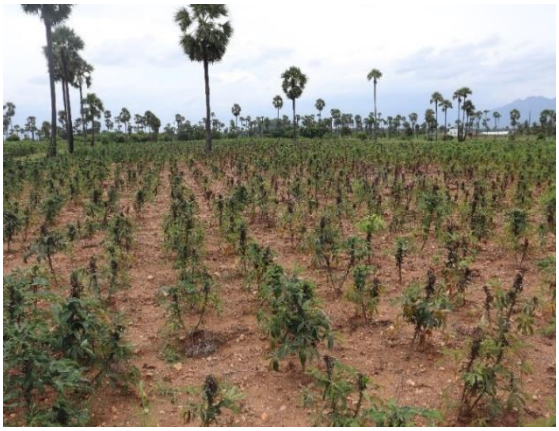

Figure 4. Stunting of infested cassava plants.

Figure 5a. Infested plants getting dried

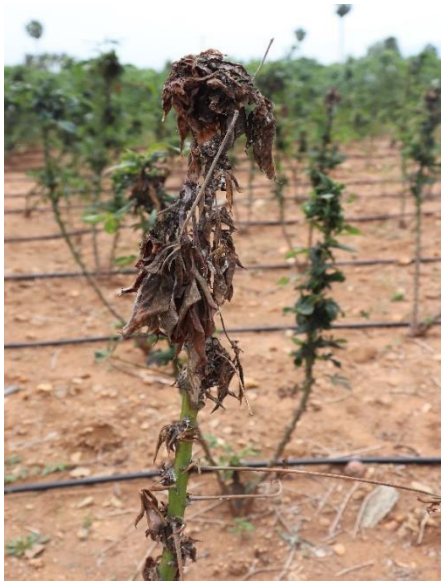

Figure 5b.

Figure 6. Infested plant showing reduced tuber numbers and length.

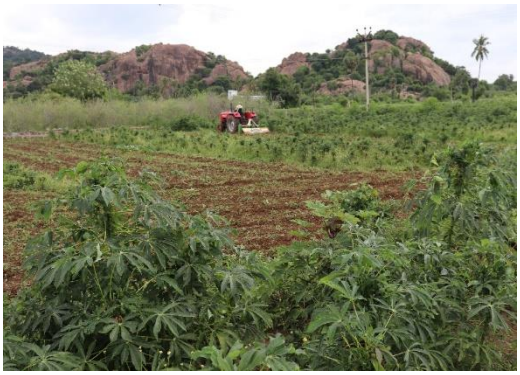

Figure 7. Ploughing and burying of mealybug affected plants.

Figure 8a *H. maindroni* grubs feeding on ovisacs of *P. manihoti*.

Figure 8b. Pupa of *H. maindroni*.

Figure 8c. Adults of *H. maindroni*.

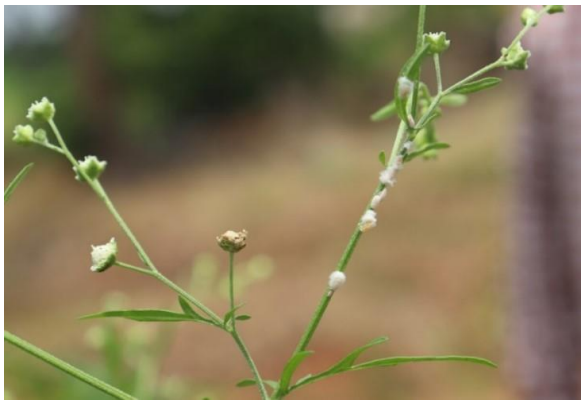

Figure 9. *Parthenium hysterophorus* infested by *P. manihoti*.

Figure 10. Weed *Corchorus olitorius* infested with *P. manihoti*.

Figure 11. Weed *Digera arvensis* infested with *P. manihoti*.

Table 1. Per cent infestation of cassava mealy bug and approximate yield loss (*Phenacoccus manihoti* Matile- Ferrero) in different blocks of Namakkal district, Tamil Nadu.

Sl. No.	Name of the Block	Variety	Age of the Crop (in months)	Crop area (ha)	Per cent infestation (Average)	Approximate yield loss (In %)	Adjacent crops grown	Adjacent crops/weeds infested
1.	Erumapatti block	White rose	6	4	50	60	Banana	Parthenium and *Digeraarvensis* weeds were infested
2.	Namakkal	Mulluvadi	6-8	13	40-60	50-60	Cassava	Yes
							Sugarcane	No
3	Mohanur	Mulluvadi	7-8	21	30-70	30-40	Sugarcane	No
							Groundnut	No
							Coconut	No
4	Paramathi	Mulluvadi	6-8	13	90-100	85-90	Groundnut	No
							Onion	No
							Sugarcane	No
5	Kabilarmalai	Mulluvadi	6-7	8	50-60	50-60	Groundnut	No
6	Thiruchengode	Mulluvadi	7-8	27	60-100	60-90 (Rain fed)	Groundnut	No
7	Elachipalayam	Mulluvadi	7-8	11	100	90	Onion	No
							Sugarcane	No
8	Malasamudram	Mulluvadi	7	10	50-75	60-88	Groundnut	No
9	Rasipuram	Mulluvadi	8	4	80	70	Sugarcane	No
		Thailand white	8	5	90	90	Cassava	Yes
10	Vennanthur	Mulluvadi	7	4	70	60	Groundnut	No
			Total area	**120 ha**				

Acknowledgements

The authors are grateful to the Joint Secretary, Department of Agriculture, Ministry of Agriculture and farmers' welfare, Government of India, New Delhi for having given the opportunity to conduct this study. Also, we are grateful to Dr. J.Poorani, Principal Scientist, National Research Centre for Banana (through personal communication) and Dr. Sunil Joshi Principal Scientist, National Bureau of Agricultural Insect Resources for Coccinelid and mealybug identification respectively. We sincerely thank the Dr. R. Arulprakash, Assistant Professor (Agricultural Entomology), Seed center, TNAU, Coimbatore and Dr. S. Suganya Kanna, Assistant Professor (Agricultural Entomology), ICAR-KVK, Sandhiyur, Salem for their critical comments and observations during survey. Shri. T. Tamilselvam, Shri. P. Chinadurai and Smt. S. Jayaprabha, Assistant Directors of Horticulture, State Department of Horticulture and Plantation crops, Tamil Nadu. Shri. P. Prakash, Shri. Sathiyaraj, Shri. Suvedhanan, Shri. Anandakumar, Shri. Ganesh, Shri. Gunasekaran, Shri. Sundar Raju, Assistant Horticulture officers of Namakkal district are gratefully acknowledged for their timely help and Co-operation in conducting this study. We also thank the farmers of all blocks of study area for their interaction, field assistance and for having shared their experience.

References

Cock, M.J.W., Lenteren, J. C. V., Brodeur, J., Barratt, B.I.P., Bigler, F., Bolckmans, K., Cônsoli, F.L., Haas, F., Mason, P.G. and Parra, J.R.P., 2009. The use and exchange of biological control agents for food and agriculture. In Background Study Paper No. 47. Commission on Genetic Resources for Food and Agriculture, FAO, Rome.

Edison, S., Anantharaman, M. and Srinivas. T., 2013. Status of Cassava in India an Overall View, Technical Bulletin Series: 46, the Director Central Tuber Crops Research Institute Sreekariyam, Thiruvananthapuram 695 017. Kerala, India.

Gupta, A., Mohan, M., Sampathkumar, M., Shylesha, A.N, Venkatachalam, S.R. and Bakthavatsalam, N., 2020. Cautionary note on the presence of *Homalotylus turkmenicus* Myartseva (Hymenoptera: Encyrtidae) in the colonies of *Phenacoccus manihoti* MatileFerrero (Hemiptera: Pseudococcidae) in southern India. *Journal of Biological Control*, **34**(2): 158–160.

Herren, H.R. and Neuenschwander, P., 1991. Biological control of cassava pests in Africa. Annual Review of Entomology, 36: 257-283.

Joshi, S., Sachin, G.P., Deepthy, K.B., Ballal, C.R., Watson, G.W., 2020. The cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Coccomorpha: Pseudococcidae) arrives in India. *Zootaxa.,* **4772**(1): 191–194.

Lohr, B., Varela, A.M. and Santos, B., 1990. Exploration for natural enemies of cassava mealybug, *Phenacoccus manihoti* (Homoptera: Pseudococcidae), in South America for biological control of this introduced pest in Africa. *Bulletin of Entomological Research*, **80:** 417–425.

Muniappan, R., Shepard, B.M., Watson, G.W., Carner. G.R. and Rauf, A., 2009. New Records of Invasive Insects (Hemiptera: Sternorrhyncha) in Southeast Asia and West Africa. *Journal of Agricultural Urban Entomology*, **26:** 167–174.

Neuenschwander, P., Hammond, W.N.O., Ajuono, O., Gado., A., Echendu, N., Bokonon-Ganta A. H., Allomasso, R. and Okon, I. 1990. Biological control of the cassava mealybug, *Phenacoccus manihoti* (Hom., Pseudococcidae) by *Epidinocarsis lopezi* (Hym., Encyrtidae) in West Africa, as influenced by climate and soil. *Agricultural Ecosystem & Environment.,* **32,** 39-55 (1990).

Neuenschwander, P., Hammond, W.N.O., Gutierrez, A.P., A.R. Cudjoe, J.U. Baumgaertner, U. Regev. and R. Adjakloe., 1989. Impact assessment of the biological control of the cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Pseudococcidae) by the introduced parasitoid Epidinocarsis lopezi (De Santis) (Hymenoptera: Encyrtidae). *Bulleting of Entomolgical Research,* **79,** *579*-594 (1989).

Nwanze, K.F., Leuschner, K.H.C. Ezumah, 1982a: The cassava mealybug, *Phenacoccus* sp. in the Republic of Zaire. *PANS,* **25**(2): 125–130.

Nwanze, K.F., 1982b: Relationships between cassava root yields and crop infestations by the mealybug, *Phenacoccus manihoti*. *Tropical Pest Management*., 28(1):27-32.

Parsa, S., Kondo. T. and Winotai A., 2012, The Cassava Mealybug **(***Phenacoccus manihoti***)** in Asia: First Records, Potential Distribution, and an Identification Key. *PLoS ONE*., **7**(10): e47675.

Paul-Andre Calatayud (ed.). and Le Ru, Bruno (ed.), 2006. Cassava-Mealybug interactions. New edition [online]. Marseille: IRD Éditions, 2006. ISBN: 9782709922814.

Sampathkumar, M., Mohan, M., Shylesha, A. N., Sunil Joshi, , Ankita Gupta, S. Vennila, S. R. Venkatachalam, M. Vijayakumar, Madhu Subramanian, M. Yoganayagi, T. R. Ashika and N. Bakthavatsalam: Occurrence of cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero (Pseudococcidae: Hemiptera), a new invasive pest on cassava in India and prospects for its classical biological control, *Curr. Sci.*, **120**(2), 432-435 (2021).

Schulthess, F., P. Neuenschwander. and S. Gounou: Multitrophic interactions in the cassava, *Manihot esculenta*, cropping system in the sub-humid tropics of West Africa. *Agric. Ecosyst. Environ.,* **66**: 211-222 (1997).

Tertuliano, M., P. A. Calatayud, and Le Ru, Bruno: Seasonal changes of secondary compounds in the phloem sap of cassava in relation to fertilisation and to infestation by the cassava mealybug. *Insect Sci. Appl.,* **19**, 91-98 (1999).

Williams, D. J. and M.C. De Granara Willink: Mealybugs of Central and South America, Wallingford, UK: CAB International (1992).

Winotai, A., G. Goergen, M. Tamò. and P. Neuenschwander: Cassava mealybug has reached Asia. Inf. *Bio-control News*., **31**: 10N–11N (2010).

Wu, S.A. and Y.P. Wang: Precaution of cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero in China. *Environ. Entomol*. **33**: 122–125 (2011).

Wyckhuys, K. A. G., Zhang, W., Prager, S. D., Kramer, D. B., Delaquis, E., Gonzalez, C. E. and van der Werf, W., Biological control of an invasive pest eases pressures on global commodity markets. Environ. Res. Lett., 2018a, 13(9), 094005.

Wyckhuys KAG, Wongtiem P, Rauf A, Thancharoen A, Heimpel GE, Le NTT, Fanani MZ, Gurr GM, Lundgren JG, Burra DD, Palao LK, Hyman G, Graziosi I, Le VX, Cock MJW, Tscharntke T, Wratten SD, Nguyen LV, You M, Lu Y, Ketelaar JW, Goergen G, Neuenschwander P. 2018b. Continental-scale suppression of an invasive pest by a host-specific parasitoid underlines both environmental and economic benefits of arthropod biological control.

Wyckhuys, Kris A. G.; Burra, Dharani Dhar; Tran, D.H.; Graziosi, Ignazio; Walter, Abigail Jan; Nguyen, T.G.; Trong, H.N.; Le, B.V.; Le, T.T.N.; Fonte, S.J: Soil fertility regulates invasive herbivore performance and top-down control in tropical agroecosystems of Southeast Asia. Agric. Ecosyst. Environ., 2017, 249, 38–49.

Yonow, T., D.J. Kriticos. and N. Ota: The potential distribution of cassava mealybug (Phenacoccus manihoti), a threat to food security for the poor. *PLoS ONE* 12(3): e0173265 (2017).

Zeddies, J., R.P. Schaab, P. Neuenschwander., and H. R. Herren: Economics of biological control of cassava mealybug in Africa. *Agric. Econ.*, **24**(2), 209–219 (2001).

MS Received 30 September 2022

MS Accepted 26 November 2022