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Article

Effect of agro-ecological zones on predacious mites (Acari: Phytoseiidae) and pest mite, *Eutetranychus africanus* (Acari: Tetranychidae) populations in citrus orchards of Kenya

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ABSTRACT
Phytoseiidae mites' survival and reproduction depend on optimal environmental factors. A total of five different agro-ecological zones (AEZs) were surveyed twice each year from 2017 to 2019 in Kenya. In Eastern Kenya sample farms were small scale citrus orchards in the counties of Machakos [Low Midlands-Four (LM4)] and Makueni [Upper Midlands-Three (LM3)]. In the Coastal Lowlands-Four (CL4) similar small-scale citrus plots were sampled in Kwale, while in the highland Rift Valley region sample sites were ADC- Suam orchards of Kitale of the Lower Highlands-Two (LH2), where the large-scale farms were under citrus crop culture. The fifth site sampled was Baringo area of the Low Midlands-Five (LM5) where small plot citrus crop dominated the sample sites. Out of 68 fields of repeat surveys, 40% of citrus plots yielded varied diversity of phytoseiid mites. The major pest from the sites was citrus brown mite, *Eutetranychus africanus*. In this study, population fluctuation of phytoseiid mites was observed under different climatic conditions of temperature, relative humidity, dew-point and citrus plant age (in years). On the major pest *E. africanus*, three factors were evaluated for correlation and significance to infestation levels on the citrus crop. Of the three evaluated factors of temperature, citrus tree age and phytoseiid density in the orchards, temperature parameter did not significantly influence the pest mite (*E. africanus*) infestation levels for all combined AEZs factors. In the present case studies of specific AEZs, older trees led to higher pest mite density while low phytoseiid numbers correlated inversely to higher *E. africanus* infestation levels on the citrus trees. The information here could be used proactively to plan for management of *E. africanus* as the major pest in citrus orchards in specific agro-ecological zones.

KEY WORDS: Citrus brown mite; citrus tree age; density; herbivore invertebrates; predatory mites; temperature.

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INTRODUCTION

Predatory mites of the family Phytoseiidae are the major natural enemies of most small-sized herbivore arthropods (Yaninek *et al.* 1993; Demite *et al.* 2014; Mutisya *et al.* 2014; Onzo *et al.* 2014). Many studies on phytoseiid mites have shown how these Acari have suppressed pests of various crops to below economic injury levels (IITA 1989; Yaninek *et al.* 1993; Gnanvossou *et al.* 2005; Yaninek and Hanna 2003; Kariuki *et al.* 2005). Reports on benefits of phytoseiid mites on fruit trees, cassava, tea, tomato, coffee, ornamental plants, among other crops of economic importance, demonstrate the benefits of using biological control agents in crop production systems (Ferrero *et al.* 2007; Mutisya *et al.* 2015, 2018; Samaras *et al.* 2021). These predatory mites require specific climatic conditions to achieve their highest performance in suppressing populations of their prey (Yaninek and Schulthess 1993; Jaques *et al*. 2015). Some of the Phytoseiidae species are host-specific while others are generalists which feed, survive and reproduce on a variety of diets ranging from herbivorous prey, plant pollens to even plant leaf substrates in times of food scarcity (Cuellar *et al.* 2001; Vantornhout *et al.* 2004; Gnanvossou *et al.* 2005). Field surveys and laboratory studies have identified niches in which performance of the predatory mites are enhanced by ambient temperatures and relative humidity (Shipp *et al.* 1997; Yaninek and Hanna 2003; De Courcy *et al.* 2004; Zundel *et al.* 2007).

Pests of economic importance on citrus trees in Kenya include fruit flies, false coddling moth, phytophagous mites and various diseases (Seif and Hillocks 1998; Gerson *et al*. 2003; Pole *et al.* 2013). The major pest mite in Kenya on citrus is *Eutetranychus africanus* (Tucker), the citrus brown mite (Toroitich *et al*. 2009). Farmers who grow citrus in Kenya mainly report fruit flies and the false coddling moth as the major pests although leaf-sucking ones like *E. africanus*, various species of thrips, mealybugs and scale insects could also hugely reduce yield if not controlled (Quiros-Gonzalez 2000; Ouma 2008; Gerson and Vacante 2012; Sahraoui *et al*. 2012; Wangithi 2019). The suppression of these pests by phytoseiid mites are important natural control methods in citrus orchards all over the world (Argov *et al*. 2005; Metwally *et al*. 2005; Van Leeuwen *et al.* 2015; Fang *et al.* 2020).

Phytoseiid mites cause mortality mainly by sucking the abdominal fluids of their prey (Muma 1971; Metwally *et al*. 2005). It is reported that female phytoseiids could consume between 20–200 individual tetranychid mites daily, depending on prey preference and temperature-relative humidity regimes (Jeyarani *et al.* 2012; Warburg *et al*. 2019). Mutisya *et al.* (2014) reported a daily consumption rate by *Typhlodromalus aripo* (De Leon) of 2–3 crawlers of the whitefly *Bemisia tabaci* and the nymphal stage of the mealybug *Phenacoccus manihoti* (Matile-Ferrero) (Mutisya *et al.* 2014). It is expected that phytoseiid mites contribute positively to suppressing populations of invertebrate pests on citrus leading to improved and sustainable crop health and better fruit yield (Gerson and Vacante 2012; Mutisya *et al*. 2014). The objective of the present study was to investigate the annual population dynamics of *E. africanus* and its Phytoseiidae predatory mites in orchards located in different agro-ecological zones of Kenya.

MATERIALS AND METHODS

Selected agro-ecological zones

Field sampling was done twice per year from 2017 to 2019 during wet and dry months of each year. Sample sites and related data are shown in Table 1. Geographical information was captured by (GPS). The different agro-ecological zones (AEZs) selected for the study were within the regions where citrus crop was grown in Kenya. These AEZs were defined by Food Agricultural Organization (FAO 2008) (https://infonet-biovision.org/EnvironmentalHealth/AEZs-FAO-System) in the Kenyan context. In Eastern Kenya, sample farms were small scale citrus orchards in the counties of Machakos Low Midlands (LMs) and Upper midlands (UMs) of Makueni; ranging from

LM3 to LM3-4 of cool to warm humid conditions where the altitude and climatic conditions are shown in Table 1 and geographical areas occur as in Figure 1. The coastal and eastern regions AEZs had bi-modal rainfall; October-December (OND) and March-June (MAMJ) while the Rift Valley had the main wet season from March-August (MAMJJA).

Table 1. Geographical information and agro-ecological zones (AEZs) description of sample sites in Kenya.

Site	GPS range	Altitude ± SD (m)	Rainfall (mm) /month	AEZ	Description	Citrus (Years)
Kitale	0° 30' 42.91" N 35° 11' 57" E	1,908 ± 20	112 ± 55	Lower Highlands-two (LH2)	Wet-cool	6.6
Baringo	0° 42' 59" N 34° 52' 54" E	1,020 ± 9	78 ± 35	Lower Midlands-five (LM5)	Semi-humid	11.7
Machakos	1° 30' 46" S 37° 14' 13" E	1,355 ± 16	65 ± 27	Lower Midlands-four (LM4)	Cool-humid	13.7
Makueni	1° 47' 5" S 37° 37' 15" E	1,267 ± 41	98 ± 63	Upper Midlands-three LM3)	Warm-humid	8.5
Kwale	4° 10' 43" S 39° 26' 55" E	395 ± 574	66 ± 28	Coastal lowlands-four (CL4)	Warm-wet-humid	11.1

Figure 1. Sampling sites.

Analysis of climatic factors

At each site Easy Log USB electronic data loggers (made in United Kingdom) (Fig. 2) were set in the citrus fields under shelter covers and placed 10–15 m from the sample plants. The loggers recorded climatic data of temperature (℃), dew-point (℃) and relative humidity (RH %) every 10 minutes. The data loggers stayed in place for at least six months before data was downloaded on a computer and batteries for the devices replaced. In the Coastal and Eastern AEZs of CL4, LM3 and LM4 data was collected during the short rains from October to December (OND) and the long rains from March to July (MAMJJ) period, whereas for the Rift Valley (LH3 and LM5) data was collected during the single rain season from March to August (MAMJJA). Data was collected throughout the year inclusive of the dry months. As the climatic factor values would be used to compare predator-prey values on citrus plants, it was important to score summary statistics of average data of temperature, RH% and dew-points during data processing. The climatic variables were to be used for the regression and correlation in relation to both herbivore and predacious mite population fluctuations in citrus orchards of each defined specific and combined AEZs under study. Species abundance in specific AEZs would show climatic conditions preferred by phytoseiid mites. Unfortunately, data loggers for Taita-Taveta county were lost, leading to data sets of that site not being included in the analysis.

Figure 2. EasyLog USB electronic data logger device.

Sampling program

A total of four plants were sampled per site field in five AEZs CL4, LM3, LM4, LM5 and LH2. In each field four citrus trees per plot were sampled for fauna of pests and predacious mites. At each site comparative Phytoseiidae and Tetranychidae mite population counted during the OND and MAMJJ during the three-year period (2017–2019). A blue plastic disk of 60-cm diameter was held under citrus branches as the sample trees were shaken with a one-meter stick (Fig. 3) separately at four positions of the plant canopy (a branch immediately in front of sampler, one each to the left, right and furthest side of the plant). Arthropods from each plant which fell onto the disk were counted using a tally/hand counter and separated into Phytoseiidae, Tetranychidae and other arthropod specimens. With the aid of a camel hair-brush, the different samples from each site were picked and placed in vials containing 70% alcohol. The total counts of Phytoseiidae, Tetranychidae and other arthropods were scored for each sampling site as average mites/plant. The three-type specimens of Phytoseiidae, Tetranychidae and other arthropod in 70% alcohol vials were taken to the laboratory for further preparation for identification. Both Tetranychidae and Phytoseiidae mite specimens were mounted on slides at University of Nairobi (in Kenya) and shipped for expert morphological identification in France, *Montpellier SupAgro, Directrice du département Biologie et Ecologie, University de Montpellier, Montpellier (France)*. As communicated by M. Stephane Tixier (in France), the morphological identification of phytoseiid mites were performed with a phase contrast microscope (× 400) using keys developed by Moraes *et al.* (2001, 2007), Chant and McMurtry (2005), El-Banhawy and Knapp (2011).

Data analysis

The climatic data sets of temperature, humidity and dew point were analyzed for average values, using EasyLog-USB data software (UK, 2012). Population density counts of both *E. africanus* and predator were normalized using log-transformation ([log (x + 1]) and subjected to analysis of variance (ANOVA) using a GLIM statistical software package with temperature, humidity, dew point and citrus age as the main factors. The data was analyzed for the years of 2017–2019 and presented in Table 2. ANOVA General Linear Model was used to evaluate significant differences between pest and predatory mite densities. Means were separated using Student-Newman-Keuls (SNK) Post Hoc test at p = 0.05. The analysis of Linear Regression and Correlation Model (at 5%) was used to determine the significance and correlation status of the climatic factors in each AEZ in relation to both densities of Phytoseiidae and *E. africanus* in specific AEZs.

Figure 3. Mite sampling.

RESULTS

Prevailing climatic factors

Climatic conditions at the five sites during the survey were as presented in Table 2. In reference to Table 1 where agro-ecological zone LH2 (high altitude) range was 1,908 ± 20 m above sea level, scored temperature, RH% and dew-points were at 21.4 ± 1.1 °C, 15.5 ± 0.9 °C and 74.7 ± 3.2 (%), respectively for Kitale. Within the same Rift Valley, the LM5 region had altitude range of 1,020 ± 9 m a.s.l. and climatic factor score was at 23.9 °C ± 0.6, 50.9 ± 3.4% and 16.1 ± 0.3 °C for temperature, RH (%) and dew-point for Baringo site farms.

The LM4 region had factor levels for climatic conditions as follows: temperature, RH% and dew-points at 27.5 ± 0.7 °C, 68.1 ± 3.6%, 20.4 ± 0.4 °C, respectively for Machakos farms. Similarly, LM3 region of Makueni farms had climatic factors of temperature, RH% and dew-points at 23.2 ± 2.3 °C, 74.8 ± 13.1% and 18.0 ± 0.8 °C, respectively. The coastal region CL4 of Kwale farms had factors of temperature, RH% and dew-points at 24.8 ±1.2 °C, 77.4 ± 1.9% and 18.8 ± 0.6 °C, respectively. These factor levels were expected to impact positively or negatively on the overall population dynamics of both the pest and phytoseiid mites on citrus orchards in the different AEZs.

Table 2. Prevailing climatic conditions during surveys conducted at the five selected sample sites.

Period months (Jan.–Dec. 2017–19)	AEZ	Temperature (°C)	Humidity (%)	Dew-point (°C)
2017 (MAMJJA), 2018 (MAMJJA)	LH2	21.4 ± 1.1	74.7 ± 3.2	15.5 ± 0.9
2017 (MAMJJA), 2018 (MAMJJA)	LM5	23.9 ± 0.6	50.9 ± 3.4	16.1 ± 0.3
2018, 2019 (OND, MAMJ)	LM4	27.5 ± 0.7	68.1 ± 3.6	20.4 ± 0.4
2018, 2019 (OND, MAMJ)	LM3	23.2 ± 2.3	74.8 ± 13.1	18.0 ± 0.8
2018, 2019 (OND, MAMJ)	CL4	24.8 ±1.2	77.4 ± 1.9	18.8 ± 0.6

Phytoseiid mite abundance

The population density of phytoseiid mites varied in different seasons at different sites (Fig. 4). The AEZ LM3 (Makueni) recorded the highest phytoseiid density for two species *Amblydromalus* *hum* (Pritchard & Baker) and *Amblyseius sundi* at 131 and 122 mites per plant sample totals of the year seasons of OND and MAMJ, respectively. This was followed by AEZ LM4 (Machakos) where 96 species of *Amblydromalus hum* (Pritchard & Baker) and 86 species of *Amblyseius sundi* (Pritchard & Baker) [86] per plant were collected during the same yearly periods. In AEZ LM5 (Baringo) 25 individuals of *Typlodromalus denheyeri* (Zannou, Moraes & Oliveira) and 27 of *Euseius kenyae* (Swirski & Ragusa) were scored. The coastal region of AEZ CL4 had a higher diversity of three species, recording cumulative 38 individuals of *Euseius dossei* (Pritchard & Baker), 60 of *Amblyseius duplicesetus* (Moraes & McMurtry) and 58 of *Amblyseius sakalava* (Blommers). The AEZ bearing least species abundance was LH2 (Kitale) where species *Euseius albizzae* (Swirski & Ragusa) was collected at a cumulative total of 18. The rain seasons, i.e. OND (October, November, December) and MAMJ (March, April, May, June), did not appear to influence the abundance of the phytoseiid mites.

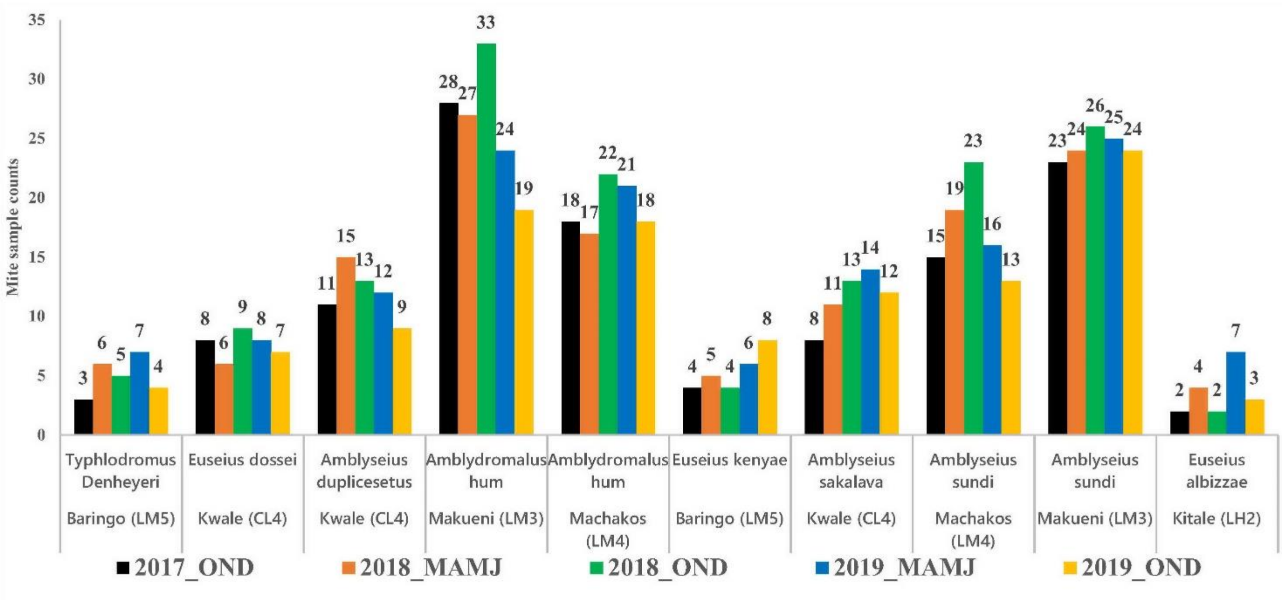

Figure 4. Seasonal abundance of phytoseiid mites per plant on citrus farms at different sample sites.

Table 3. The population density per plant per season of phytoseiid mites and pests collected from citrus farms in different agro-ecological zones (2017–2019).

AEZ	No. phytoseiids	No. *E. africanus*	No. thrips	No. W-flies	No. Mealybugs	*F*	*P*
CL4	31.2 ± 11.2^{A}	11.5 ± 3.3^{A}	4.2 ± 1.8^{C}	5.2 ± 2.2^{C}	6.5 ± 2.3^{B}	11.4	0.001
LM5	10.4 ± 3.8^{A}	7.2 ± 2.1^{B}	0.8 ± 0.3^{B}	0.9 ± 0.3^{B}	0.6 ± 0.2^{B}	6.7	0.002
LM3	50.6 ± 3.5^{A}	7.6 ± 2.8^{B}	0.6 ± 0.2^{D}	4.2 ± 0.3^{C}	0.6 ± 0.2^{D}	8.6	0.006
LM4	36.4 ± 10.4^{A}	8.4 ± 2.2^{B}	0.9 ± 0.3^{D}	5.2 ± 2.1^{C}	0.4 ± 0.1^{D}	7.3	0.043
LH2	3.6 ± 1.3^{A}	7.8 ± 4.3^{A}	3.2 ± 0.3^{B}	0^{C}	0^{C}	2.8	0.323

Different superscript letters across rows denote significant ($p < 0.05$) difference of population densities among predacious mites and herbivores on citrus crops in Kenya per season (2017–2019).

Table 3 shows the average per season population of phytoseiid mites and pests collected from citrus in the five AEZs over the three years' sampling period (2017–2019). More phytoseiid mites ($p < 0.05$) were in LM3 and LM4 at 50.6 and 36.4/season than other AEZs. Overall, the warmer and humid sites appeared to yield highest Phytoseiidae mites as in the case of LM3, LM4 and CL4. The major pest *E. africanus* was significantly ($p < 0.05$) highest among all other herbivore pests on citrus in the regions. The AEZ CL4 scored the highest average population density of *E. africanus* at 11.5/ plant per season across the sample sites from the different sites.

Phytoseiid mite density response

The warm-humid coastal region of CL4 showed all climatic factors correlating ($p < 0.05$, r = 99) positively to higher Phytoseiidae population density at 10.4 per plant with modest warm climate, high humidity and citrus age of 11.1 years (Table 4). In the drier LM5 region Phytoseiidae density was low at 5.2 mites/plant, showing a negative impact even with older trees of 11.7. In the cooler LM3 region, Phytoseiidae population density was highest at 25.3 which was probably boosted by warmer conditions even for young citrus trees of 8.5 years ($p < 0.05$, $r = 0.98$). Likewise, in the LM4 region Phytoseiidae density was high at 18.1 mites per plant, indicating positive correlation ($p < 0.05$, $r = 0.82$) to high RH (68.1%) and older tree age of 13.7 years. The coldest region of Lower Highlands-Two (LH2) showed the lowest number of Phytoseiidae mites at 3.6 at the sample sites where there were young (6.6 years) citrus trees.

Conversely, temperature appeared to influence (t = 10.3, < 0.001) higher phytoseiid population at 10.4 in the CL4 region while in other sites it was observed that the parameter was majorly affected by other factors. An observation (Table 4) of the climatic factors from all combined sites (All AEZs) showed positive effect of RH%, temperature and older trees on Phytoseiidae mite populations ($p < 0.05$).

Table 4. Effect of temperature, Relative humidity (RH, %), Dew-point (°C), citrus age (in years) on populations of phytoseiid mites in various agro-ecological zones (AEZs) in Kenya (2017–19).

Zone	Regression	Temp. (°C)	RH (%)	Dew-point (°C)	Citrus age (years)	No. phytoseiids	F-value	Correlation R-values
CL4	***t-value***	10.3	23.2	15.9	10.9	10.4	281.9	0.99
	P-value	< 0.001	< 0.001	< 0.001	< 0.001			
LM5	***t-value***	1.3	0.51	0.50	2.8	5.2	5.4	0.81
	P-value	0.255	0.633	0.638	0.056			
LM3	***t-value***	−1.3	2.3	−0.1	9.27	25.3	76.6	0.98
	P-value	0.031	0.068	0.897	0.002			
LM4	***t-value***	1.4	3.7	1.4	3.8	18.2	5.9	0.82
	P-value	0.211	0.011	0.209	0.008			
LH2	***t-value***	−1.4	−1.2	0.8	10.1	3.6	36.9	0.97
	P-value	0.236	0.271	0.450	0.002			
All	***t-value***	−2.9	−2.1	1.9	5.4	12.5	24.2	0.80
AEZs	***P-value***	0.005	0.041	0.57	< 0.001			

Regression results of environmental factors to Phytoseiidae population density (p = 0.05, df = 4, 9) among agro-ecological zones (AEZs) in Kenya (2017–19). Combined AEZs effect of the factors was positively corrected ($p < 0.001$, $F_{4,\ 51}$ = 24.2) to the dependent variable, the Phytoseiidae population density in citrus orchards (Linear Regression & Correlation Model at 5%).

Factor influence to pest density

Of the three evaluated factors (temperature, citrus tree age in years and Phytoseiidae density in the orchards), the first parameter did not significantly ($p > 0.05$, $r = 0.50$) influence *E. africanus* population density among all the AEZs (Table 5). Otherwise, in the warm-humid CL4 region, older citrus trees (11.1 years) showed significant ($p < 0.05$) higher correlation ($r = 0.79$) to higher tetranychid mite density at 12.1 mites per plant with little suppression by Phytoseiidae predators (at 10.4). The drier LM5 climatic conditions showed significant ($p < 0.05$, $r = 0.94$) higher temperature (23.9 °C) correlating to higher *E. africanus* population with higher tree age (11.7 years) and low Phytoseiidae density (at 5.1) leading to the population at 6.6 per plant. Likewise, the cooler LM3 region had low pest infestation at 5.4 mites per plant, influenced by young citrus (8.5 years) with low pest infestation and correlated to highest Phytoseiidae density at 25.3/ plant ($p < 0.05$, $r = 0.91$).

The warm-dry region of LM4 of old trees (13 years) had *E. africanus* pest population at 5.1 per plant, significantly ($p < 0.05$, $r = 0.92$) lower population level probably as a result of higher Phytoseiidae (at 13.2/ plant) population and subsequently suppressing the polyphagous mites. The cold region, LH2 pest mite infestation in the presence of predators (at 3.5) had citrus age (11.7 years) influencing significantly ($p < 0.05$, $r = 0.77$) higher pest mite infestation level at 5.6 per plant. In most of these AEZs, older trees and low Phytoseiidae numbers appeared to correlate inversely to higher *E. africanus* infestation levels on the citrus trees.

Table 5. Agro-ecological Zone (AEZ) factors influencing on Citrus brown mite, *Eutetranychus africanus* population density in Kenya citrus orchards in the period 2017–19.

Zone	value	Temp. (°C)	Citrus age (years)	No. phytoseiids	No. CRM	*F*	*R*
CL4	***t***	0.8	2.8	−2.9	12.1	5.9	0.79
	P	0.456	0.031	0.241			
LM5	***t***	3.1	8.0	−5.5	6.6	26.8	0.94
	P	0.019	< 0.001	0.009			
LM3	***t***	4.9	2.5	−3.4	5.4	17.4	0.91
	P	0.029	0.049	0.014			
LM4	***t***	1.4	0.38	−4.9	5.1	18.1	0.92
	P	0.185	0.719	0.026			
LH2	***t***	2.1	2.7	−3.1	5.6	5.3	0.77
	P	0.079	0.035	0.021			
All	***t***	0.5	3.5	−4.1	6.8	6.7	0.50
AEZs	***P***	0.641	0.011	0.002			

Environmental factors influence to Citrus Brown Mite (CRM) *E. africanus* population density ($p = 0.05$, df = 4, 9) among agro-ecological zones (AEZs) in Kenya (2017–2019). Combined AEZs effect of the factors was positively corrected ($p < 0.05$, $F_{3, 50} = 6.7$) to the dependent variable, the CRM population density in citrus orchards (Model Linear Regression & Correlation Model at 5%).

DISCUSSION

The present study shows the varied abundance and diversity of phytoseiid mites in the selected agro-ecological zones (AEZs) of Kenya. Our study aimed at determining the influence of AEZs climatic conditions on the phytoseiid mites' suppression of major citrus pests in Kenya. The highest phytoseiid population densities occurred in LM3 (Makueni), LM4 (Machakos) and CL4 (Kwale) where the annual RH% ranged from 68.1 to 77.4%. De Courcy *et al*. (2004) reported a similar range as being optimal for high populations for phytoseiid mites. It was also observed that the wet-cool AEZs of Trans-Nzoia of LH2 had the least phytoseiid mite density over the three years, compared to the warm-wet-humid areas. The areas with the highest phytoseiid population (LM3, LM4 and CL4) experienced temperatures of between 23.2 to 27.7 °C. Hardman *et al*. (2013) demonstrated the importance of optimal temperature in the increase of Phytoseiidae population and their ability to suppress their prey. In the present study, it was observed that dew-points ranging from 18.0 to 20.4 °C occurred in the AEZs LM3, LM4 and CL4, where the highest Phytoseiidae population densities occurred. Shipp and Van Houten (1997) studied the influence of temperature and vapor pressure deficit on the survival of the predatory mite *Amblyseius cucumeris* (Oudemans) and showed that the predator preferred optimal vapors where some water droplets formed on plant leaves as this increased predator population's survival during periods of extreme dry conditions.

The agro-ecological zone LM3 (Makueni) had the highest Phytoseiidae population during the study period for two species; *Amblydromalus hum* (Pritchard & Baker) and *Amblyseius sundi* (Pritchard & Baker). The species *A. sundi* has been reported on cassava and tea crops in Kenya while *A. hum* is being reported for the first time in Kenya (Mutisya *et al*. 2017, 2018). Results of the present study showed the predominance of *A. hum* among all the species and its presence only in

LM3 and LM4 AEZs of eastern Kenya in Makueni and Machakos regions. The AEZ LM5 (Baringo) bore two species *Typlodromalus denheyeri* (Zannou, Moraes & Oliveira) [being also reported for the first time in citrus in Kenya] and *Euseius kenyae* (Swirski & Ragusa) which has been reported as predominant species in coffee plantations and in small populations on tea in Kenya in the high altitude AEZs (El Banhawy *et al*. 2009; El Banhawy and Knapp 2011). The coastal region of AEZ CL4 had three species, *Euseius dossei* (Pritchard & Baker), *Amblyseius duplicesetus* (Moraes & McMurtry) and *Amblyseius sakalava* (Blommers). The species *E. dossei* has been reported on various crops in most Sub-Saharan Africa countries including Benin, Burundi, Ghana, Kenya, Rwanda, Sierra Leone, Uganda and Zaire (Moraes *et al*. 2001). The two species *A. duplicesetus* and *A. sakalava* are reported from collections of Phytoseiidae in Mohéli Island in the Indian Ocean and Kenya (El Banhawy and Knapp 2011; Kreiter *et al*. 2021). The AEZ with the least species diversity was LH2 (Kitale) where species *Euseius albizziae* (Swirski & Ragusa) was collected in the cool-wet region. El Banhawy and Knapp (2011) reported *E. abizziae* from different tree collections but later on Mutisya *et al*. (2017) reported the species on cassava.

The major pest, *E. africanus* was found to be the most abundant (at 12.5/ plant leaf) on citrus in the AEZ of CL4 in the coastal Kwale region, recording low populations of less than 7 mites per plant. Regression of *E. africanus* density against factors of temperature, citrus age and phytoseiid density showed significant inverse correlation of high predator density population resulting in low pest mite density. Older citrus trees were found to correlate to higher population density for *E. africanus* in the site orchards. Fadamiro *et al*. (2009) reported the population buildup of phytoseiid mites during the winter, and subsequent drop in the dry spell in summer where comparatively similar results were found for yearly seasons of wet and dry periods in Kenyan orchards.

The warm-humid coastal region of CL4 showed climatic factors of temperature, RH% and dew-point levels correlating ($p < 0.05$, r = 0.99) to higher phytoseiid populations. In most AEZs dew-point levels did not correlate with increased Phytoseiidae populations ($p > 0.05$) but in the combined five regions climatic factors of optimum temperature and RH% influenced sustained high population density. Other ecologists have reported phytoseiid populations on plants relating to geographical adaptations of species (Hernandes *et al.* 2011). Other reports from different ecologists show that phytoseiid mites' optimal RH (%) for reproduction and life stage development range between 70 and 80% (Janssen *et al.* 2007; Walzer *et al.* 2007; Ferreira *et al.* 2008; Hardman *et al.* 2013; Mutisya *et al*. 2014). Elsewhere, ecologists have reported similar temperature optimal conditions for reproduction and development of life stage cohorts of phytoseiid species (Dinh *et al*.1988; Shipp and Van Houten 1997; De Courcy *et al*. 2004; Ferrero *et al*. 2010; Mutisya *et al*. 2014). Success of phytoseiid mites as biological control agents of phytophagous mites is reported in Spain on citrus showing a sustainable maintenance of low polyphagous pest mites (Jasca and Urbanaja 2010; Vela *et al*. 2017). In another report on efficacy of indigenous Phytoseiidae in suppressing Tetranychidae pests in Israel on citrus orchards, recommendation of conserving the phytoseiids in the orchards is provided (Maoz *et al*. 2014). Mutisya *et al*. (2014) reported that the phytoseiid predator *Typhlodromalus aripo* (De Leon) suffered over 90% mortality in seven days when subjected to 33 ℃ temperature even in most ambient RH of 80%. Similarly, in the same study (Mutisya *et al*. 2014) high mortality occurred when the phytoseiid predator was subjected to 12 ℃ for a similar period of one week. This could explain why the hot-humid AEZ of LM5 showed the least Phytoseiidae mite population density and why similarly the cool-wet LH2 region yielded lowest Phytoseiidae numbers even in older trees of 11.7 years. Presence of high phytoseiid mite populations led to suppressed herbivore pests as noted in CL4, LM3 and LM4 AEZs highlighting a requirement for use of some irrigation for modifying the environment to warm-humid conditions for increased density growth of the phytoseiid mites in the less optimal regions. Warburg *et al.* (2019) has demonstrated similar results where climatic factors and cultivar types play important roles to phytoseiid mites population buildup in citrus orchards for structure and function of phytoseiid communities.

CONCLUSIONS

The agro-ecological zones found to favor the highest population and diversity of phytoseiid mites were the warm-wet-humid to warm-humid, specifically the LM3, LM4 and CL4, whereby the first two were sampled in Eastern region and the latter in the coastal region of Kenya. This brings us to the conclusion that AEZs bearing warm and humid conditions favored high populations of phytoseiid mites while drier conditions negatively impacted the same parameter.

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تأثیر مناطق آگرواکولوژیک بر جمعیت کنه‌های شکارگر (Acari: Phytoseiidae) و کنهٔ آفت *Eutetranychus africanus* (Acari: Tetranychidae) در باغ‌های مرکبات کنیا

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چکیده

زنده‌مانی و تولیدمثل کنه‌های Phytoseiidae به عوامل محیطی بهینه بستگی دارد. در مجموع پنج منطقه آگرواکولوژیک (AEZs) دو بار در سال از سال ۲۰۱۷ تا ۲۰۱۹ در کنیا مورد بررسی قرار گرفت. در شرق کنیا محل‌های نمونه‌برداری باغ‌های مرکبات در مقیاس کوچک در شهرستان‌های ماچاکوس [میدلندز پایین-چهار (LM4)] و ماکونی [میدلندز بالا-سه (LM3)] بودند. در مناطق پست ساحلی-چهار (CL4) کرت‌های مرکبات در مقیاس کوچک مشابه در Kwale نمونه برداری شد، در حالی که در منطقه کوهستانی درهٔ ریفت محل‌های نمونه ADC-Suam باغ‌های Kitale مناطق کم ارتفاع‌تر دوم (LH2) بودند، که در آن مزارع بزرگ مقیاس زیر کشت مرکبات بودند. پنجمین محل نمونه‌برداری شده منطقهٔ Baringo در [میدلندز پایین-پنج (LM5)] بود که در آن کرت‌های کوچک مرکبات بر در محل‌های نمونهبرداری غالب بودند. از ٦٨ مزرعه چند بار بررسی شده، ٤٠ درصد کرت‌های مرکبات دارای تنوع مختلفی از کنه‌های فیتوزیید بودند. آفت اصلی از محل‌های نمونه‌برداری کنه قهوه ای مرکبات *Eutetranychus africanus* بود. در این مطالعه، نوسانات جمعیت کنه‌های فیتوزئید در شرایط مختلف اقلیمی دما، رطوبت نسبی، نقطه شبنم و سن گیاه مرکبات (بر حسب سال) مشاهده شد. برای آفت مهم *E. africanus*، سه عامل برای همبستگی و میزان سطوح آلودگی در مرکبات مورد بررسی قرار گرفت. از سه عامل ارزیابی شده دما، سن درخت مرکبات و تراکم فیتوزئید در باغ‌ها، به نظر نمی‌رسد که آمارهٔ دما به مقدار زیادی بر سطوح آلودگی کنه آفت (*E. africanus*) برای همه عوامل ترکیبی AEZs تأثیر بگذارد. در مطالعات موردی حاضر مخصوص درختان مسن‌تر AEZs منجر به انبوهی بیشتر کنهٔ آفت شد در حالی که تعداد کمتر فیتوزئید با سطوح آلودگی بیشتر *E. africanus* در درختان مرکبات ارتباط معکوس داشت. اطلاعات این مقاله می‌تواند به طور فعال برای برنامه‌ریزی مدیریت *E. africanus* به عنوان آفت اصلی در باغ‌های مرکبات در مناطق خاص آگرواکولوژیک استفاده شود.

واژگان کلیدی: کنهٔ قهوه‌ای مرکبات؛ سن درختان مرکبات؛ انبوهی؛ بی‌مهرگان گیاهخوار؛ کنه‌های شکارگر؛ دما.

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