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# Persistence and Residual Toxicity of Some Conventional as Well as Recently Introduced Acaricides against *Oligonychus coffeae* Nietner (Acari:Tetranychidae) on Tea

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**Abstract**

An experiment was conducted during March-April, 2018–19 and 2019–20 in the Department of Agricultural Entomology, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal, India to evaluate the duration of residual toxicity of five conventional as well as recently introduced acaricides against red spider mite, *Oligonychus coffeae* on tea. Five acaricides having different mode of actions were selected for the present study. Fenazaquin10 EC, propargite 57 EC, hexythiazox 5.45 EC, spiromesifen 22.9SC and cyflumetofen 20SC were sprayed @ 100, 430, 15,96 and 125 g a.i. $ha^{-1}$, respectively. Treated leaves were collected from the field and bioassay experiments were conducted in the laboratory. The results revealed that cyflumetofen 20 SC persisted for a longer duration (28 days) with the highest PT value (2347.24) whereas, propargite 57 EC persisted for a relatively short duration (22 days) with lesser PT values (1678.93). Higher $LT_{50}$ values of 23.83 and 24.26 days were also observed in case of cyflumetofen 20 SC @ 125 g a.i. $ha^{-1}$ during 1st and 2nd years of study, respectively. The lowest $LT_{50}$ value was observed in propargite 57 EC @ 430 g a.i. $ha^{-1}$. Spiromesifen 22.9 SC was found to be the second-best treatment and it showed the $LT_{50}$ value 22.34 and 22.42 days during 1st and 2nd year of study, respectively.

***Keywords:*** Acaricide, persistence, $LT_{50}$, *Oligonychus coffeae*, residual toxicity

## 1. Introduction

Tea is produced from young leaves and buds of tea plant. It is one of the popular drinks due to its several health benefits. Polyphenols (catechins and theaflavins) present in tea act as an antioxidant and they are effective in prevention of cardiovascular diseases, hypertension, diabetes, obesity and alleviation of metabolic syndrome, inhibition of antiviral activity and modulation of immunity (Barooah, 2020; Yang, 2018; Tang et al., 2019). This crop is cultivated more than 36 countries of the world including India. India is the second largest producer of tea after China and the fourth largest exporter in the world. In India tea is cultivated in as many as 15 states of which Assam, West Bengal, Tamil Nadu and Kerala contribute about 98% of the total production (Anonymous, 2022). Tea from each location has its own characteristics based on locational climate, soil condition, altitude and the method of processing. But the production and productivity of this crop is affected by several constraints. This crop is infested by various arthropod pests (Hazarika et al., 2009) due to availability of the host throughout the year. Tea is infested by 1031 species of arthropod pests across the world, of which only 300 species are recorded in India and about 167 species from North east India (Das, 1965; Muraleedharan, 1992; Rattan, 1992; Sivapalan, 1999). Among different pests that infest tea, *Oligonychus coffeae* is one of the most important ones. It remains active and it breeds on tea throughout the year in North East India (Mukhopadhyay et al., 2009). Both the adult and nymphs of *O. coffeae* feed on sap of the upper surface of mature leaves. Minute reddish brown marks develop on the upper surface of mature leaves as a result of their feeding. In case of severe infestation, the infested leaves turn reddish bronze in colour and the yield loss can be as high as 100% (Muraleedharan and Chen, 1997). Thus, it is one of the major constraints in obtaining maximum yield. Moreover, this pest has developed resistance against different group of acaricides in different tea growing areas of India (Das et al., 2017; Patra and Hath, 2023; Roy et al., 2010, 2012, 2014, 2018, 2019). Higher activity of detoxifying enzymes is one of the major mechanisms for development of pesticide resistance in mite as well as in other insect pest of tea (Patra and Hath, 2023; Patra et al., 2022; Mukhopadhyay and Roy, 2013; Biswa and Mukhopadhyay, 2013).

Among different tactics of pest management, use of synthetic acaricides is popular among the planters and synthetic pesticides of different groups are routinely applied to keep the pest under control (Sannigrahi and Talukdar, 2003; Gurusubramanian et al., 2008). Acaricides having fast acting as well as long lasting effect are preferred because it may reduce the number of sprayings and thereby cost of production. Moreover, sometimes acaricides are used close to harvest in order to get pest free attractive produce. This may increase the residue of the toxic chemicals in the final product. Hence, the information regarding the residual toxicity resulting from foliar spray of acaricides will be of great significance in indicating the effective duration over which an acaricide could persist in active stage under field condition. But such kind of information particularly under Sub-Himalayan region of West Bengal is scattered and limited. These inputs are crucial to the tea industry for effective pest management. Hence, it is necessary to determine the duration of residual toxicity of conventional as well as recently introduced acaricides for development of effective management strategies against the target pest. Such kind of studies will definitely be helpful to provide scientific guidance and will act as a ready reckoner for the prudent selection of acaricides for IPM programmes by the planters. These data could be used as critical inputs in acaricide resistance management programmes too.

## 2. Materials and Methods

The study was carried out during March-April of 2018-2019 and 2019-2020 at the Department of Agricultural Entomology, Uttar Banga Krishi Viswavidyalaya (Latitude 26.404°N and Longitude 89.384°E), Pundibari, Cooch Behar, West Bengal, India.

### *2.1. Rearing of tea red spider mite (TRSM)*

A stock culture of field-collected population was maintained in the laboratory by following the detached leaf culture technique as described by Helle and Sabelis (1985) with slight modifications. Fresh matured tea leaves were collected from unsprayed field and brought to the laboratory for maintenance of mite population. These collected leaves were washed properly with distilled water and air dried before placing them on a water-soaked cotton pad (1.5 cm thick) kept on a rectangular plastic tray with the dimension 42×30×6.5 cm (Roy et al., 2016; Roobakkumar et al., 2012). The adaxial surface of the leaves was kept upward as *O. coffeae* prefers to live on the upper surface of mature tea leaves. Thus, the mite in the rearing tray was maintained at a temperature of 25±2°C, 75±5% RH. Distilled water was added to the rearing trays as and when required to keep the cotton pad moist and thereby it also helped the mite from escape and to prevent the leaves from drying. Withered leaves were replaced with new leaves at regular interval. The adult mites were used for determination of residual toxicity of the selected acaricides.

### *2.2. Tested acaricides*

Five acaricides were evaluated for their residual effects towards *O. coffeae,* by applying the recommended doses. The acaricides used are presented in table 1. Five acaricides have different mode of actions and they belong different group of acaricides. These acaricides were purchased from the local market. Among these five acaricides, cyflumetofen 20SC has been introduced recently in comparison to other acaricides. This acaricide has unique mode of action.

### *2.3. Application of acaricides in the field*

The field experiment was conducted in the tea garden of Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal, India during 2018–2019 and 2019–2020. The field was sprayed with the selected acaricides for evaluating the persistence of residual toxicity against *O. coffeae*.

A hand operated knapsack sprayer fitted with hollow cone nozzle was used for spraying in the field. The untreated control plots were sprayed first with clean water. Thereafter, each acaricide was sprayed ensuring thorough coverage. Sprayer was washed properly before application of each insecticide and also rinsed with the spray solution of the chemical to

Table 1: Acaricides used in the residual toxicity study against *Oligonychus coffeae* Nietner

| Acaricides | Class | Trade names | Manufacturer | IRAC MoA |
|---|---|---|---|---|
| Fenazaquin10 EC | Quinazolines | Magister | E.I. DuPont India Ltd | (METI) Mitochondrial complex I electron transport inhibitor |
| Propargite 57 EC | Organosulfur | Omite | Dhanuka Agritech Ltd. | (MASI) Mitochondrial ATP synthase inhibitor |
| Hexythiazox 5.45 EC | Thiazolidionone | Maiden | Biostadt India Ltd. | (MGI) Mite growth inhibitor by affecting chitin synthase 1(CHS1) |
| Spiromesifen 22.9SC | Tetronic acid derivatives | Oberon | Bayer Crop Science Limited | (LSI) Lipid synthesis inhibitor by inhibiting acetyl CoA carboxylase |
| Cyflumetofen 20SC | Beta-ketonitrile derivative | Foster | Dhanuka Agritech Ltd. | (METI) Mitochondrial complex II electron transport inhibitor |

NB: IRAC-Insecticide Resistance Action Committee; MoA- Mode of action avoid contamination. Each plot was separated by two rows of untreated bushes as buffer rows. The experiment was laid out in randomized block design (RBD) having plot size of 40 square meter with 6 treatments including untreated check and each treatment was replicated thrice.

*2.4. Bioassay*

The residual effects of the acaricides were evaluated in the Department of Agricultural Entomology, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal, India during two consecutive years (2018–19 and 2019–20).

Mature leaves were collected from the treated plots and were used for bioassay study. The collected leaves were cut into 4-cm diameter discs. The leaf discs were then placed on a water-saturated cotton pad in a petri dish (90 mm diameter) keeping the ventral surface down. Twenty laboratory reared adult mites were then released on each leaf disc using a camel-hair brush and one disc was considered as one replication. Each treatment was replicated thrice. Adult mites were exposed to field treated tea leaves starting from zero day (six hours after application of acaricides in the field) to till the per cent mortality records reached almost 10% at an interval of two days.

Observations were recorded on number of dead mites after 24 hours of release. A mite was considered as dead if no movement was detected after prodding with a fine but soft brush. Similarly, control mortality was also observed by releasing the mites on leaves collected from control plots.

*2.5. Statistical analysis*

The mortality data in each concentration of test acaricides were then corrected using Abbott's formula (Abbott, 1925) based on the observation on control mortality, if any. The corrected mortality data were subjected to Probit analysis based on Finney (1971) using statistical package POLO plus (LeOra software, 2002) to calculate the median lethal time ($LT_{50}$) values (time required to cause 50% mortality).

The persistent toxicity values (in days) were determined following the method prescribed by Pradhan and Venkatraman (1962) and Pradhan (1967).

Persistent toxicity=P×T

Where P=period for which toxicity is persisted,

T=Average residual toxicity.

Average residual toxicity(T)=(Sum of corrected mortalities at different intervals)/Number of observations)

The order of relative persistence of the insecticides was calculated based on PT values.

## 3. Results and Discussion

The duration of effectiveness (persistent toxicity) and residual toxicity of five commonly used acaricides under five different classes *viz.,* quinazolines (fenazaquin 10 EC), organosulfur (propargite 57 EC), thiazolidionone (hexythiazox 5.45 EC), tetronic acid derivatives (spiromesifen 22.9 SC) and beta-ketonitrile derivative (cyflumetofen 20 SC) were evaluated on the basis of PT (persistence) and $LT_{50}$ (residual toxicity) values respectively against adults of *O. coffeae.* The duration of residual toxicity varied among the tested acaricides.

*3.1. Persistent toxicity of acaricides based on PT values against O. coffeae on tea.*

It was evident from Table 2 that the recommended dose (@ 125 g a.i.ha$^{-1}$) of cyflumetofen 20SC persisted for a longer duration (28 days) as compared to other acaricides against *O. coffeae.* Fenazaquin 10 EC, hexythiazox 5.45 EC and spiromesifen 22.9 SC exhibited persistence toxicity for 24–26 days. The lowest duration of effectiveness (22 days) was observed in propargite 57 EC @ 430 g a.i.ha$^{-1}$.

The highest average residual toxicity (T) was observed in cyflumetofen 20 SC (83.83%) followed by spiromesifen 22.9 SC (83.81%), hexythiazox 5.45 EC (81.09%) and fenazaquin 10EC (78.07%). Propargite 57 EC exhibited the least average residual toxicity (76.32%) (Table 2).

The highest PT value was observed in cyflumetofen 20SC @ 125 g a.i. ha$^{-1}$ (2347.24) followed by spiromesifen 22.9 SC @ 96 g a.i.ha$^{-1}$ (2179.06). Propargite 57 EC @ 430 g a. i. ha$^{-1}$ registered the lowest PT value (1678.93). Based on the PT values during both the years of study, the order of

Table 2: PT values and order of relative efficacy of different acaricides against adults of *O. coffeae* Nietner during 2018–19 and 2019–2020 (Pooled)

| Acaricides | Doses (g a.i.ha$^{-1}$) | Period (P) (Days) | Average residual toxicity (T) | PT | REPT | ORE (Based on PT values) |
|---|---|---|---|---|---|---|
| Fenazaquin 10 EC | 100 | 24 | 78.07 | 1873.68 | 1.12 | 4 |
| Propargite 57 EC | 430 | 22 | 76.32 | 1678.93 | 1.00 | 5 |
| Hexythiazox 5.45 EC | 15 | 24 | 81.09 | 1946.04 | 1.16 | 3 |
| Spiromesifen 22.9 SC | 96 | 26 | 83.81 | 2179.06 | 1.30 | 2 |
| Cyflumetofen 20 SC | 125 | 28 | 83.83 | 2347.24 | 1.40 | 1 |

PT: Product of mean residual toxicity (T) and the period (P) for which the toxicity persisted; REPT: Relative efficacy based on PT values; ORE: Order of relative efficacy relative efficacy of the tested acaricides in decreasing order was as follows: cyflumetofen 20SC > spiromesifen 22.9 SC> hexythiazox 5.45 EC>fenazaquin 10EC > propargite 57 EC.

### 3.2. *Residual toxicity of acaricides based on $LT_{50}$ values against O. coffeae on tea*

The relative efficacy of different acaricides based on $LT_{50}$ values against *O. coffeae* have been presented in table 3 and 4. The $LT_{50}$ values varied with the class of acaricides. The present study clearly revealed that $LT_{50}$ values of the tested acaricides ranged between 17.06 to 23.83 days during first year of study (2018-19). Cyflumetofen 20SC showed the highest $LT_{50}$ values (23.83 days) among all the tested acaricides. It was followed by spiromesifen 22.9 SC (22.34 days), hexythiazox 5.45 EC (19.78 days) and fenazaquin 10 EC (19.09 days). Propargite 57 EC was found to have the least $LT_{50}$ values (17.06 days) among all the acaricides evaluated. The decreasing order of relative efficacy of acaricides based on $LT_{50}$ values was as follows: cyflumetofen 20SC (1.40)> spiromesifen 22.9 SC (1.31)>hexythiazox 5.45 EC (1.16)>fenazaquin 10EC (1.12)>propargite57EC (1.00). The relative efficacy was calculated considering the lowest $LT_{50}$ values (propargite 57 EC) as unity.

Results of the second year's study (2019–20) also indicated the same trend as found during the first year of study. $LT_{50}$ values of the tested acaricides ranged between 17.17 to 24.26 days. Cyflumetofen 20SC was found to have the highest $LT_{50}$ values (24.26 days) among all the tested acaricides. It was followed by spiromesifen 22.9 SC (22.42 days), hexythiazox 5.45 EC (20.12 days) and fenazaquin 10 EC (19.24 days). Propargite 57 EC was found to have the least $LT_{50}$ values (17.17 days) among all the acaricides evaluated. The decreasing order of relative efficacy of acaricides based on $LT_{50}$ values was as follows: cyflumetofen 20SC (1.41)> spiromesifen 22.9 SC (1.30)> hexythiazox 5.45 EC (1.17)>fenazaquin 10EC (1.12)>propargite 57EC (1.00).

In the present study, cyflumetofen 20SC showed longer residual efficacy as compared to other tested acaricides and this persistence will be helpful in terms of long-term control. It can control mite populations up to 28 days after application (Anonymous, 2013). From planters' point of view this acaricide is fast acting as well as long lasting. Hence use of this chemical will definitely reduce the number of sprayings on tea for red spider mite management. Due to longer persistency, growers should not apply this chemical closer to harvest time. According to Takahashi et al. (2012) some of the important advantages of this acaricide are excellent activity against all developmental stages of mite, unique of mode of action, no cross resistance between cyflumetofen and other available acaricides. Moreover, acute toxicity of cyflumetofen to mammals was quite low. It showed no effect or limited impact on beneficial arthropods and natural enemies. Toxicity towards non-target aqueous species was

Table 3: Residual toxicity of selected acaricides to *Oligonychus coffeae* Nietner on tea during 2018–19

| Acaricides | Doses (g a.i. $ha^{-1}$) | $LT_{50}$ (days) | Fiducial limit (days) | | Regression equation | Chi square ($\chi^2$) | $RELT_{50}$ | ORE (Based on $LT_{50}$) |
|---|---|---|---|---|---|---|---|---|
| | | | LL | UL | | | | |
| Fenazaquin 10 EC | 100 | 19.09 | 18.60 | 19.61 | Y= 22.53-13.68x | 1.51 | 1.12 | 4 |
| Propargite 57 EC | 430 | 17.06 | 16.55 | 17.59 | Y= 19.43-11.74x | 1.87 | 1.00 | 5 |
| Hexythiazox 5.45 EC | 15 | 19.78 | 19.25 | 20.32 | Y= 23.19-14.03x | 0.99 | 1.16 | 3 |
| Spiromesifen 22.9 SC | 96 | 22.34 | 21.87 | 22.83 | Y= 29.41-18.10x | 0.54 | 1.31 | 2 |
| Cyflumetofen 20 SC | 125 | 23.83 | 23.34 | 24.35 | Y= 30.15-18.27x | 0.81 | 1.40 | 1 |

$LT_{50}$: Median lethal time (days); LL: Lower limit; UL: Upper limit; $RELT_{50}$: Relative efficacy based on $LT_{50}$ values; ORE: Order of relative efficacy

Table 4: Residual toxicity of selected acaricides to *Oligonychus coffeae* Nietner on tea during 2019–20

| Acaricides | Doses (g a.i. $ha^{-1}$) | $LT_{50}$ (days) | Fiducial limit (days) | | Regression equation | Chi square ($\chi^2$) | $RELT_{50}$ | ORE (Based on $LT_{50}$) |
|---|---|---|---|---|---|---|---|---|
| | | | LL | UL | | | | |
| Fenazaquin 10 EC | 100 | 19.24 | 18.74 | 19.76 | Y= 22.34-13.49x | 1.72 | 1.12 | 4 |
| Propargite 57 EC | 430 | 17.17 | 16.66 | 17.71 | Y= 19.07-11.41x | 0.92 | 1.00 | 5 |
| Hexythiazox 5.45 EC | 15 | 20.12 | 19.61 | 20.64 | Y= 25.13-15.44x | 1.37 | 1.17 | 3 |
| Spiromesifen 22.9 SC | 96 | 22.42 | 21.96 | 22.90 | Y= 30.85-19.14x | 1.24 | 1.30 | 2 |
| Cyflumetofen 20 SC | 125 | 24.26 | 23.78 | 24.75 | Y= 33.02-20.21x | 0.76 | 1.41 | 1 |

$LT_{50}$: Median lethal time (days); LL: Lower limit; UL: Upper limit; $RELT_{50}$: Relative efficacy based on $LT_{50}$ values; ORE: Order of relative efficacy also quite low. Spiromesifen 22.9SC showed excellent residual toxicity against *O. coffeae*. Kavya (2014) also revealed that spiromesifen showed median lethal concentration ($LT_{50}$) value of 22.18 days against *Tetranychus urticae* infesting brinjal. Hexythiazox 5.45 EC and fenazaquin 10EC also showed good residual efficacy.

The residual toxicity resulting from application of a chemical plays an important role in selecting the effective pesticide for management of pests. It indicates duration over which a pesticide molecule persists in biologically active stage under the field condition. In the present study, duration of effectiveness was evaluated on the basis of PT values and $LT_{50}$ values. Sarup et al (1970) indicated the importance of PT and $LT_{50}$ values in determining the relative residual toxicity of pesticides. According to them PT value is important because it takes into account the duration of effectiveness of a particular pesticide. Results of the present study will be helpful for prudent selection of acaricides for management of *O. coffeae* on tea.

## 4. Conclusion

The cyflumetofen 20SC was the most persistent acaricide followed by spiromesifen 22.9SC. Propargite 57 EC was found to be the least persistent acaricide. Spiromesifen 22.9 SC, hexythiazox 5.45 EC and fenazaquin 10EC also showed good residual efficacy.

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## 6. References

Abbbott, W.S., 1925. A method of computing the effectiveness of an insecticide. Journal of Economic Entomology 18(2), 265–267.

Anonymous, 2022. Annual Report, 2021-22. Tea Board of India.14, B.T.M Sarani, Kolkata. Available from https://www.teaboard.gov.in/pdf/Final_Annual_Report_2021_22_14_12_2022_pdf414.pdf . Accessed on 4th September, 2023.

Anonymous, 2023. Sultan™ Miticide,U.S. Technical Information Brochure. BASF Agricultural Products, USA. Available from https://betterturf.basf.us/content/dam/cxm/agriculture/better-turf/united-states/english/products/sultan/sultan-miticide-technical-information-bulletin.pdf. Accessed on 4th September, 2023.

Barooah, A.K., 2020. Black tea antiviral activity & boosting immunity. Tea Research Association Tocklai Tea Research Institute, Jorhat, 1–14.

Biswa, R., Mukhopadhyay, A., 2013. Levels of Detoxifying Enzyme (General Esterases and GST) in the Worker and the soldier castes of *Odontotermes obesus* (R.): a possible adaptation to tolerate exposure to pesticides. International Journal of Bio-resource and Stress Management 4(3), 404–407.

Das, G.M., 1965. Pests of tea in North East India and their control. Memorandum No. 27, Tocklai Experimental Station, Jorhat, Assam, India, 1–115.

Das, S., Saren, J., Mukhopadhyay, A., 2017. Acaricide susceptibility of Oligonychus coffeae (Nietner) (Acari:Tetranychidae) with corresponding changes in detoxifying enzymelevels from tea plantations of sub-Himalayan Terai, India. Acarologia 57(3), 581–590. https://doi.org/10.24349/acarologia/20174175.

Finney, D.J., 1971. Probit analysis: a statistical treatment of the sigmoid curve. Cambridge University Press, London, 333.

Hazarika, L.K., Bhuyan, M., Hazarika, B.N., 2009. Insect pests of tea and their management. Annual Review of Entomology 54, 267–84.

Helle, W., Sabelis, M.W., 1985. Spider mites: their biology, natural enemies and control. Elsevier Science Publishing Company Inc. New York, USA, 335.

Kavya, M.K., 2014. Toxicity of newer acaricides to two spotted spider mite, Tetranychus urticae Koch (Acari: Tetranychidae) infesting brinjal, Solanum melongena Linn. Thesis submitted to the University of Agricultural Sciences, Bengaluru, India. Master of Science (Agriculture) in Agricultural Entomology. Accessed from the website: https://krishikosh.egranth.ac.in/assets/pdfjs/web/viewer.html?file=https%3A%2F%2Fkrishikosh.egranth.ac.in%2Fserver%2Fapi%2Fcore%2Fbitstreams%2Fc286b3cf-ad5f-4e08-811b-6331ba6c6073%2Fcontent.

LeOra Software, 2002. Polo-plus, a user guide to probit or logit analysis. Leora Software, Berkeley, CA. https://leora-software.com/products/poloplusonline.

Mukhopadhyay, A., Roy, S., 2009. Changing dimensions of IPM in the tea plantations of the north eastern sub-Himalayan region. In: Ramamurthy, V.V., Gupta, G.P., Puri, S.N. (Eds.), IPM strategies to combat emerging pests in the current scenario of climate change. Entomological Society of India, IARI, New Delhi, 290–302.

Mukhopadhyay, A., Roy, S., 2013. Development of tolerant traits in tea mosquito bug (*Helopeltis theivora* Waterhouse) (Hemiptera: Miridae) under insecticide stress. International Journal of Bio-resource and Stress Management 4(3), 418–423.

Muraleedharan, N., 1992. Pest control in Asia. In: Wilson, K.C., Clifford, M.N. (Eds.), Tea: cultivation to consumption. Chapman & Hall, London. 375–412.

Muraleedharan, N., Chen, Z.M., 1997. Pests and diseases of tea and their management. Journal of Plantation Crops 25, 15–43.

Patra, B., Hath, T.K., 2023. Resistance status and activity of detoxifying enzymes in *Oligonychus coffeae* (Nietner) (Acari:Tetranychidae) on tea. Crop Protection, 167.

https://doi.org/10.1016/j.cropro.2023.106201.
Patra, B., Mandal, S., Sahoo, S.K., Hath, T.K., 2022. Higher activity of glutathione stransferase enzyme is associated with field evolved resistance in *Empoasca flavescens* Fabricius. International Journal of Tropical Insect Science 42, 2887–2895. https://doi.org/10.1007/s42690-022-00813-7.

Pradhan, S., 1967. Strategy of computing the effectiveness of an insecticide. Journal of Economic Entomology 18(2), 265–267.

Pradhan, S., Venkatraman, T.V., 1962. Integration of chemical and biological control of *Chilo zonellus* (Swinhoe), the stalk borer of maize and jowar. Bulletin of National Institute of Science India 19, 119–125.

Rattan, P.S., 1992. Pest and disease control in Africa. In: Wilson, K.C., Clifford, M.N. (Eds.), Tea: cultivation to consumption. Chapman and Hall, London, 331–352.

RoobakKumar, A., Babu, A., Subramaniam, M.S.R., Kumar, P., 2012. Assessment of resistance level in tea red spider mite, *Oligonychus coffeae* against certain acaricides. Journal of Plantation Crops 40(1), 23–27.

Roy, S., 2019. Detection and biochemical characterization of acaricide resistance in field populations of tea red spider mite, *Oligonychus coffeae* (Acari: Tetranychidae): in Assam tea plantation of India. International Journal of Acarology. https://doi.org/10.1080/01647954.2019.1671489.

Roy, S., Handique, G., Barua, A., Bora, F.R., Rahman, A., Muraleedharan, N., 2016. Comparative performances of jatropha oil and garlic oil with synthetic acaricides against red spider mite infesting tea. Proceeding of National Academy of Sciences. Sect. B: Biological Science DOI 10.1007/s40011-016-0734-y.

Roy, S., Mukhopadhyay, A., Gurusubramanian, G., 2010. Baseline susceptibility of *Oligonychus coffeae* (Acarina: Tetranychidae) to acaricides in North Bengal tea plantations, India. International Journal of Acarology 36(5), 357–362. https://doi.org/10.1080/01647951003733731.

Roy, S., Mukhopadhyay, A., Gurusubramanian, G., 2012. Chemical-based integrated approaches for the management of tea red spider mite, *Oligonychus coffeae* (Nietner) (Acari:Tetranychidae) in tea plantations of sub-Himalayan North Bengal, India. International Journal of Acarology 38(1), 74–78. https://doi.org/10.1080/01647954.2011.590154.

Roy, S., Muraleedharan, N., Mukhopadhyay, A., 2014. The red spider mite, *Oligonychus coffeae* (Acari: Tetranychidae): its status, biology, ecology and management in tea plantations. Experimental and Applied Acarology 63, 431–463. https://doi.org/10.1007/s10493-014- 9800-4.

Roy, S., Prasad, A.K., Handique, G., Deka, B., 2018. Susceptibility to acaricides and detoxifying enzyme activities in the red spider mite, *Oligonychus coffeae* (Nietner) (Acari: Tetranychidae). Acarologia 58 (3), 647–654. https://doi.org/10.24349/ acarologia/20184261.

Sarup, P., Singh, D.S., Amarpuri, S., Rattan, L., 1970. Persistent and relative residual toxicity to some important pesticides to the adults of sugarcane leafhopper, *Pyrilla perpusilla* (Walker) (Lophopidae: Homoptera). Indian Journal of Entomology 32(3), 256–267.

Sivapalan, P., 1999. Pest management in tea. In: Jain, N.K., (Ed.), Global advances in tea science. Aravali Books, New Delhi, 625–646.

Takahashi, N., Nakagawa, H., Sasama, Y., Ikemi, N., 2012. Development of a new acaricide, cyflumetofen. Journal of Pesticide Science 37(3), 263–264.

Tang, G., Meng, X., Gan, R., Zhao, C., Liu, Q., Feng, Y., Li, S., Wei, X., Atanasov, A.G., Corke, H., Li, H., 2019. Health functions and related molecular mechanisms of tea components: an update review. International Journal of Molecular Sciences 20, 6196, doi:10.3390/ijms20246196.

Yang, C.S., 2018. The potential role of tea in combating chronic diseases. In: Sharma, V.S., Gunasekhare, M.T.K. (Eds.), Global tea science current status and future needs. Burleigh Dodds Science Publication, 427–451.