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TYPHLODROMALUS ARIPO DE LEON (ACARI: PHYTOSEIIDAE) DEVELOPMENT AND REPRODUCTION ON MAJOR CASSAVA PESTS AT DIFFERENT TEMPERATURES AND HUMIDITIES: AN INDICATION OF ENHANCED MITE RESILIENCE

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ABSTRACT — Both prey type and abiotic conditions limit performance of phytoseiid predators. The exotic predatory mite, *Typhlodromalus aripo* developed and reproduced when maintained on eggs and active stages of the cassava green mite (CGM) *Mononychellus progresivus* at three different temperatures. At the highest temperature of 33 °C and the lowest at 12 °C, mite survival was less than 15 % over a period of ten days with low fecundity. At 12 °C, immatures took longer to reach maturity, while at 33 °C high mortality (>80 %) occurred. The best performance was recorded at 27 °C and 75 % relative humidity. *Typhlodromalus aripo* was also able to feed, develop and reproduce on the crawlers' stage of the whitefly, *Bemisia tabaci* and the nymphal stage of the mealybug, *Phenacoccus manihoti*, though a low survival rate (<10%) was observed for the stages of protonymph, deutonymph and adults. Normal life stage development and egg hatchability were recorded at 27 °C and 75 % RH. The egg stage exhibited high drought tolerance (70 % hatching at 40 % RH). *Typhlodromalus aripo* females consumed less than 3 crawlers and produced less than one egg/day when fed with *B. tabaci* and *P. manihoti* at 75 % RH. The study indicated that for successful utilization of *T. aripo* in the biological control of CGM, it would be important to introduce the predator at low prey density whether in absence or presence of alternative prey on cassava. In conclusion, results revealed *T. aripo* to have drought resilient survival attributes which enhances this phytoseiid as an effective biological control agent.

KEYWORDS — Phytoseiidae; *Typhlodromalus aripo*; *Mononychellus progresivus*; *Bemisia tabaci*; tolerance; *Phenacoccus manihoti*

INTRODUCTION

The predatory mite, *Typhlodromalus aripo* De Leon (Acari: Phytoseiidae) was first described from Trinidad and reported later from Brazil (Denmark and Muma 1973). This predator among others was introduced to East Africa during the 1990's to control the cassava green mite (CGM), *Mononychellus progresivus* Doreste, a pest that constrains production of the cassava (Gutierrez 1987; Hanna *et al.* 1998). In Kenya *T. aripo* was released in 1995/6 and

its establishment and subsequent persistence led to reduction of severity of CGM on cassava (Kariuki *et al.* 2000; Jones 2002; Yaninek and Hanna 2003). Cassava is a drought tolerant crop and could be produced in regions where relative humidity is usually less than 50 % (Hillocks 2002; Bellotti 2002). The success of *T. aripo* in suppressing populations of CGM has been mainly attributed to the predator's capacity to live in the apices of cassava during the dry spells and feeding on the plant sap and other al-

ternative food substances in absence of CGM (Magalhães and Bakker, 2002; Gnanvossou *et al.* 2003; Onzo *et al.* 2003, 2009).

Typhlodromalus aripo develops and reproduces on the different stages of CGM and survives on some plant material like pollen grains of maize, castor oil and cassava plant exudates (Cuellar *et al.* 2001; Gnanvossou *et al.* 2005). Our observations on cassava fields in Kenya showed that *T. aripo* congregates on cassava apices infested with the whitefly *Bemisia tabaci* (Genn.) (Hemiptera: Aleyrodidae). Another pest infesting cassava growing shoot is *Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Pseudococcidae) leading to poor root yield (Kariuki *et al.* 2000). Except for few species, the majority of phytoseiid mites are able to survive, develop and reproduce on different animal prey or plant materials (McMurtry *et al.* 1970, 2013; Bakker *et al.*, 1993). This wide range of alternative diets is useful in biological control for longer survival of the beneficial organism in the absence of preferred prey. In absence of the main target pests, other food substances would maintain the population of the natural enemy from elimination until the main prey increased in sufficient numbers to support the population of the predators (McMurtry and Scriven 1966). Although predacious mites usually achieve excellent control of most phytophagous mites and some insects, there are factors limiting their efficiency like initial predator-prey ratio and diet preference (Grout and Richards 1992; Bakker *et al.* 1993). The present study aims to evaluate *T. aripo* consumption rate, immature development and reproduction on different cassava pests as preferred and alternative prey types of CGM, *P. manihoti* and *B. tabaci* in different temperatures and humidity conditions.

MATERIALS AND METHODS

Source of prey

Cassava green mite (CGM), *M. progresivus* was reared on a local cassava cultivar, x-Mariakani planted in a plot 50 m x 30 m at KARI-Katumani Research Station (01°34.949 S, 037°14.426 E, 1609 m asl). CGM natural infestation began in April and

reached peak levels of 200-350 mites per leaf on the top plant canopy during the dry period (July to October). The mite infested plant apices were collected each morning for mass rearing of *T. aripo* in the laboratory.

Cassava mealybug, *P. manihoti* was mass reared on young cassava plants (one meter high) in a screen house (20 ± 4 °C, 62 ± 10 % RH). *Phenacoccus manihoti* crawlers were daily collected for experiments in the laboratory. A *B. tabaci* rearing was established on cassava plants in another screen house (22 ± 8 °C, 62 ± 12 % RH). Regular watering and additions of fresh plantlets were carried out to provide a good stock of young plants for whitefly reproduction and development.

Predator rearing

Typhlodromalus aripo was collected from a cassava field at Kenya Agricultural Research Institute- Kiboko Station (02°12.872 S, 037°42.960 E, 934 m asl). Fifty cassava apices infested with CGM and *T. aripo* were transferred in a cool box and brought back to the laboratory at KARI-Katumani for mass rearing. Four plastic containers of 23 cm-height x 24 cm-diameter were filled-half way with water. In the water some 8 – 10 apices of the x-Mariakani cultivar of 30 – 35 cm stems were stood with apex plant part above the water. The cultivar x-Mariakani plant shoot is usually tri-branched resulting to three apices per shoot. Each shoot had between 200-350 CGM, which is enough to feed 30 mobile stages of *T. aripo* for two days. Five apices infested with *T. aripo* were placed next to the x-Mariakani apices infested with CGM actives in the containers. Both the *T. aripo* infested apices and CGM infested apices were stood in the containers with their shoots 30 cm high above water to prevent phytoseiids from drowning. Ten similar containers were maintained in room (27 ± 1 °C, 75 ± 5 % RH, 12L: 12D) for mass production of the predator (Friese *et al.* 1987). *Typhlodromus aripo* life stage cohorts were collected from the apices after three to four days. To get same age life stage cohorts, 50-100 *T. aripo* female were placed on a 4 cm-diameter leaf disc infested with CGM in a Petri-dish ringed with wet cotton where eggs are collected two days later for the experiment. On one side of disc, a

plate hole corresponds to the area where the predator and the prey were placed and observed daily (12 hrs) under dissecting microscope lens (Mag. X 160).

Prey consumption rate test

Freshly emerged individual larvae, protonymphs, deutonymphs and females were each placed on leaf disks inside a plastic hole of 0.4 cm-depth x 1.5 cm-diameter (Fig. 1). The abaxial face of disc was covered with 22 mm glass slide fastened with rubber-band. A wet Whatman filter paper slip was inserted between the cassava leaf disk and the glass to prolong leaf disk freshness. Another 22 mm glass slide was used to cover the rearing hole to prevent escape of both prey and predator. Individual life stages (larva, protonymph, deutonymph and mated female) were daily fed with prey as follows for each treatment: 100 CGM eggs, 40 CGM mobile stages, 20 *B. tabaci* crawlers and 20 for *P. manihoti*. For each experiment (food) and each life stage (larvae, protonymphs, deutonymphs, females) 22-24 individual replicates were carried out. The evaluations were repeatedly carried out at the three relative humidities (40, 75, 92 ± 2 %) and at the three temperatures (12, 27, 33 ± 1 °C) with a photoperiod 12L: 12D. A control unit of cassava leaf without any prey for each life stage (22-24 individuals) was set in similar abiotic conditions to measure *T. aripo* survival and

development without prey. Humidity containers of 10 cm-diameter x 9 cm height with tight covers were used to hold RH using salt solutions (Winston and Bates 1960). The containers (10 cm-diameter x 9 cm-depth) and salt solutions, NaCl (H₂O), KI and K₂C₂O (H₂O), were used for experimental units of 40, 75 and 92 % RH as in Ferrero *et al.* (2010). Prey rations replenishment was carried for each unit after observation and recording of fed quantity. Life stage prey consumption rate / day, immature development and survival to adult stage, as well as female fecundity were recorded.

An additional test on female response to increased amount of CGM and *B. tabaci* was carried out in a rearing unit room (27 ± 1 °C, 75 ± 5 % RH). Combination of 10 *B. tabaci* crawlers and CGM mobile stages at rations of 1, 2, 4, 8, 16, 32, 64, 128 and 256 were set. The study was repeated three times on mated females (one mated female per replicate) in similar previously described conditions. Female consumption rate / day and eggs laid were recorded each day until female death.

Egg drought tolerance

Fifty freshly laid *T. aripo* eggs were observed each 6 hours in the described chambers of 40, 75 and 92 % RH and at temperatures of 12, 27 and 33 °C. The eggs were observed until they hatched into larvae.

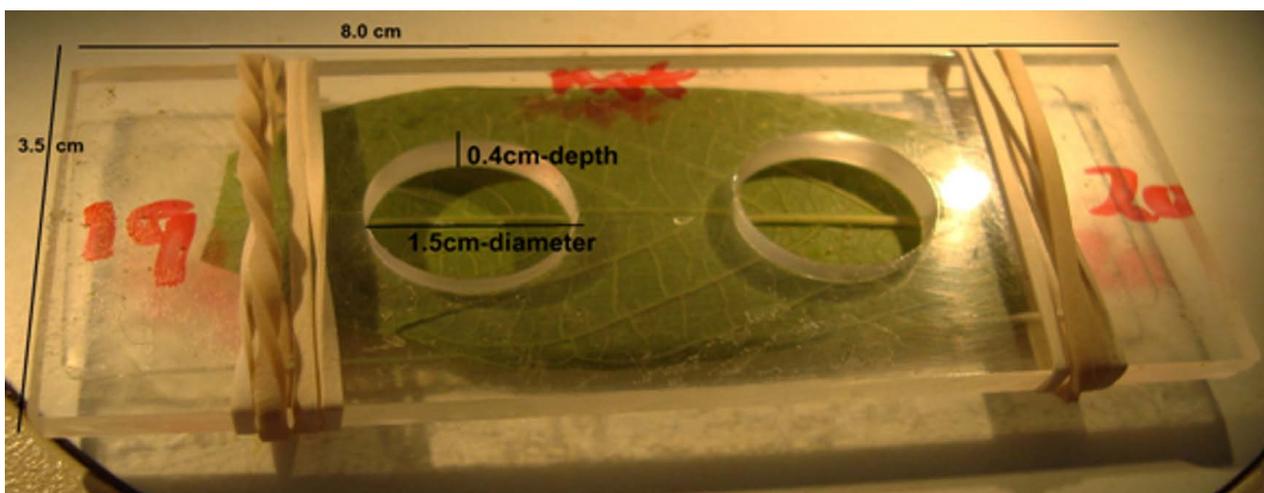


FIGURE 1: Leaf disk unit showing dimensions (0.4 cm-depth x 1.5 cm-diameter) of feed area of *Typhlodromalus aripo* life stage cohorts on cassava green mite (eggs and active), *Bemisia tabaci* and *Phenacoccus manihoti*.

TABLE 1: Mean numbers (\pm standard error) of prey consumed per day by *Typhlodromalus aripo* fed on cassava green mite (CGM) *Mononychellus progresivus*, *Bemisia tabaci* and cassava mealybug *Phenacoccus manihoti* crawlers at three different temperatures and at $75 \pm 2\%$ RH.

Prey	Prey Consumption rate / day				F, P(df)
	larva	Protonymph	deutonymph	Adults females	
12 °C					
CGM eggs	0	2.3 \pm 1.6aB	2.2 \pm 1.1aB	4.3 \pm 1.1aA	6.9, 0.043 (2, 65)
CGM actives	0	2.1 \pm 0.9bB	2.3 \pm 0.6aC	2.7 \pm 1.3abA	25.6, 0.004 (2, 71)
<i>B. tabaci</i>	0	1.2 \pm 0.5cA	1.0 \pm 0.4bA	1.3 \pm 0.8bA	0.1, 0.962 (2, 68)
<i>P. manihoti</i>	0	0.6 \pm 0.4dA	1.1 \pm 1.0bA	1.1 \pm 1.2bA	0.88, 0.546 (2, 71)
Cassava leaf	-	-	-	-	-
P-Value	-	< 0.0001	< 0.0001	0.0101	
27 °C					
CGM eggs	0	5.1 \pm 0.6aC	16.5 \pm 4.5aB	61.6 \pm 14.2aA	132.4, <0.001 (2,68)
CGM actives	0	4.8 \pm 0.3aB	12.2 \pm 3.2bB	28.3 \pm 2.3bA	16.3, 0.034 (2, 65)
<i>B. tabaci</i>	0	1.2 \pm 0.4bB	1.1 \pm 0.7cB	1.8 \pm 0.4cA	10.8, 0.024 (2, 71)
<i>P. manihoti</i>	0	1.1 \pm 0.4bB	1.4 \pm 0.4cB	1.8 \pm 0.6cA	15.9, 0.012 (2, 65))
Cassava leaf	-	-	-	-	-
P-Value	-	0.0017	< 0.0001	0.0007	
33 °C					
CGM eggs	0	4.3 \pm 2.1aC	9.6 \pm 1.5aB	23.4 \pm 3.2aA	290.8, <0.001(2, 59)
CGM actives	0	4.2 \pm 1.2aB	8.6 \pm 2.0aA	10.2 \pm 2.5bA	28.9, 0.042 (2, 62)
<i>B. tabaci</i>	0	1.4 \pm 0.8bC	1.7 \pm 1.2bB	2.2 \pm 1.0cA	147.0, 0.002 (2, 59)
<i>P. manihoti</i>	0	1.3 \pm 1.2bC	1.5 \pm 1.0bB	1.9 \pm 0.9cA	84.0, 0.005 (2, 71)
Cassava leaf	-	-	-	-	-
P-Value	-	0.0108	< 0.0001	< 0.0001	

Different lower case letters denote significant difference for each life stage under different temperatures (df=3, 91).

Different upper case letters denote significant difference (P<0.05) of consumption rate among the different

Typhlodromalus aripo life stages for same food and temperature condition.

The hatching rates and live larvae were used to determine *T. aripo* egg hatch (%) in optimum and adverse climatic conditions.

Data analysis

Mean duration of developmental periods (days) of *T. aripo* (larva, protonymph, deutonymph female), female mean fecundity, and average daily prey consumption by each life stage were subjected to analysis of variance (ANOVA) using Fishers Least Significance Difference (LSD) test in a three-way ANOVA (GLM) to determine temperature, RH and prey effect on *T. aripo* development. Newman and

Keuls Post Hoc test was used to determine significant differences between mean values. Log (x+1) data transformation was carried out before applying ANOVA. SAS Version 8 (2001) was used for the analyses.

RESULTS

Life stage prey type consumption rate

Typhlodromalus aripo consumed significantly (P < 0.05) different quantities of the four prey types of CGM (eggs and actives), *B. tabaci* and *P. manihoti* whatever the life stage considered and the temper-

ature applied at 75 % RH (Table 1). *Typhlodromalus aripo* larvae did not feed for all the considered conditions. In all cases the adult consumed significantly ($P < 0.05$) higher prey quantities than the immature stages except at 12 °C where the consumption of *B. tabaci* and *P. manihoti* was not different between immatures and adults.

For all temperatures, for all *T. aripo* life stages and for the three RH, CGM were significantly ($P < 0.05$) more consumed than *P. manihoti* and *B. tabaci* (less than three individuals per predator / day) (Tables 1 & 2). Higher numbers of CGM eggs than CGM mobile stages were significantly ($P < 0.05$) consumed by *T. aripo* adult females and deutonymphs (except at 12 °C). The highest prey consumption was observed at 27 °C, for all life stages and the preys considered. The lowest consumption rates were observed at 12 °C. The cassava leaf without prey only supported *T. aripo* during two days, before complete mortality of cohorts for all conditions.

At the lowest humidity (40 % RH) CGM daily consumption rate was significantly higher ($P < 0.0001$) than *B. tabaci* and *P. manihoti* consumption for all life stages (Table 2) and all temperature. The CGM prey consumption by immature and females was significantly higher at 27 °C than at 12 and 33 °C while the consumption rates of *B. tabaci* and *P. manihoti* were not significantly different between the temperatures (Table 2).

At 92 % RH, similar significant ($P < 0.05$) higher CGM prey consumption than *B. tabaci* and *P. manihoti* one was observed for immature and female stages for the three temperature conditions.

Female egg reproduction was significantly ($P < 0.05$) higher on CGM prey than on *B. tabaci* and *P. manihoti* preys at 27 °C in all humidities. No egg was produced at 40 % RH whatever the temperature. At 92 %, the fecundity was lower than at 75 % whatever the temperature considered. Again for this RH, *T. aripo* fecundity was higher when fed on CGM than on *B. tabaci* and *P. manihoti* (Table 2).

Life stage development on prey types

At 75 % RH. At 12 °C, all *T. aripo* larvae suffered total mortality in 10 days (Table 3). *Typhlodroma-*

lus aripo immature development period (days) was longest at 12 °C than at 27 °C and 33 °C for all prey types (CGM, *B. tabaci* and *P. manihoti*). At 27 °C no significant ($P > 0.05$) difference in development days was scored among prey types. Survival to maturity (%) was highest on CGM (eggs: 96 % and mobile stages: 94 %) at 27 °C than on other two preys. At 12 °C and 33 °C less than 15 % immatures reached maturity but this survival was higher when *T. aripo* was fed with CGM than with the two other preys.

Female longevity was significantly ($P < 0.0001$) highest at 27 °C on CGM prey than *B. tabaci* and *P. manihoti*. At 12 °C and 33 °C female longevity was highly reduced but always higher when fed on CGM than on the two other preys. Females did not lay eggs at 12 °C, while at 27 °C and 33 °C significant higher amount of eggs ($P < 0.05$) was laid when *T. aripo* was fed on CGM prey than on *B. tabaci* and *P. manihoti*.

At 40 % RH. Significant ($P < 0.0001$) longer development time of immatures was observed on *B. tabaci* and *P. manihoti* than CGM for the three temperatures tested (Table 4). Female longevity was longer when the predator was fed with CGM than with *B. tabaci* and *P. manihoti* whatever the temperature. The highest longevity was observed at 27 °C. Immature survival was always higher when *T. aripo* was fed with CGM than with the two other preys whatever the temperature even at 12 °C and 33 °C characterized by very low survival.

At 92 % RH. Immature development time was significantly higher ($P < 0.0001$) when the predator was fed on *B. tabaci* and *P. manihoti* than on CGM preys. Immature survival was very low at 12 °C and 33 °C suggesting that temperature is a key point for immature survival. At 33 °C and 27 °C, the immature survival was clearly higher when the predator was fed with CGM than with the two other preys. Female longevity was significantly ($P < 0.0001$) higher when fed on CGM than with the two other preys, whatever the temperature. However, the longevity was clearly higher at 27 °C for CGM preys than at 12 °C and 33 °C. This observation also applied for the two other RHs.

TABLE 2: Mean daily number (± SE) of prey consumed by immature and females of *Typhlodromulus aripo*, and egg production at three temperatures and three RH

RH	Prey	Life stage daily consumption and female fecundity											
		12 °C				27 °C				33 °C			
		Immatures (1a)	Females (1b)	N. eggs (1c)	Immatures (2a)	Females (2b)	N. eggs (2c)	Immatures (3a)	Females (3b)	N. eggs (3c)	F_1P (1a,2a, 3a)	F_1P (1b,2b, 3b)	F_1P (1c, 2c, 3c)
40%	CGM eggs	1.8 ± 2.3aC	4.1 ± 2.2aC	0aB	11.6 ± 3.9aA	52.3 ± 8.4aA	2.1 ± 4.1aA	6.4 ± 5.2aB	33.6 ± 7.6aB	0.8 ± 4.2abA	77.1, 0.0005	888.6 < 0.0001	20.1, 0.0062
	CGM actives	1.5 ± 0.9bC	2.3 ± 1.2bB	0aC	8.1 ± 6.1bA	26.2 ± 6.2bA	1.8 ± 3.2aA	5.6 ± 2.9aB	24.1 ± 6.5bA	1.1 ± 1.2aB	1679.0, <0.0001	285.6 < 0.0001	53.0, 0.0010
	<i>B. tabaci</i>	0.4 ± 2.1cA	0.2 ± 0.8cC	0aB	0.9 ± 1.3cA	1.2 ± 3.2cB	0.1 ± 0.8bB	0.5 ± 0.2bA	1.4 ± 4.2cA	0.9 ± 0.8aA	1.1, 0.2460	66.5, 0.0007	38.0, 0.0019
	<i>P. manihoti</i>	0.3 ± 0.9dC	0.1 ± 0.6cB	0aB	1.0 ± 1.8cA	1.4 ± 5.2cA	0.2 ± 0.7bB	0.6 ± 0.1bB	1.6 ± 2.3cA	0.4 ± 0.5bA	InfHy, <0.0001	23.0, 0.0051	7.5, 0.0383
	<i>P-Value</i>	< 0.0001	< 0.0001	-	< 0.0001	< 0.0001	0.0037	< 0.0001	< 0.0001	0.0537	-	-	-
75%	CGM eggs	2.2 ± 0.8aC	4.3 ± 1.1aC	0aC	10.2 ± 4.5aA	61.6 ± 4.2aA	2.2 ± 5.5aA	7.2 ± 4.3aB	23.2 ± 3.2aB	1.9 ± 3.5aB	9030.5, <0.0001	58.3, 0.0008	93.3, 0.0003
	CGM actives	2.1 ± 0.4aC	2.7 ± 1.3bC	0aC	7.6 ± 3.7bA	28.3 ± 3.6bA	1.9 ± 6.2aA	6.9 ± 2.6aB	10.2 ± 2.5bB	1.6 ± 0.8bB	142.7, 0.0001	318.2, < 0.0001	313.0, < 0.0001
	<i>B. tabaci</i>	1.2 ± 0.3bB	1.4 ± 0.5cB	0aC	1.1 ± 2.3cB	1.8 ± 2.2cA	0.2 ± 0.4bB	1.5 ± 0.5cA	2.2 ± 1.0cA	0.8 ± 0.9cA	291.5, <0.0001	9.2, 0.0271	27.5, 0.0036
	<i>P. manihoti</i>	0.8 ± 0.2cC	1.1 ± 0.3cA	0aB	1.2 ± 1.8cA	1.2 ± 0.8cA	0.1 ± 0.8bB	0.6 ± 0.3dB	1.9 ± 0.9cA	0.7 ± 0.4cA	7.1, 0.0419	3.0, 0.0255	23.0, 0.0051
	<i>P-Value</i>	< 0.0001	< 0.0001	-	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	-	-	-
92%	CGM eggs	1.2 ± 0.1bC	2.4 ± 4.6aC	0aC	9.4 ± 5.2aA	42.3 ± 8.7aA	2.0 ± 2.2aA	7.3 ± 4.3aB	25.4 ± 4.6aB	1.4 ± 2.2aB	2735.0, <0.0001	249.4, < 0.0001	41.0, 0.0017
	CGM actives	1.5 ± 0.3aC	2.5 ± 8.2aC	0aC	7.2 ± 3.8aA	26.5 ± 9.4bA	2.1 ± 2.2aA	6.8 ± 5.5aA	22.4 ± 6.3aB	1.5 ± 2.2aB	4580.0, <0.0001	82.6, 0.0004	7.4, 0.0395
	<i>B. tabaci</i>	0.2 ± 0.6cC	0.9 ± 0.4bC	0aB	1.6 ± 4.2bA	1.6 ± 7.1cA	0.2 ± 2.2bA	0.9 ± 0.6bB	1.3 ± 4.9bB	0.1 ± 2.2bB	233.0, <0.0001	24.5, 0.0045	6.5, 0.0486
	<i>P. manihoti</i>	0.3 ± 0.2cC	0.7 ± 0.6bA	0aB	1.4 ± 2.2bA	1.5 ± 5.2cA	0.3 ± 2.2bA	1.0 ± 0.8bB	0.9 ± 0.9bA	0.1 ± 2.2bB	152.0, 0.0001	0.9, 0.5478	12.5, 0.0156
	<i>P-Value</i>	< 0.0001	0.0046	-	0.0007	< 0.0001	< 0.0001	0.0001	< 0.0001	0.0002	-	-	-

Different lower case letters denote significant difference for each life stage under different temperatures (df=3, 92) for 10 days observation. Different upper case letters denote significant difference for each parameter at different temperatures (df =2, 64).

TABLE 3: Life stage development durations (days) and fecundity of *Typhlodromalus aripo* when fed on the cassava green mite (CGM) *Mononychellus progresivus* and crawlers of *Bemisia tabaci* and cassava mealybug *Phenacoccus manihoti* at three different temperatures and 75 ± 2% RH.

Prey	Life stage durations (days)			Total Develop. Days	% maturity	Female Longevity	Eggs / female/ day
	Larva	Protonymph	Deutonymph				
12 °C							
CGM eggs	-	9.5 ± 2.5a	9.2 ± 2.1b	18.7 ± 1.7b	8	9.3 ± 4.3a	0
CGM actives	-	10.2 ± 1.6a	9.1 ± 2.7b	19.3 ± 1.8b	5	6.4 ± 2.1b	0
<i>B. tabaci</i>	-	11.4 ± 4.4a	14.8 ± 3.2a	23.4 ± 3.6a	3	4.2 ± 0.8b	0
<i>P. manihoti</i>	-	12.7 ± 3.5a	15.3 ± 4.1a	25.0 ± 2.6a	2	4.6 ± 1.5b	0
Cassava leaf	-	-	-	-	-	-	-
P-Value	-	0.0017	0.0043	0.0039		0.0192	-
27 °C							
CGM eggs	1.4 ± 0.5a	1.8 ± 0.8ab	1.3 ± 0.8b	4.4 ± 0.3a	96	27.6 ± 2.6a	1.9 ± 1.3a
CGM actives	1.2 ± 0.3b	2.0 ± 0.5a	1.1 ± 0.2c	4.3 ± 0.5b	92	26.3 ± 1.8a	1.6 ± 0.9a
<i>B. tabaci</i>	1.2 ± 0.4b	1.1 ± 0.4c	1.1 ± 0.2c	3.4 ± 0.1d	14	3.4 ± 1.7b	0.3 ± 0.5b
<i>P. manihoti</i>	1.1 ± 0.3b	1.5 ± 0.3b	1.6 ± 1.1a	4.2 ± 0.3c	11	4.3 ± 1.2b	0.2 ± 0.1b
Cassava leaf	1.2 ± 0.2b	-	-	-	-	-	-
P-Value	0.0029	0.0008	0.0020	< 0.0001		< 0.0001	0.0073
33 °C							
CGM eggs	1.2 ± 0.2b	0.9 ± 0.1b	1.3 ± 0.6a	3.4 ± 0.2ab	14	7.4 ± 1.6b	1.8 ± 0.6a
CGM actives	1.0 ± 0.1d	1.1 ± 0.2b	0.9 ± 0.5c	3.0 ± 0.1b	8	7.1 ± 0.9b	1.6 ± 0.2a
<i>B. tabaci</i>	1.1 ± 1.0c	1.0 ± 0.3b	1.0 ± 0.0b	3.1 ± 0.1b	3	3.8 ± 2.3b	0.3 ± 0.1b
<i>P. manihoti</i>	1.3 ± 0.5a	1.4 ± 0.1a	1.0 ± 0.0b	3.7 ± 0.2a	0	2.1 ± 1.1b	0b
Cassava leaf	1.2 ± 0.2b	-	-	-	-	-	-
P-Value	< 0.0001	0.0142	< 0.0001	0.0289		0.0312	0.0005

Different lower case letters denote significant difference for each life stage under different temperatures (df=3, 92) for 10 days observation.

TABLE 4: *Typhlodromulus aripo* immature developmental duration (days ± SE) and female (F.) longevity when fed with four prey, at three temperatures and three RH.

RH	Prey	Immature development period (days) and female longevity											
		12 °C				27 °C				33 °C			
		Dev. days	% maturity	F. longevity	Dev. days	% maturity	F. longevity	Dev. days	% maturity	F. longevity	Dev. days	% maturity	F. longevity
40%	CGM eggs	12.3 ± 6.4d	10	6.2 ± 7.2a	5.1 ± 3.2d	94	24.6 ± 4.3a	4.6 ± 2.6d	12	4.8 ± 1.8a			
	CGM actives	15.8 ± 9.3c	7	5.2 ± 1.2b	5.5 ± 2.6c	92	22.3 ± 3.7b	4.8 ± 6.2c	7	5.2 ± 0.8a			
	<i>B. tabaci</i>	16.8 ± 7.2b	3	2.2 ± 2.4d	7.3 ± 3.5b	12	5.2 ± 4.0c	5.5 ± 2.4b	4	1.8 ± 2.2b			
	<i>P. manihoti</i>	18.4 ± 4.8a	2	3.2 ± 1.8c	8.4 ± 2.7a	8	6.5 ± 6.2c	5.8 ± 2.5a	2	1.9 ± 0.4b			
	<i>P-Value</i>	< 0.0001		< 0.0001	< 0.0001		< 0.0001	< 0.0001		0.0140			
75%	CGM eggs	18.7 ± 4.3b	8	9.3 ± 4.2a	4.3 ± 0.9c	96	27.6 ± 2.6a	3.4 ± 0.2b	14	7.4 ± 2.9a			
	CGM actives	19.3 ± 3.6b	5	6.4 ± 2.1b	4.2 ± 0.6c	92	26.3 ± 1.8b	3.0 ± 0.1c	8	7.1 ± 2.1b			
	<i>B. tabaci</i>	23.4 ± 5.2a	3	4.2 ± 1.5d	7.4 ± 2.2b	14	3.4 ± 1.7d	3.1 ± 0.1c	3	2.7 ± 3.8c			
	<i>P. manihoti</i>	25.0 ± 4.2a	2	4.6 ± 0.8c	8.3 ± 1.8a	11	4.3 ± 1.2c	5.7 ± 0.2a	0	2.1 ± 1.9d			
	<i>P-Value</i>	0.0156		< 0.0001	< 0.0001		< 0.0001	< 0.0001		< 0.0001			
92%	CGM eggs	16.5 ± 8.2c	6	9.6 ± 5.2b	3.8 ± 0.8c	92	25.2 ± 4.4b	4.2 ± 3.2d	14	6.4 ± 4.2a			
	CGM actives	15.9 ± 6.8c	4	9.9 ± 4.5a	3.6 ± 0.2c	92	27.5 ± 5.6a	4.6 ± 2.7c	10	5.6 ± 2.0b			
	<i>B. tabaci</i>	21.3 ± 4.7b	2	3.8 ± 3.6c	6.2 ± 1.4b	8	3.2 ± 4.7c	6.5 ± 2.4a	6	1.2 ± 1.0c			
	<i>P. manihoti</i>	23.1 ± 5.5a	2	2.3 ± 4.1d	8.4 ± 1.2a	5	3.1 ± 7.2c	6.3 ± 1.2b	4	0.9 ± 0.1c			
	<i>P-Value</i>	< 0.0001		< 0.0001	< 0.0001		< 0.0001	< 0.0001		< 0.0001			

Different lower case letters denote significant difference for each life stage under different temperatures (df=3, 92) for a 10 days observation period.

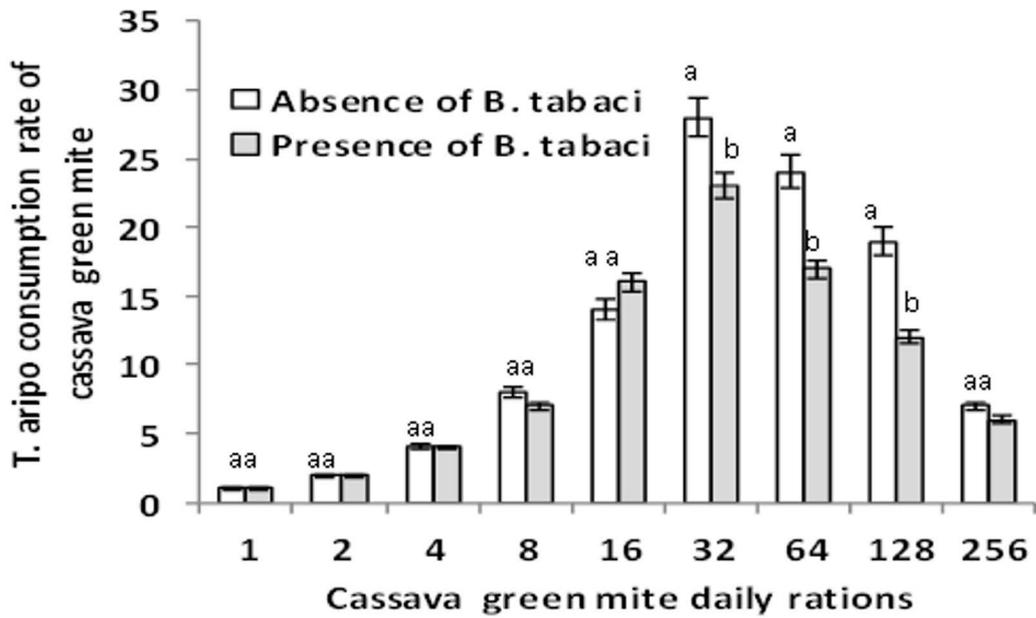


FIGURE 2: Mean daily consumption rate by *Typhlodromalus aripo* female of cassava green mite in absence and presence of *Bemisia tabaci* crawlers.

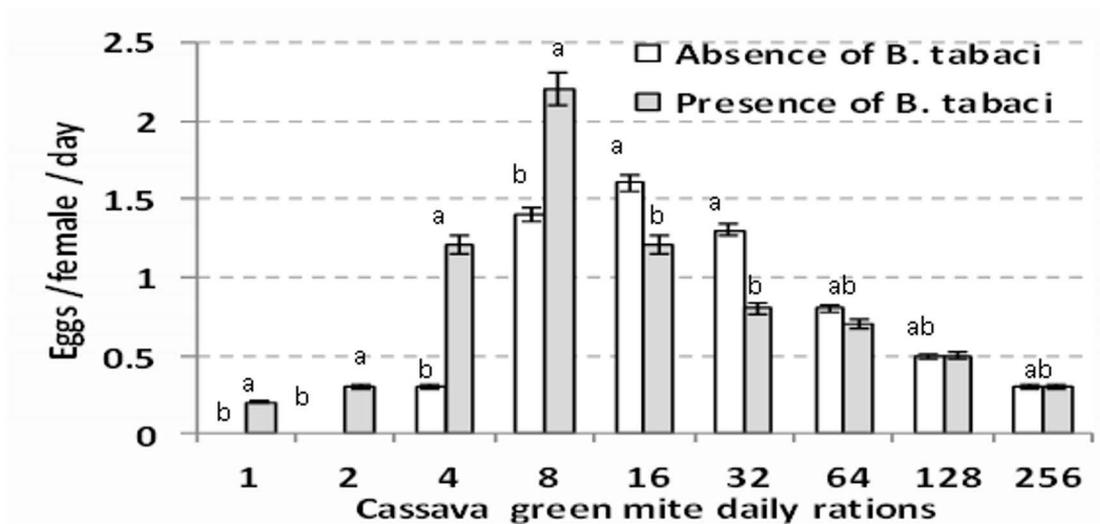


FIGURE 3: Mean daily fecundity of *Typhlodromalu aripo* female on cassava green mite *Mononychellus progresivus* in absence and presence of *B. tabaci* crawlers.

Female prey numerical response

In absence of *B. tabaci*, the consumption rate of CGM increased with prey density from 2 to 32 mobile stages of CGM and decreased afterwards even if food provided increased ($P < 0.0001$) (Fig. 2). The consumption rates were between 100 % and 90 % when densities ranged between 2 and 32 CGM / day. At 64 prey ration provided, the consumption dropped to about 36 %, and reached less than 3 % at 256 GCM per day.

The presence of the crawlers of *B. tabaci* did not change the type of the predator-prey numerical response. However, it slightly affected the predator feeding capacity of CGM. The presence of *B. tabaci* significantly decreased the consumption rate: 72 %, 25 %, 9 % and 1 %, for ration quantities of 32, 64, 128 and 256 CGM / day respectively.

Similarly, the egg reproduction increased with increasing prey density up to 8 CGM provided ($P < 0.0001$) (Fig.3). In absence of *B. tabaci*, the maximum reproduction was recorded at 16 prey / day. In presence of *B. tabaci*, the egg reproduction was higher (> 1.0) even for densities of CGM ranging from 4 to 8. When higher densities of CGM actives (16 and 32) were provided, *T. aripo* female consumption rate was lower (< 25) in presence of *B. tabaci*. Finally, with more than 64 CGM actives no difference in fecundity was observed whether *B. tabaci* were present or not. The maximum egg reproduction was recorded at 8 prey ration per day when *B. tabaci* was present.

Egg drought tolerance

The rates of egg hatch (%) of *T. aripo* at 40 % RH indicated high drought tolerance as 70, 92 and 85 % hatch was scored at 12, 27 and 33 °C respectively (Table 5). One hundred percent (100%) egg hatch was scored at 27 °C and 12 °C at both 75 and 92 % RH with durations (days) ranging between 4.4 to 8.8 days, respectively. Notable shorter significant ($P < 0.05$) egg hatch (85 %) duration was scored at 33°C and 40 % RH (3.2 days).

DISCUSSION

Majority of the Phytoseiidae mites are polyphagous and feed on different prey and non-animal diets like pollen grains (El-Banhawy *et al.* 2000, 2001; Knapp *et al.* 2013). Other studies on *T. aripo* diets, reported that this species was able to develop and reproduce on CGM under laboratory conditions (Gnanvossou *et al.* 2003, 2005). Furthermore, *T. aripo* life stage cohorts were reported to survive for a limited period on pollen grains of castor oil (Magalhães and Bakker 2002; Gnanvossou *et al.* 2005). The present study indicates that *T. aripo* can develop when fed with *B. tabaci* and *P. manihoti* at 12, 27 and 33 °C even though development rates were much lower than

on CGM eggs and mobile stages. Bakker *et al.* (1993) reported that *T. aripo* benefits from cassava leaf apex domatia where it could survive long periods without the preferred CGM prey. Hence, the present study confirms that *T. aripo* has a wide range of prey on cassava including crawlers of the whitefly *B. tabaci* and nymphs of cassava mealybug, *P. manihoti*. In absence of the main prey CGM, *T. aripo* could survive and reproduce as long as the two herbivore preys are available on cassava plants. The high CGM consumption rates (61.6 eggs or 28.3 actives / day) and development parameters on this prey present *T. aripo* as an efficient biological agent in suppressing this pest mite species below economic injury levels within a short period of time once introduced on cassava.

Effect of combined humidity and temperature conditions showed that the main factor affecting both development and predation parameters is temperature for all the prey provided. The optimum combined conditions were 75 % RH and 27 °C at which both immature and adult stages had highest (> 90 %) survival to maturity and female highest longevity. At extreme temperatures (12 °C and 33 °C), development and predation parameters were always low whatever the hygrometry. At low humidity regime (40 %) and high hygrometry regime (92 %), *T. aripo* can develop predate preys. For these extreme RH regimes, a temperature of 27 °C allow to increase clearly life and predation parameters. These results show that *T. aripo* will continue to be quite efficient for biological control even at low and high RH if the temperature is maintained at 27 °C.

The number of CGM daily consumption increased with the prey numbers availed up to 32 CGM actives / female predator, while at higher prey densities the consumption decreased. Chant (1961) reported negative effects of large prey densities for the phytoseiid *Galendromus occidentalis* (Nesbitt). The addition of fixed numbers of *B. tabaci* significantly reduced the number of CGM consumed by *T. aripo*. Earlier studies on most phytoseiid species showed that the presence of an alternative diet like plant pollens significantly reduced the consumption rate of prey and increased fecundity (McMurtry and Scriven, 1966; El-Badry and El-Banhawy, 1968). In the present work, the addition of fixed number of *B. tabaci* led to the same type of response up to 32 CGM ration. As other workers have reported most Phytoseiidae species were less effective at high prey densities. The best results were obtained when predatory mites were released at lower prey densities (Bravenboer and Dosse, 1962; Chant, 1961; Dosse, 1958). Onzo *et al.* (2009) studied *T. aripo* feeding behavior on cassava canopy. This species demonstrated prey avoidance at the lower cassava canopy by moving to the plant apex as it was more suitable to rest at day time. Magalhães and Bakker (2002) reported that *T. aripo* get supplement food from cassava apex tissue unlike other phytoseiids like *Neoseiulus idaeus* Denmark and

TABLE 5: Egg hatch rates (%) of *Typhlodromalus aripo* at three different temperatures and three RH.

Parameter		12 °C		27 °C		33 °C	
RH (%)	No.	Hatch (%)	Days	Hatch (%)	Days	Hatch (%)	Days
40	50	70	12.2 ± 4.1a	92	4.8 ± 2.8ba	85	3.2 ± 3.4c
75	50	100	8.6 ± 3.3b	100	4.4 ± 3.8b	96	4.2 ± 2.3b
92	50	100	8.8 ± 3.4b	100	5.2 ± 2.6a	94	4.5 ± 2.7a
<i>P-Value</i>			0.0557	0.0544		0.0004	

Different lower case letters denote significant difference for egg hatch (%) in different climatic conditions.

Muma and *Phytoseiulus persimilis* Athias-Henriot. McMurtry *et al.* (2013) has classified *T. aripo* as phytoseiids with mouth piercers which enable them feed on cassava plant sap during absence of prey. During the first day-experiment, *T. aripo* individuals were observed nibbling with their mouth parts on the cassava leaf midrib part. This enabled *T. aripo* females to survive on cassava leaf two days without prey diet. Furthermore, the larvae of *T. aripo* as a Type III and IV do not feed on prey and develop to protonymph without feeding (McMurtry *et al.*, 1997). As noted from the present study most eggs of *T. aripo* were presently found on the plant apex than on plain leaves in the mass rearing unit. The low humidity (40 %) led to 85 % egg hatch at 33 °C but recovery to 92 % at 27 °C. When humidity increased to 92 % high egg hatch (100 %) was achieved. The prey response behavior of female *T. aripo* led to the conclusion that for successful biological control of CGM, it is logical to release the predator *T. aripo* when there is low prey density and monitor the populations of CGM until the predatory mite achieve the desired prey control.

The present has shown that *T. aripo* is sensitive to extreme low humidities and temperatures in comparison to other phytoseiids (Dinh *et al.*, 1988; Bakker *et al.*, 1993; Walzer *et al.*, 2007; Ferrero *et al.*, 2010). The optimal conditions for its survival were recorded at around 75 % RH and 27 °C. Shipp *et al.* (1997) reported that abiotic factors such as temperature and humidity limit prey consumption. *Typhlodromalus aripo* has been reported not to impact negatively the presence of other local phytoseiids in the ecosystems in Africa (Zannou *et al.*, 2007). De Courcy *et al.* (2004) reviewed different phytoseiid species performance on prey populations in extreme low temperature and concluded that strain difference need to be considered as well. In the present study *T. aripo* immatures suffered the highest mortality in both low temperatures (12 °C) and humidities (40 % RH). At the optimum humidity (75 %) both immatures and adult females had lower mortality on the different prey options. At higher 33 °C (in 75 % RH) of *T. aripo* females were resilient in that advance conditions for 7.4 days still enabling presence of the phytoseiid on cassava. The results from egg drought tolerance showed that *T. aripo* was fairly tolerant to dry

conditions in comparison to other phytoseiid species analyzed by Ferrero *et al.* (2010) where *Typhlodromus athiasae* Porath and Swirskii and *Phytoseiulus longipes* Evans were the most drought tolerant at lower than 50 % in similar humidity regime. The tolerance of *T. aripo* to dry conditions could explain why it re-appears in a field after an extreme drought where all cassava plant leaf foliage was shed as reported by Zundel *et al.* (2007).

CONCLUSION

Typhlodromalus aripo's long persistence on cassava plants in absence of preferred prey (CGM) could be explained in part by its ability to develop and survive feeding on *B. tabaci* crawlers and *P. manihoti* nymphs. Further, *T. aripo* was found highly tolerant to dry conditions as long as it is on cassava plants. Further, *T. aripo* was found highly sensitive to cold (12 °C) conditions and somewhat to high temperature (33 °C), hence the most limiting factor for its development on cassava would be this abiotic factor. These findings on *T. aripo* ecological requirements would enhance efficient biological control of CGM in the varied ecological systems in Africa if their applications are considered for each target area.

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