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Spatial and Temporal Distribution of Cassava Green Mite, *Mononychellus tanajoa* Bonder (*Acarina*: *Tetranychidae*) in Tanzania

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Authors' contributions

This work was carried out in collaboration between all authors. Author BSW (PhD Student) designed the study, wrote the protocol and the first draft of the manuscript. Author GMR (Major Supervisor) made conceptual contributions, corrections and objective criticisms; he was assisted by author ABK. While author SJ coordinated the fields work with close supervision. All authors read and approved the final manuscript.

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ABSTRACT

Two diagnostic surveys were conducted during the 2015 and 2016 growing seasons in three major cassava growing zones of Tanzania. The studies aimed at establishing the spatial and temporal distribution of *M. tanajoa* on commonly grown commercial cassava varieties landraces across seasons in Tanzania. A total of 2,700 plants in 90 fields were assessed in nine districts of which five fields were in the Lake zone and two districts in each of the Southern and Eastern zones. Results indicated that the distribution of *M. tanajoa* significantly *(P = .05)* differed across seasons, Southern and Lake zones were statistically similar and higher in *M. tanajoa* population than the Eastern zone. Crop age, altitude and cassava varieties significantly *(P = .05)* influenced the

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population of *M. tanajoa* while crop mixture (inter cropping) had no significant effect in both seasons. The relationship among the environmental variables and population distribution of *M. tanajoa* were significant *(P = .05)*. Variations in *M. tanajoa* population within and between seasons and locations were due to differences in the cassava varieties and the environment. The survival, perpetuation and distribution of *M. tanajoa* were attributed to the crop age, suitability of the variety and intensity of cassava cultivation.

Keywords: Cassava green mite; spatial; temporal; distribution; cassava varieties; Tanzania.

1. INTRODUCTION

Cassava*, Manihot esculenta* Crantz: Euphorbiaceae, is a tropical and subtropical short-lived perennial shrub originating from Latin America, most probably the Amazon region [1]. It is grown throughout the Tropics from wet equatorial forest to drier areas where annual rainfall is at least 500 mm. The crop is grown in over 39 African countries, of which Nigeria, Democratic Republic of Congo, Ghana, Angola, Mozambique, United Republic of Tanzania, Uganda and Malawi are among the top twenty (20) producers in the world [2]. Throughout Africa, cassava is used as food (fresh, boiled or flour) and source of starch for industrial purposes. Cassava leaves are nutritious vegetables in some countries and can also be used as animal feed. Tanzania is the sixth producer of cassava in Africa and annual root production is estimated at 5,462,454 tons from 761,100 hectares [2,3,4,5]. Despite its importance and diverse use, cassava production in Tanzania (5462454 metric tons) and the rest of African countries (149479840 metric tons) is grossly low compared to world production statistics (256529314 metric tons) [2]. Excerpts in production data from early 2000s to date indicates that the cassava production in Tanzania ranges from 45737 (in 2003) to 57.228 tons/ha (in 2012) which is far less than that of India, 262400 (in 2003) and 364,770 tons/ha (in 2012) in Asian countries [2].

Cassava is attacked by various pests but the most important ones as far as cassava production in Tanzania is concerned are cassava mealy bug (*Phenacoccus manihoti,* Matile-Ferrero) and cassava green mite [6]. Several efforts have been made since mid-1980s by the Tanzanian national root crop research program and international organizations particularly the International Institute of Tropical Agriculture (IITA) to breed for new varieties with acceptable agronomic qualities mainly yield. Such efforts have greatly addressed disease problems (cassava mosaic and cassava brown streak viral diseases) although production has not improved to great extent. As such many other biotic and abiotic production constraints remains to be addressed among which Cassava green mite is important.

Cassava green mite, *Mononychellus tanajoa* is the most serious pest worldwide, and has the widest distribution range because of its ability to tolerate harsh environmental conditions. Jackknife tests revealed that environmental variables (rainfall and relative humidity) associated with temperature has more influence on distributions on the pest than any other variable [7]. According to some reports, [8,9] temperature has a significant influence on the physiology of *M. tanajoa* population density. During the rainy season, the mites are substantially reduced as a result of rainfall washing off the colonies on leaves [10,11,12,13]. Conversely, the pest builds up in larger populations during the dry season, which is characterized by high temperatures and low rainfall [6] reported that the overall densities of eggs, adults and nymphs of *M. tanajoa* were higher than densities of larvae throughout the cultivation cycle of cassava, suggesting that each developmental stage of the cassava green mite experiences and respond uniquely to environmental factors operating at local scale. The current study aimed at establishing the spatial and temporal dynamics of *M. tanajoa* in Tanzania. This information will be useful in designing strategies to manage the pest to minimum damage threshold level and subsequent losses in Tanzania.

2. MATERIALS AND METHODS

Two diagnostic surveys were conducted on farmers' fields during 2015 and 2016 growing seasons in Lake, Southern and Eastern Zones of Tanzania. The timing was during the dry season between July to September, a period characterized by conditions that favour mite perpetuation. Surveyed areas were: five districts in Lake Zone (Sengerema, Misungwi, Kwimba, Bunda and Ukerewe Islands), two districts in Southern Zone (Mtwara Rural and Mtwara Municipal) and two in the Eastern Zone (Kibaha and Mkuranga). The climatic conditions are unimodal and normally dry season starts in late May and ends in November in the Lake Zone and April to September or October in the Southern zone. On the other hand, the Eastern zone has a bimodal pattern of season that the dry season starts in July or late June sometimes with showers in between the months (personal communication, 2016). In each district, ten farmers' fields were randomly selected and the sampling interval was 4 km along accessible roads. In each survey a total of 2700 plants were assessed in ninety (90) farmlands. In each farm, one diagonal line of thirty (30) cassava plants was selected and assessed at 1 m sampling interval leaving at least two boarder rows to avoid the edge effects [14]. A total of 5400 plants were assessed for *M. tanajoa* during the two seasons.

2.1 Assessment of the *Mononychellus tanajoa* Population

The population of *M. tanajoa* was assessed by inspecting 5 upper most cassava leaves which were sampled from the topmost expanded leaf on the abaxial parts and the mites were manually counted using a hand lens (Model No. YT1045/50 mm) and the numbers recorded. Data were also collected by using Geographic Positioning System (GPS) (Oregon 450, Germin International Co-operations), crop age, cassava variety grown, the cropping system (Inter cropped or Sole cropped) and the other biotic stresses such as viral diseases including cassava mosaic disease and cassava brown streak disease.

2.2 Statistical Analysis

All collected data were subjected to non-parametric (K-Independent samples) analyses in SPSS version 16.0, [15] and Kruskal-Wallis test was used to compare among populations of *M. tanajoa.* Multiple regression analysis was conducted to predict the relationship between weather variables and *M. tanajoa* population and damage. Weather data on temperature, rainfall and relative humidity were collected from the Tanzania meteorological stations of the respective zones.

3. RESULTS AND DISCUSSION

The obtained results in Fig. 1. suggested significant *(P = .05)* differences in the population of *M. tanajoa* across the two seasons (2015 and 2016 dry seasons). Highest number of *M. tanajoa* was recorded in the Southern and the Lake zones and the two were statistically similar. The population in the two zones was higher than the Eastern zone in both years. Despite the general reduction in the number of *M. tanajoa* across the zones in 2016, the Lake zone remained statistically similar to the Southern zone. In Fig. 2. a comparative analysis of the pest's population among districts indicated that Kwimba and Misungwi districts of the Lake Zone recorded the highest population compared to all other Zones in the country across the two seasons.

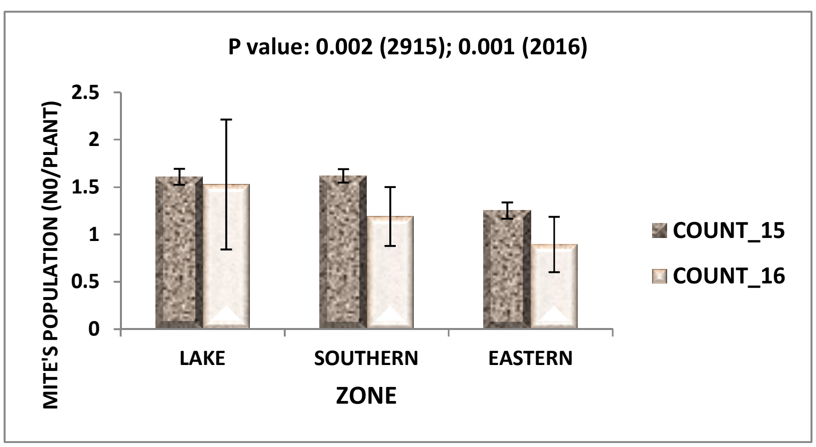

Fig. 1. Population number of *M. tanajoa* during the 2015 and 2016 rainy and dry seasons in the Tanzania

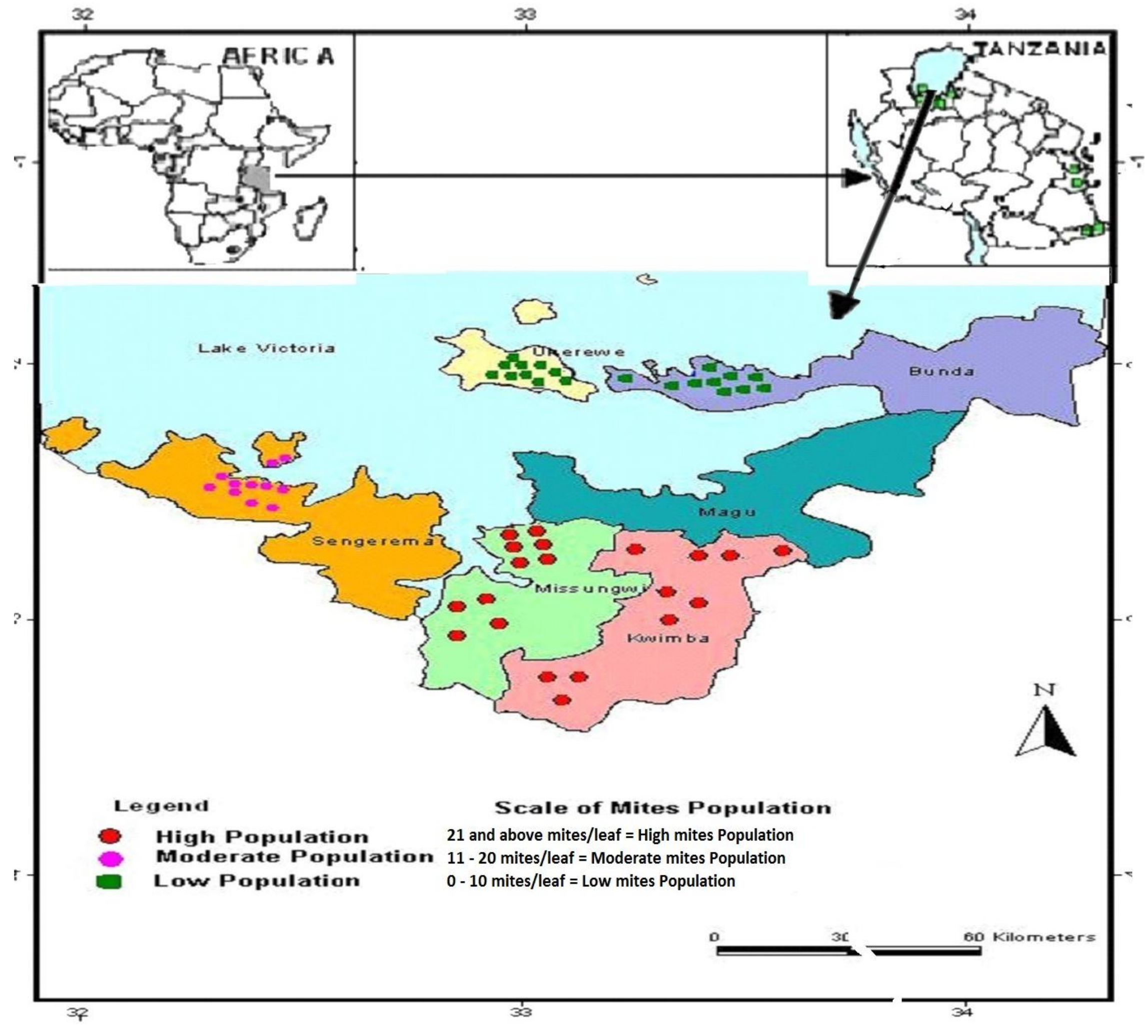

Fig. 2. Population distribution of *M. tanajoa* at Sengerema, Misungwi, Kwimba, Bunda and Ukerewe areas in the Lake Zone, Tanzania

Contrary to what was expected particularly to Ukerewe, the district recorded minimal to moderate number of the pest despite the fact that the first record of *M. tanajoa* in Tanzania was in the Island. Similar to Ukerewe, the neighbouring district, Bunda in the Lake Zone also recorded low mites' numbers in 2015 and were moderate in 2016. The higher population of *M. tanajoa* in 2015 compared to 2016 could be attributed to the lower amount of rainfall received during the period that preceded (three months before) data collection in the growing season of 2015 and this influenced the growth, development and perpetuation of the mites compared to the 2016 growing season. Drier conditions might have encouraged the survival, perpetuation and distribution of cassava green mite.

Conversely, in 2016 low mite's population was observed suggesting the impacts of high rainfall on the pest. Rainfall exerted its kinetic energy that struck on *M. tanajoa* washing off the mites from cassava shoots and killing them. Similar result was reported by [16]. The dew droplets that drowns and kill mites, high relative humidity and low temperatures might all triggered delayed growth and development of *M. tanajoa* contributing to the low mite population in the rainy season [16]. Limited availability of fresh plant growth (during the main part of the dry season) and occasional rainfall in between July and September could be among factors that kept the pest populations low as was similarly observed by other workers [10,11].

The differences in number of the *M. tanajoa* among the zones might be due to the different inherent characteristics of the planted cassava varieties that triggers varied responses to the pest, the cropping systems that affect the abundances and dispersion of the mites, and the altitudinal differences of the agro- ecologies that influences the weather elements inclusive of rainfall, temperature and relative humidity. Similar finding was reported by [17]. The effect of environmental factors such as temperature, relative humidity and rainfall being important mechanisms mediating the population dynamics of arthropods in agro-ecosystems has been broadly reported [17,18,19].

The Lake and Southern zones have similar longevity of dry season, the most conducive environmental conditions for the survival and perpetuation of the *M. tanajoa* explaining the reasons for similarities in *M. tanajoa* population and distribution. The dry season normally starts in late May and ends in November in the Lake Zone and April to September or October in the Southern zone. On the other hand, the Eastern zone has a bimodal pattern of season that the dry season starts in July or late June sometimes with showers in between the months. Therefore, the environmental variables especially rainfall, temperature and relative humidity might sometimes differ based on zones, especially Lake Zone and seasons and these factors might have probably dictated for the differences in the survival and perpetuation of the mites among the zones. Several researchers have reported that spider mites are often positively influenced by temperature and negatively affected by rainfall.

Negative correlations between rainfall and the developmental stages of *M. tanajoa* have been reported [20,21,22] suggesting that the population of *M. tanajoa* decreases with increasing rainfall and this could be related to the Lake and Southern Zones' high density of the pest. Other similarities that exist between Lake and Southern zones could also be attributed to the higher intensity of cassava cultivation in the two zones. The two have been reported the leading cassava producing zones in the country [23].

The intensive cassava production and favourable weather (temperature and rainfall) ensures cumulative population build–up over time continuously on the preferred host, the cassava. Available production data indicates that the cassava variety Kiroba is the dominantly cultivated by farmers in the Eastern zone and is said to be moderately resistant to *M. tanajoa*, whereas Liongo Kwimba variety is the predominantly cultivated in the Lake Zone and is highly susceptible to *M. tanajoa* attack [24].

Fig. 3 shows the Southern Zone with higher population of *M. tanajoa* and significantly ($P > .001$) similar to the Lake Zone. More so, Mtwara rural district recorded higher population number of *M. tanajoa* in 2015. However, it was moderate in 2016 and in Mtwara Municipal in both years.

The result indicated in Fig. 4 shows that the Eastern Zone (Coast) has generally recorded the lowest population number of *M. tanajoa* among the Zones in both seasons. All the two districts (Kibaha and Mkuranga) have lowest mites' number.

Varied influence of crop age on *M. tanajoa* was observed during the two seasons. The age of cassava (months) crop significantly ($P < .001$) affected the population of *M. tanajoa* in the three agro-ecological zones in 2016 contrary to the pest population in 2015 which was statistically insignificant. Analysis of the crop age influence in each year indicated that cassava plants below six months of age (<6 months) had higher number of *M. tanajoa* followed by those aged 9 to 11 months and greater than 12 months respectively. The least count of *M. tanajoa* was recorded on cassava plants of less than 9 months but older than 6 months. Generally, higher population were significantly ($P = .05$) recorded in 2015 compared to 2016. On cassava age, the results have proven that *M. tanajoa* prefer young, tender and succulent parts of the cassava plant as they are more nutritious (Nitrogen rich) attracting higher mite density [16]. Colonization and concentration of *M. tanajoa* on the apical parts of the cassava plant has been reported [14]. Similar observations were reported [24] that cassava plants aged 2-9 months are the most vulnerable to mites' infestation. However, older plant leaves (<12 months and above) are of inferior nutritive value (e.g. low nitrogen) thus they habours low mite population. Some contrasting results however were reported in Kenya [25] that crop age was associated with severe mite distribution in older plants.

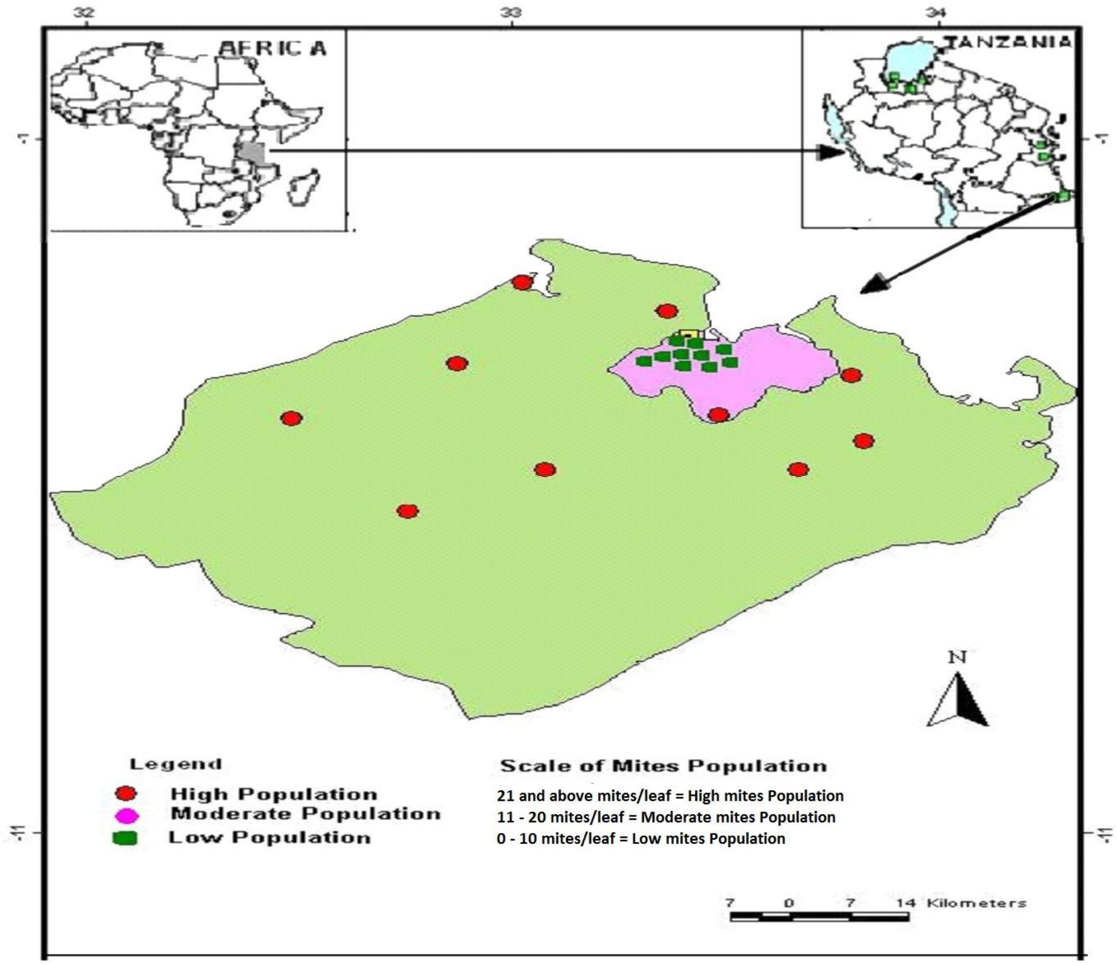

Fig. 3. Population distribution of *M. tanajoa* at Mtwara rural and Mtwara Municipal areas in the Southern Zone, Tanzania

Altitude had significant impact on *M. tanajoa* counts *(P = .05)* throughout the three agro-ecological zones. Low altitude (<300 m asl) along the coast in the Southern zone and high altitude (>800 m asl) in the Lake zone significantly *(P = .05)* recorded the highest population of *M. tanajoa* in 2015 despite the highest numbers in the former than the later. However, the variation trend was similar but generally minimal in 2016. The intermediate altitude (301 – 500 m asl) in the Eastern zone (coastal region) recorded the least population of *M. tanajoa*. The higher population recorded in the low altitude area (the least 6 m asl) followed by the high altitude area (above 1000 m asl) indicated that environmental factors (especially temperature, rainfall and relative humidity) played a more vital role than the altitude on the perpetuation of *M. tanajoa* population in the two zones as they share similar pattern of seasons.

The cassava varieties assessed had varied responses to pest, suggesting that population build up and subsequent distribution of the pests is influenced by the characteristics of the respective varieties. The response of the cassava varieties to *M. tanajoa* was highly significant (*P* > *.001*) in 2015 and 2016. In 2015, cassava variety Lufaili (LFLI) recorded the highest number of *M. tanajoa*, followed by Kachaga (KCHG), Kigoma red (KGMR), Kachongoma (KCGM) and Liongo Kwimba (LNGK) respectively all in the Lake zone. The least infested varieties were Kalingisi (KLGS), Lwakitangaza (WKTGZ) and Rasta (RSTA) followed by Kiroba (KRBA). Unlike the observations in the previous year, the cassava local varieties namely Zagazaga (ZGZG), Kalingisi and Lwakitangaza recorded the lowest *M. tanajoa* population in 2016 compared to all other varieties while Kachaga, Lufaili, Ismaili (ISML) and Liongo Kwima (local landraces in the Lake zone) recorded the highest population. Nevertheless, the differences in mites' density in the two years may not only be attributed to variation in weather factors but also the inherent genetic traits of the grown cassava varieties which in turn affected preferences by the *M. tanajoa* [26]. The inherent characteristics may lead to some varieties being resistant whiles others susceptible to *M. tanajoa*. Available reports suggest that the resistant cassava varieties tend to have high leaf pubescence and high canopy retention ability during the dry season [26]. Such particular characteristics were apparent in Kiroba (a variety grown in the Eastern zone) and some few mildly attacked varieties in the Lake and Southern zones. Nonetheless, other defense mechanisms by the host plants have been reported to bring about variation in cassava response to *M. tanajoa*. Non-preference and antibiosis are among common mechanisms on the leaves of the resistant genotypes [23]. According to [27] and [28], T. aripo is able to survive and develop also on alternative food, such as cassava extra floral exudates, and maize pollen therefore, might predate on *M. tanajoa* at later time of the data collection.

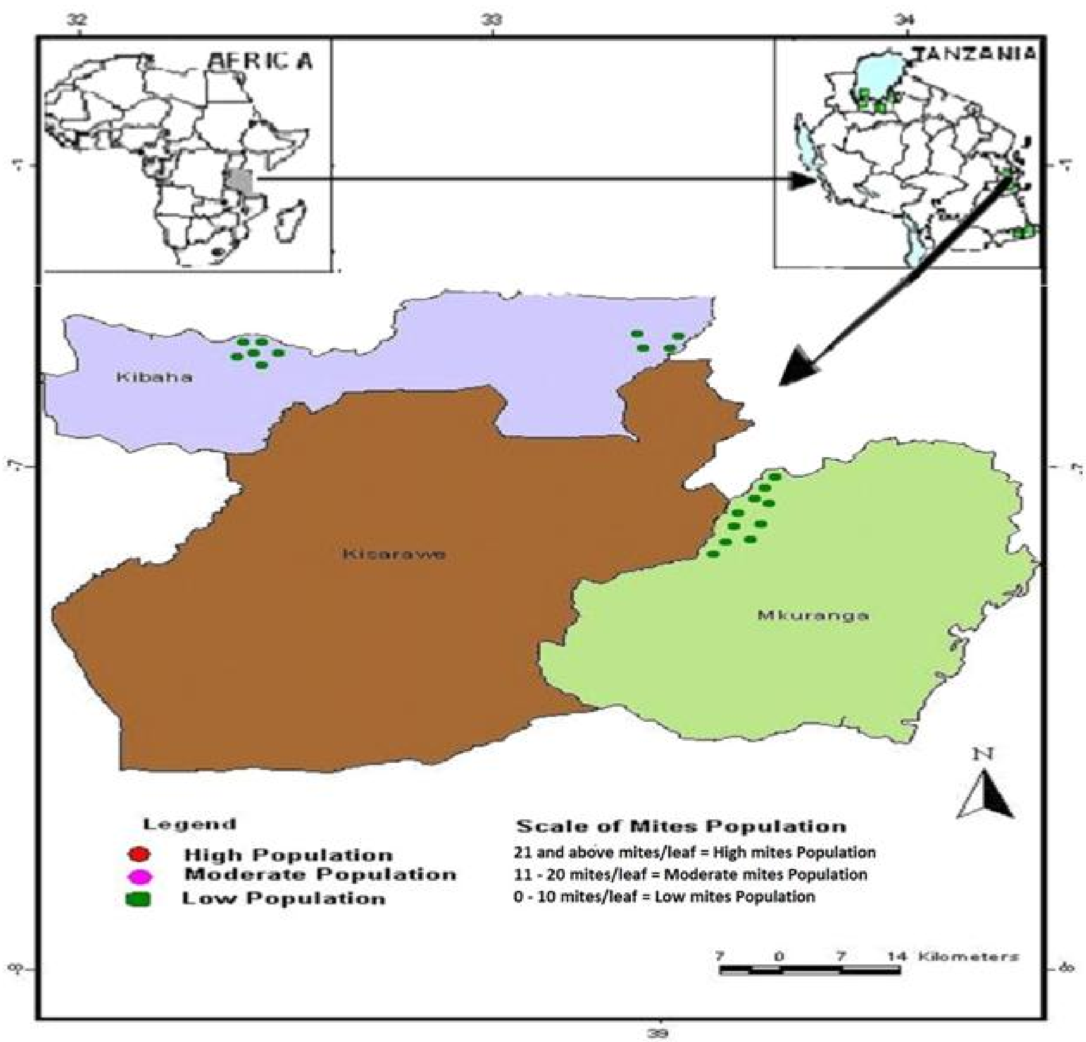

Fig. 4. Population distribution of *M. tanajoa* at Kibaha and Mkuranga areas in the Eastern Zone, Tanzania

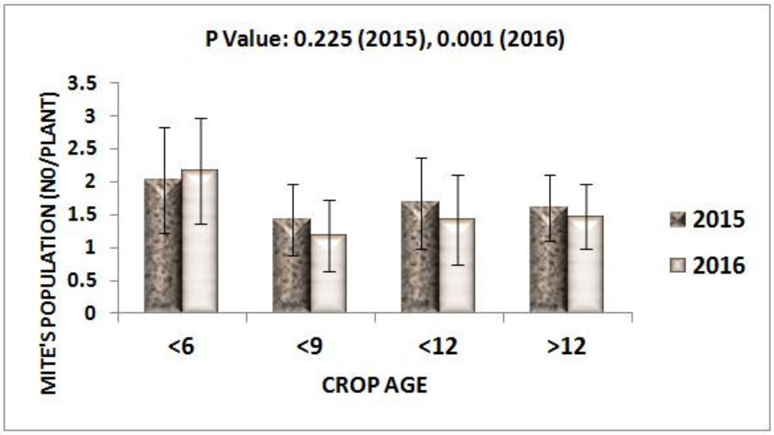

Fig. 5. Effects of crop age on the population of *M. tanajoa* in Tanzania

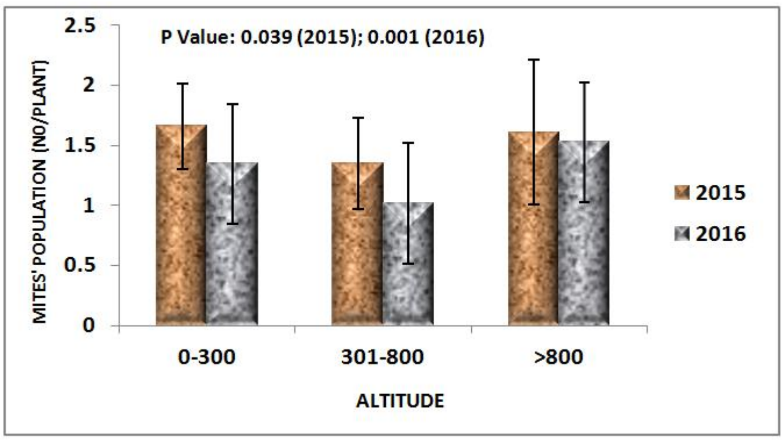

Fig. 6. Effects of altitude on the population of *M. tanajoa* in Tanzania

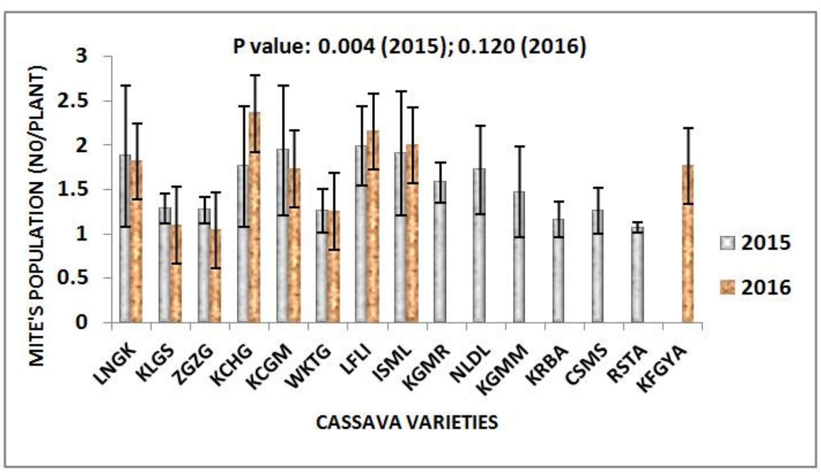

Fig. 7. Effects of cassava varieties on the population of *M. tanajoa* in Tanzania

Key: NLDL (Naliendele), KGMM (Kigoma Mafia), CSMS (Cosmos) and KFGYA (Lufangonya)

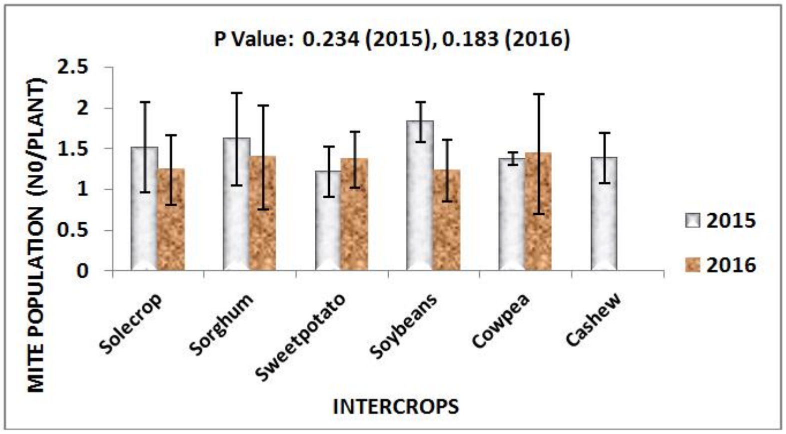

Fig. 8. Effects of intercropping systems on the population of *M. tanajoa* in Tanzania

The effect of intercropping systems on the population of *M. tanajoa* suggested insignificant difference between the sole crop and intercropped plantings in 2015 and 2016 seasons. However, the comparative assessment of the influence of crops intercropped with cassava showed that soybeans-cassava mixture recorded the highest number of *M. tanajoa* followed by sorghum-cassava mixture. The lowest mite's population was recorded in sweet potato-cassava mixture followed by cowpea-cassava and cashew-cassava respectively.

Cassava inter crop with other crops had no significant effect on the population number of the cassava green mite, this corroborates the work of [29], who reported that intercropping cassava with maize had no significant effect on *M. tanajoa* and associated phytoseiid predator populations during the intercropping dry, and post dry seasons, however this is in contrast with the findings of [25] that the intercropping was associated with reduced frequency of high damage severity scores. More so, [30] have reported that cassava intercropped with pigeon pea suffered less damage from *M. tanajoa* than that grown on a pure stand. They also found that cassava intercropped with pigeon pea in triple and double rows gave higher tuber yields than when it was alternated in a single row or in a pure stand.

Therefore, the distinction between the two years (2015 and 2016) could generally be linked to the number and types of cassava varieties found during the periods of the surveys. The population trends in both years are quite similar with a slight difference in number which fluctuates among crop types. This could be due to the differences in the weather variables among the zones and within and between the years.

The influence of weather parameters on occurrence and perpetuation of *M. tanajoa* was analyzed through multiple regressions. Three weather variables considered were rainfall, temperature and relative humidity. The predicted influence of the weather parameters on the pest population was assessed based on three months before and after the actual survey in the three zones in 2015 and 2016. Such timing of the period under consideration covered three months in the rainy and dry seasons. The percentage contribution of each of the dependent variable to the mite's population and distribution was also determined.

The overall variance on mites count before the data collection in 2015 as explained by the three predictors was 8.1%. All tested predictors (except the temperature) were negatively related to the population of *M. tanajoa*, that is, rainfall ($\beta = -0.003$, $p \leq 0.05$), relative humidity ($\beta = -0\ .054$, $p \leq 0.05$) and maximum temperature ($\beta = 0.019$, $p \leq 0.645$). Moreover, three months after data collection, the same variables were also significant *(P = .05)* including maximum temperature ($\beta = 0.821$, $p \leq 0.007$), rainfall ($\beta = -0.050$, $p \leq .010$) and relative humidity also significant at *(P = .05)* ($\beta = -0\ .035$, $p \leq 0.07$) on the population of *M. tanajoa*, with rainfall and temperature recording negative effects while relative humidity having positive effect on the population of *M. tanajoa* (Table 1).

Table 1. Regression analysis of some weather variables against *M. tanajoa* count three months before counting and three months after counting during 2015 and 2016 seasons

	2015 COUNT (3 months before counting)				2015 COUNT (3 months after counting)			
Model	**Regression coefficient**	**(SE±)**	**(P Value)**	**(t – value)**	**Regression coefficient**	**(SE±)**	**(P Value)**	**(t – Value)**
Rainfall	-0.003	0.001	(0.015)*	-2.471	-0.050	0.019	(0.01)*	-2.620
Max. Temp	0.019	0.042	(0.645)	0.462	-0.821	0.298	(0.007)*	-2.769
RH	-0.054	0.022	(0.015)*	-2.471	0.035	0.013	(0.007)*	-2.769
	2016 COUNT (3 months before counting)				**2016 COUNT (3 months after counting)**			
Rainfall	-0.002	0.003	(0.518)	-.649	-0.035	0.018	(0.057)*	--3.486
Max. Temp	-0.491	0.362	(0.179)	-1.356	0.368	0.113	(0.002)*	3.267
RH	-0.020	0.014	(0.179)	-1.356	0.004	0.004	(0.002)*	-3.267

*Figures in parentheses are P values (significant at * < .05, ** < .001) Key: RH = Relative Humidity, Max. Temp. = Maximum Temperature*

Table 2. Regression analysis of some weather variables against *M. tanajoa* count during 2015 and 2016 rainy and dry seasons in Lake Zone, Tanzania

	2015 COUNT				2016 COUNT			
Parameter	**Regression coefficient**	**(SE±)**	**(P Value)**	**(t- value)**	**Regression coefficient**	**(SE±)**	**(P Value)**	**(t-value)**
Rainfall	0.000574	0.000261	(0.028)*	2.20	-0.11429	0.00834	(0.001)**	-13.70
RH	-0.0331	0.0110	(0.003)**	-3.00	-0.02773	0.00286	(0.001)**	-9.69
Max.Temp	-0.1788	0.0566	(0.002)**	-3.16	0.1273	0.0239	(0.001)**	5.34
Min. Temp	0.1449	0.0523	(0.006)*	2.77	0.3840	0.0371	(0.001)**	10.34

*Figures in parentheses are P values (significant at *< .05, ** < .001)*
Key: RH = Relative Humidity, Max. Temp. = Maximum Temperature, Min. Temp. = Minimum Temperature

The established overall variance between the predictors and the number of mites during the 2016 seasons was 17.7% and weather variables during the three months prior to data collection had insignificant influence on *M. tanajoa* population. Negative correlation was established between weather variables and population of *M. tanajoa* (rainfall, β = -0.002, $p \leq 0.518$; relative humidity, β = -0.020, $p \leq 0.179$; and temperature, β = -0.491, $p \leq 0.179$). However, during the dry season (three months after data collection) all the three weather variables were significantly related to the *M. tanajoa* population with positive correlation except rainfall which exhibited a negative correlation (rainfall, β = -0.035, $p \leq 0.05$; relative humidity, β = 0.015, $p \leq 0.002$; and temperature, β = 0.368, $p \leq 0.002$) (Table 1).

Generally, most of the cassava varieties found during the two diagnostic surveys were varied which might affect the differences and similarities that exist across the zones in the two years. The influence of seasonal changes in temperature, rainfall and relative humidity on diversity and density of arthropods in the tropical regions have previously been reported [21,31,32]. The influence of temperature on *M. tanajoa* development was exacted through a research in Kenya and Benin that due to the low average temperature (21°C in the mid-altitudes; 23°C in the lower altitudes) mites development was very slow [14]. Nevertheless, the work by [9] showed that, at 20°C, the egg-to-adult period takes 1.4 times longer than at 24°C, and 1.7 times longer than at 27°C. At 20°C, females lay only 40% and 25% of the number of eggs per day which they lay at 24°C and 27°C, respectively. It takes a population 1.8 times longer to double its number at 20°C than at 24°C, and 2.6 times longer than at 27°C.

The variations in population between the two experimental years (2015 and 2016), might be due to the fact that different cassava varieties were used, that the sites were located in different places, and that possible climate differences occurred between the two years. This has been reported by other researchers [9,14,16] that the differences in number of CGM peaks (i.e two peaks in 2002; and only one peak in 2003) while the peak length (when released in 2002 from January to June 2003; and released in 2003 from January to April 2004) and in peak densities between the two experimental years might be due to the above reasons. In a research in Rwanda reported a widespread distribution of *M. tanajoa* [33] suggesting a limited impact of weather factors on mites population. Future studies should target to understand the relationship between mites dispersion, weather parameters and the cassava plants with respect to the inflicted damages.

4. CONCLUSION

Results of the two year (2015 and 2016) studies indicated that the distribution of cassava green mite in Tanzania is dictated mostly by the prevailing weather variables especially rainfall and temperatures. This resulted to the three agro-ecological zones of Tanzania to have different *M. tanajoa* distribution patterns across seasons and locations. The intensity of cassava cultivation had a significant contribution to the abundance, perpetuation and dispersal of cassava green mite in the three agro-ecological zones of Tanzania. Environmental predictors against the population of *M. tanajoa* proved that the variations among locations and seasons were due to differences in the cassava varieties and the environment. There is need for breeders to explore possibilities of crossing the highly preferred but susceptible varieties with resistant or tolerant ones to come up with *M. tanajoa* resistant and high yielding varieties in each of the agro-ecological zones. Specifically, Liongo Kwimba and Kalingisi (Lake Zone), Kigoma red and Kigoma Mafia (Southern zone) should be improved as per their poor responses to *M. tanajoa* and are among the most commonly grown varieties in their respective zones.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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