INFLUENCE OF RELATIVE HUMIDITY ON THE GROWTH AND DEVELOPMENT OF THE MITE TYPHLODROMALUS ARIPO DE LEON (ACARI: PHYTOSEIIDAE): EVIDENCE FROM LABORATORY AND GREENHOUSE EXPERIMENTS/

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Thesis Submitted to the University of Nairobi, School of Biological Sciences, in Partial Fulfilment of the Master of Science (M.Sc.) Degree in Agricultural Entomology of the University of Nairobi.

Declaration

This thesis is my original work and has not been presented for a degree award in any other university

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We confirm that the work reported in this thesis was carried out by the candidate under our supervision and has been submitted for examination with our approval

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Dedication

This work is dedicated to my family; Wife Zipporah, Son George and Daughter Abigail for their patience, encouragement, for allowing me time and giving me peace of mind and understanding on my being away from them, busy and about, to college and back, during the two years of study period.

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INFLUENCE OF RELATIVE HUMIDITY ON THE GROWTH AND DEVELOPMENT OF THE MITE TYPHLODROMALUS ARIPO (DE LEON): EVIDENCE FROM LABORATORY AND GREENHOUSE EXPERIMENTS

ABSTRACT

The influence of selected relative humidity regimes on the development and growth of of the various immature stages from egg to adult of the predacious mite, Typhlodromalus aripo De Leon, was studied in the laboratory at a constant temperature of 27 ± 2 ° C. A related greenhouse study where the temperatures and relative humidity fluctuated closely paralleling the outdoor conditions in Eastern Kenya Province was also carried out. T. aripo was raised on its natural diet of phytophagous cassava green mite, Mononychellus tanajoa Bondar, reared on cassava apices of young stems. Development was measured as the life history of the mite, that is, the total duration of development from egg to egg; whereas growth was determined as the duration in days it took each immature stage to change into the next stage. A coefficient of correlation between the mite developmental period or life cycle duration and relative humidity showed that there was a negative relationship between decreasing relative humidity and the length of development or duration of the mite's life history. In other words, a decrease in the relative humidity increased the duration length of the life history which also resulted in increased mortalities. Similarly, there was a negative relationship between the fecundity or number of offspring (eggs) produced by individual female mites with respect to lower relative humidity regimes. In this case, the growth period of individual young stages was not affected by either low or high relative humidity levels. The tendency by T. aripo motile cohorts to aggregate at the fresh cassava apices than at the older or wilting ones was an

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indication that they were attracted to areas of high relative humidity regimes usually caused by transpiration. These findings on the relationship between relative humidity regimes and durations of the life cycle stages and growth rates of the various immature stages of mite allows a better understanding of its population dynamics. In a similar experiment the current study has confirmed these findings. The knowledge gained will contribute to mass rearing methods of this predacious mite in greenhouse for further release in cassava fields for biological control of cassava green mite pest.

Chapter 1

1.0 GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1 General Introduction

The phytoseiid mite *Typhlodromalus aripo* De Leon (Acari: Phytoseiidae) is known to be an effective predator of the arthropod pest cassava green mite, *Mononychellus tanajoa* (Bondar) *sensu lato*, (Acari: Tetranychidae) of the cassava crop in Africa (Zundel *et al.*, 2007). The predator has been used for over a decade as a biological control agent to increase yields. Cassava is a major carbohydrate food for over 500 million people worldwide (Cock, 1985) and in tropical Africa, it is the single most important source of calories in the human diet (Mackane, 1995). However, the major constraint to its stable production is the damage caused by insects, mites and diseases. As mentioned above, the cassava green spider mite, *M. tanajoa* leads other arthropods such as the cassava mealybug *Phenacoccuss manihoti* Mat-Ferr and the whitefly *Bemisia tabaci* (Genn.), as the most important pests of cassava in Africa (Onwueme and Charles, 1994).

Of all the cassava pest management strategies, biological control is the best method of managing arthropod pests of cassava (Byrne *et al.*, 1982). For this reason, *T. aripo* was first introduced in Kenya in the Coast Province in 1995 and in the Western Province in 1996 (Kariuki *et al*, 2000). Recent evaluation studies on its performance in the control of the cassava pests have revealed enormous economic returns in cassava yields while at the same time providing, by and large, an environmentally safe alternative to chemical control of cassava pests (Kariuki personal communication).

Studies by Bakker (1993) on the relative humidity (saturation deficit) tolerance range of plant-feeding or phytophagous mites and their phytoseiid predators on cassava has demonstrated that pest outbreaks coincided with dry, warm weather. Specifically, this author showed that outbreaks of spider mite pests in cassava fields were favoured by hot, dry weather (low humidity), whereas highly humid conditions tended to preclude or prevent major damage to plants (Boudreaux, 1957). Generally, Yaninek et al (1989) determined that populations of the cassava green spider mite in Africa increased rapidly at the beginning of the dry and hot season, followed by a dramatic decline as the wet season progressed. They also noted that other physical factors such as temperature and rainfall would be major factors in influencing cassava pest population dynamics in Africa. They concluded that in most regions where cassava is cultivated, the climate is characterized by relatively constant temperatures. The temperature changes during the year are often smaller than the daily fluctuations. Although altitude and other topographical factors might exercise a strong influence on mean annual temperature, the season was defined by humidity and rainfall rather than by temperature. Briefly stated, they concluded that, on long term basis, average meteorological data such as average annual rainfall, relative humidity, vapour pressure deficit and number of dry months per year affect the development and growth of mite predators of cassava arthropod pests.

T. aripo's development, as with other arthropods, is defined as its life history, that is, the total duration of development from egg to egg; whereas growth is determined as the duration of days it takes for each immature stage to change into the next stage. It was on the basis of these observations that the main objective for designing these studies was perceived, namely, to investigate the influence of the relative humidity,

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one of the physical factors that would most likely affect the development and growth of T. aripo in the laboratory. The findings will go along way in contributing to the formulation of better methods for its mass production for release in the fields for the biological control of the common and notorious cassava arthropod pest, M. tanajoa.

1.2 Literature Review

1.2.1 Taxonomy and Morphology of T. aripo

Typhlodromalus aripo (De Leon) belongs to the family Phytoseiidae of the Subclass Acari, Order Parasitiformes in the more recent classification under the Phylum Chelicerata (Yaninek et al, 1989). The distinguishing features of these spider mites are being 8-legged with no antennae or jaws. The body parts are divided into 2 parts; Prosoma and Opisthosoma. The phytoseiids are fast moving, shiny and their sizes range from 270 to 500 microns in length (Yaninek et al, 1989). The males are smaller than the females; the former being wedge-shaped and the latter tear-drop shaped. The phytoseiid species identification criteria are based on the arrangement of the setae on the ventral and dorsal body parts of the spider mites. The dorsal and idiosoma shields characteristics are used to differentiate genus level, together with the peritreme shape and extent to the fixed digit of chelicera (Yaninek et al, 1989). The juvenile stages of *T. aripo* are colourless unlike the adults' pink colour due to their herbivore diet. The protonymph, deutonymph and adults stages are 8-legged while the larva is 6-legged. The eggs are ovalish and light pink.

1.2.2 Biology and Ecology

The Phytoseiid group of the Acari are predaceous to the herbivore group of phytophagous mites of the family Tetranychidae. The two families have similar

developmental stages of egg, larva, protonymph, deutonymph and adults. T. aripo egg stage, as with other phytoseiids, is reported to take about 2-3 days to hatch to the larval stage (Yaninek et al, 1989). The larval stage takes a day to moult to protonymph stage. The protonymph stage takes 1-2 days to reach the deutonymph, which in turn takes from 1-2 days to adulthood. Work done by Yaninek et al (1989) at the International Institute of Agriculture (Benin) showed that egg to adult takes about 10 days with total adult life span being a mean of 29 days for most phytoseiids. Female fecundity was found to be about 48 eggs per life span. These phytoseiid predatory mites are reported in the same study by Yaninek et al (1989), to be optimally mass reared in the laboratory conditions of 27 °C and 70 % relative humidity. Specifically, T. aripo has been reared on cassava leaf-discs due to its reliance on cassava leaf tissue for its survival (Gnanvossou et al 2005; Magalhaes and Bakker 2002). The ecological requirements of the phytoseiid group of spider mites was reported by Bakker and Klein (1992) when they studied predatory spider mites for control of the cassava green mite pest, M. tanajoa. Bakker (1993) detailed in a study the environmental factor of relative humidity in the survival and development of phytoseiid eggs of the South American origin. T. aripo eggs were evaluated in the study along with other phytoseiid eggs, and found to have a higher relative humidity tolerant spectrum than other phytoseiid species of the same South American origin. From different ecological studies T. aripo has been found to survive longer in cassava plants at varied agro-ecological zones than most other local and exotic phytoseiid (Zundel et al, 2007).

Most phytoseiids are found on the abaxial part of cassava leaf tissue but *T. aripo* inhabits the cassava plant apex stratum (Yaninek *et al* 1989; Bakker 1993). Other workers have found a co-existence of *T. aripo* with other local and exotic phytoseiids

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which also prey on *M. tanajoa* pest (Onzo *et al* 2003a; Zannou *et al* 2007). Zannou *et al* (2007) found that *T. aripo* does not compete with other local phytoseiids and cause their elimination in the African cassava fields, but enhances increase of some species. *T. aripo* co-existence with *Typhlodromalus manihoti* Moraes which lives on the midleaf stratum of cassava plant canopy demonstrated a suitable habitat sharing by the two predators. As cassava pest, *M. tanajoa*, move from the mid to lower stratum of the plant canopy to avoid *T. aripo* presence, *T. manihoti* would still prey on the escaping pest individuals and result to less damage to the cassava plant (Gnanvossou *et al* 2005, Onzo *et al* 2003b). There is no other cassava green mite predatory mite reported to inhabit the cassava apex stratum both in Africa and the exotic spider mite's origin (Bakker 1993; Magalhaes and Bakker 2002). This makes identification easier for this phytoseiid mite *T. aripo* when sampling for it in cassava fields.

1.2.3 The Role of *T. aripo* as a Biological Control Agent of the Cassava Green Mite

T. aripo origin is the South American Amazon basin (Hanna et al., 2005). Yaninek and Hanna (2003) reported that it was retrieved from the Brazilian northern part of the country and mass reared in farmers' fields in Benin, near Cotonou City, before being released to other countries (Onzo et al 2005). Zundel et al (2007) reported that this predatory mite is widely distributed in most cassava belt regions of Africa. While the climatic matching of classical biological control is credited to scientists at the International Institute of Tropical Agriculture (IITA), other scientists in Europe and South America have contributed much in study, identification and studies of different phytoseiid species before release of T. aripo (Megevand et al, 1987). In some parts of Sub-Sahara Africa T. aripo was reported to get eliminated by adverse climatic conditions (Zundel et al, 2007). As a biological control agent of M. tanajoa, T. aripo was reported to be able to excel where other predators failed to establish and disperse (Zundel et al, 2007). T. aripo is reported to suppress M. tanajoa populations in fields of the host plant cassava below economic injury levels (EILs). This is by having low individual mites which do not reduce much the photosynthetic leaf area of the cassava plant (Yaninek et al, 1989). In studying anti-predator behaviour exhibited by M. tanajoa pest, Magalhaes et al (2002) showed how odours of the predator T. aripo caused M. tanajoa on the upper leaf canopy migrate to the lower ones, escaping predation. From the same study, Magalhaes et al (2002), revealed that prey discrimination among other mite predators was based upon the perception of body odours from T. aripo. Onzo et al (2003a) showed that T. aripo was more effective than other local and exotic phytoseiids in maintaining M. tanajoa population below economic injury levels due to the longest persistence on cassava plants. Zannou et al (2005) displayed how T. aripo was superior in survival by practicing cannibalism and inter-specific predation characteristics. Onzo et al (2003b) found that T. aripo inhabited cassava apices at day time but would roam about the upper stratum leaf canopy foraging on M. tanajoa pest, thus lowering possible damage by the pest.

T. aripo has some more pest management attributes in the field as Amusa and Ojo (2002) reported that high population of T. aripo reduced cassava crop diseases like bacterial blight (CBB), cassava anthracnose disease (CAD) and African cassava mosaic virus disease (ACMD). Gnanvossou *et al* (2005) reported that when cassava green mite prey was absent T. aripo had alternative food source like pollen from maize plant and reproducing on such with shorter immature development periods than on cassava exudes. A study to evaluate for negative effects of introduction of T. aripo

in Southern Africa countries of Malawi and Mozambique by Zannou *et al* (2007) found that the predatory mite *T. aripo* did not displace local phytoseiids in the region. It was observed that one local phytoseiid *Eusius batae* (Meyer and Rodrigues) shifted from the upper plant canopy leaves to the lower parts of the plant stratum. Kariuki (personal communication) reported that *T. aripo* presence in the Western Kenya fields improved root yield in some cassava varieties. All this information, displays that *T. aripo* has brought both ecological and economic advantages in the cassava belt of Africa.

1.3 Objectives and Justification

1.3.1 General Objective

The aim of the study was to determine the effects and relationship between various relative humidity regimes on growth and development stages of the predatory mite, *Typhlodromalus aripo* (De Leon).

1.3.2 Specific Objectives

- To elaborate the life cycle and development of *T. aripo* from egg through larval, protonymph, deutonymph and adult at selected relative humidity regimes
- To elucidate the relationship between the mortality of the life cycle stages of *T. aripo* and relative humidity regimes
- To determine the optimal relative humidity for rearing *T. aripo* in greenhouses in the lower, moderate and upper regimes
- Evaluate greenhouse mass rearing of *T. aripo*, in eastern Kenya at KARI-Katumani Research Station for release in farmers' fields.

1.3.3 Hypothesis Statement

The life cycle of T. aripo is affected by relative humidity regimes in the environment.

1.3.4 Justification

T. aripo has been found to be a reliable biological control agent of cassava green mite pest, *M. tanajoa* and hence there was need to study why it is not found in every cassava field in Kenya. If cassava crop root production is to be increased in Kenya there is need to find a way of enhancing biological control by *T. aripo* which is already established in places like Coast and Western regions of the country. Increased information on relative humidity requirements would lead to better simulation models of bio-control options for the cassava green mite. The study would also contribute to new information on acarology in the growth and development in the family Phytoseiidae. General information on how different relative humidity regimes affect *T. aripo* growth and development would show the reliability and capability of this predatory mite to control the cassava green mite pest in different relative humidity regimes prevailing in Eastern and other parts of Kenya. Briefly stated, the findings of this research would enable simulation models in the future use of *T. aripo* as a biological control agent in different agro-ecological zones of Kenya and beyond.

1.4 General Materials and Methods

1.4.1 Collecting of T.aripo from the Field

T.aripo which inhabits cassava crop apices was collected from Coast region at the Kenya Agricultural Research Institute (KARI)-Regional Centre-Mtwapa demonstration research field. The KARI-Mtwapa Centre is 31m above sea level on Latitude 03° 56.284 S and Longitude 039° 43.957 E. With the aid of head-eye lenses

(magnification x 4) it was possible to identify apices with *T. aripo* which were then collected and carried for laboratory rearing at KARI-Katumani Research Centre, Machakos. The Centre is situated approximately 70 Km east of Nairobi, at an altitude of 1604 m above sea level and Latitude $01^{\circ}348.36^{\circ}$ S and Longitude $037^{\circ}14.591^{\circ}$ E. The research station is part of a large area of gently undulating eastern plains of Kenya with well drained, reddish-brown friable sandy loam soils fairly suitable for cassava production. These detached cassava apices were placed in plastic containers measuring 28 cm-diameter x 29 cm-height. This was a large enough container to carry about 50 apices of cassava plants infested with *T. aripo* for mass rearing in the climate controlled-rooms. The plastic container was covered with air tight lid to enable retention and maintenance of high humidity that reduced mortalities en route to the laboratory.

1.4.2 Laboratory Mass Rearing of T. aripo at KARI-Katumani

These 50 apices in the plastic container from KARI-Mtwapa were divided into three portions to give aerated environment to minimize fast rotting and drying up in the laboratory's climate-controlled rooms. Each of the three plastic containers was divided by wire-mesh of 0.5 x 0.5 cm, partitioning the containers into three sections. A total of about 16 apices were placed on the wire-mesh sections in the containers so that saprophytic micro-organisms would not cause fast rotting of the cassava apices. Fresh cassava leaves, heavily infested with *M. tanajoa* from KARI-Katumani cassava field were placed on the wire-mesh with the cassava apices infested with *T. aripo*. These were then placed on the bench of each of the temperature-relative humidity controlled climatic chambers adjusted at 70 % relative humidity and temperature of 27 ± 2 ° C (Yaninek *et al*, 1989). The room had automated timer set to allow 12 hours

light and 12 hours darkness, 12L: 12D photoperiod, provided by four fluorescent bulb tubes of model TL-D 58 w/54-756 (Phillips). This was to make sure *T. aripo* life stage cohorts were not negatively affected by more or less light duration in the new environment. The three plastic containers were used as the mother cultures for providing all *T. aripo* life development stages needed for the experimental units in the subsequent rearing experiments.

1.4.3 Determination of Effects of Different Relative Humidity Regimes on Growth and Development of the Mite T. aripo

Three relative humidity saturation regimes were arrived at for observing the relationship of RH to the life history and growth of T. aripo under laboratory conditions. The selected levels were as follows: $40 \pm 10\%$, $60 \pm 10\%$ and $80 \pm 10\%$ relative humidity regimes. The criteria for choosing these relative humidity ranges was on the consideration of the agro-climatic conditions prevailing in Western, Coast and Eastern regions of Kenya. T. aripo life stages from egg through larva, protonymph deutonymph and adult were mass reared under these relative humidity regimes, observing and recording their growth and life cycle measured as period taken to change from one stage to the next stage. The fecundity level was used as measure for normal development together with total life span. The phytoseiid intrinsic rate of increase (rm), doubling time (Td) and generation time (Tg) parameters were determined as important growth factors for T. aripo in selected relative humidity regimes. The choice of 27 ± 2 ° C experimental temperatures was based on the work done by Yaninek et al (1989). Throughout the experiments an electronic device (battery-powered) of combined instant recording of temperature and relative humidity was used. The device was Model QA-CE, made in Britain (Fig. 1.1). The constant

temperature of 27 ± 2 °C was maintained throughout the experiments by monitoring it with a maximum and minimum thermometer. This enabled observations for twelve hours fluctuations recorded as maximum and minimum values reached in the given periods for recording.



Fig. 1.1: Temperature and Relative humidity electronic device (hygrometerthermometer) for measuring temp and relative humidity, (Model QA-CE, made in Britain).

The climate chambers used in the experiments were the temperature and relative humidity climate controlled rooms set at 60 and 80 % relative humidity regimes at constant temperature of 27 ± 2 ° C. For the 40 % relative humidity regime, an incubator (Model Gallenkamp Economy Size 2, Great Britain) was used. It was mounted with temperature control thermostat and a fan for aeration in the chamber to ensure a constant temperature of 27 ± 2 ° C. The day light in the incubator was artificially provided for by a light bulb of 40 Watts (Phillips) for 12 hours daily, with

its intensity lowered by covering it with butter paper. The bulb was fixed at the roof of the incubator 30 cm above the leaf cultures on which *T. aripo* was infested for observations.

1.4.4 Relationship between Mortalities and Relative Humidity Regimes of the Mite T. aripo

From actual relative humidity regimes achieved in the experiments on *T. aripo* life stages it was possible to calculate saturation vapour deficits (SVDs) from the saturation vapour tables by Prenger and Ling (2008). The calculated SVD values were included in the data tables of *T. aripo* life stages along the relative humidity regimes causing the highest and the lowest mortalities of the predatory mite. In the relationship of RH and mortality, the actual RH (%) was used in the regression analysis.

1.4.5 Relative Humidity Requirement for Rearing *T. aripo* as a Biological Control Agent in Greenhouse

For rearing a biological control agent like *T. aripo*, a supply of its host, in this case, *M*. *tanajoa* is usually necessary. This was carried out in an open greenhouse at KARI-Katumani Research Centre. In the rearing method, *M. tanajoa* populations were allowed to grow on potted cassava plants in a greenhouse under ambient conditions. In other words, within and during 24-hours period relative humidity and temperature fluctuated closely parallel to outdoor conditions. Being a glass greenhouse diurnal photoperiods were the natural settings of 12L: 12D (Schroeder, 2000). These conditions, which affect reproduction and development of *M. tanajoa* were within the preferred margins of (15-30° C, 50-70 % RH) and remained at optimum levels throughout the experimental period as required according to Yaninek *et al* (1989). The

greenhouse used measures 5 m-length by 3 m-width and accommodated about 30 pots on a bench with the pots being about 4-cm apart. The pots on which cassava was grown measured 40 cm wide in diameter by 43 cm height, and had a maximum of three seedlings. *M. tanajoa* was introduced on the plants when the plants were approximately 30 cm tall. After a month, the plants had approximately 40 mites per leaf. At this stage laboratory- reared females *T. aripo* were picked with a soft camel brush and introduced on the cassava green mite-infested plants. An individual female *T. aripo* was introduced on each of the tips of 100 plants in the greenhouse. The monitoring for the population build up of *T. aripo* on the plant apices was monitored for one month and repeated thrice for reliability of the results. The procedure for assessing mite population was according to the IITA sampling protocol (Yaninek *et al*, 1989) which involved: (1) counting the number of *T. aripo* individuals in apex per randomly picked 30 plants, and (2) counting the number of *M. tanajoa* on the second fully developed mature leaf on the plant growing shoot attached to the sampled plant apex.

1.4.6 Simulation for Suitable Agro-ecological Zones for Release of the Mite T. aripo

The agro-meteorological data for Eastern and Coast regions were acquired from the respective meteorological stations for the 2007/2008 years. This was to determine the natural conditions in the field that affect *T. aripo* dispersal/establishment and the present population density status since release of the predator in 1995 and 2007 at Coast and Eastern Provinces, respectively. Simulation regression analyses were carried out for an open greenhouse for mass rearing of *T. aripo* on the phytophagous mite cassava green mite on potted cassava plants. A method to calculate for effective

predator-prey ratio, for suppression of *M. tanajoa* population density below economic injury level (EIL) was deduced from an initial *M. tanajoa* population in relation to the number of individual *T. aripo* actives released.

Chapter 2

2.0 THE EFFECTS OF LABORATORY SELECTED RELATIVE HUMIDITY REGIMES ON *TYPHLODROMALUS ARIPO* (DE LEON) LIFE CYCLE AND DEVELOPMENT

2.1 Introduction

Eggs of the predatory mite Typhlodromalus aripo were found to be sensitive to low relative humidity regimes by Bakker (1993). Comparison of both the phytophagous Tetranychid mite eggs, with those of phytoseiid group, in low and high relative humidity regimes were evaluated. In the study, it was shown that most phytoseiid species have narrow saturation vapour deficit tolerance spectrum unlike the phytophagous cassava green mite which has a broad saturation vapour deficit tolerance spectrum. Most phytoseiids inclusive of T. aripo eggs were found to have a saturation of moderate relative humidity to near saturation levels. In a field study, Zundel et al (2007) could not fully explain where T. aripo was taking refuge to when cassava plants completely lost their leaves during the dry seasons of the Sub-Sahara Savannah regions of Africa. In the study it was speculated that the predatory mite T. aripo could be living in the soil or some how on the cassava plant stem (cf Onzo et al, 2005). When rains returned T. aripo would re-infest the cassava apices four to eight weeks later. In the study by Zundel et al (2007) explained that the disappearance of this predatory mite was due to low relative humidity prevailing in the Sub-Sahara Savannah fields of Central Africa.

T. aripo was released in Kenya's Coast and Western cassava growing regions over 10 years ago (Kariuki personal communication). While T. aripo has been reported as the most effective biological control agent of M. tanajoa, it has not dispersed to every

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cassava field in Kenya, probably due to the varied agro-ecological zones where cassava grows (Kariuki personal communication; Zundel *et al* 2007). Eastern Kenya region is one of the areas in the country where few *T. aripo* phytoseiids are found in low numbers compared to Coast and Western Kenya regions since release in 1995 and 1996, respectively (Kariuki *et al*, 2000). With no biotic constraint, either predatory enemy or disease organism it was assumed that relative humidity was the immediate abiotic factor to be evaluated for its effects on the growth and development of this exotic predatory mite, as a reason as to why it has not dispersed to every cassava field of the low altitude-drier eastern region of Kenya (Oduor *et al*, 1996). A laboratory study was therefore chosen as the most ideal to determine influence of relative humidity on the life history of the predacious mite at different life stages at selected relative humidity regimes (Janssen and Sabellis, 1992).

This study has been focused to determine: (1) at what relative humidity regime the highest *T. aripo* mortalities occurred from egg to adult life stage, thus affecting development of *T. aripo*, (2) effect of different relative humidity regimes to *T. aripo* growth and development across all life stages, and (3) what relative humidity range is optimum for *T. aripo* development across all life stages of the predatory mite. (4) Relation of relative humidity to *T. aripo* survival was also determined.

2.2 Materials and Methods

2.2.1 Laboratory Mass Rearing of T. aripo

The 50 apices in the plastic container from KARI-Mtwapa were divided into three portions to give aerated environment to minimize fast rotting and drying up in the laboratory's climate-controlled rooms. Each of the three plastic containers was divided by wire-mesh of 0.5×0.5 cm, partitioning the containers into three sections.

A total of about 16 apices were placed on the wire-mesh sections in the containers so that saprophytic micro-organisms would not cause fast rotting of the cassava apices. Fresh cassava leaves, heavily infested with M. tanajoa from KARI-Katumani cassava field were placed on the wire-mesh with the cassava apices infested with T. aripo actives and their eggs. These were then placed on the bench of each of the temperature-relative humidity controlled climatic chambers adjusted at 70 % relative humidity and temperature of 27 ± 2 ° C (Yaninek et al, 1989). The room had automated timer set to allow 12 hours light and 12 hours darkness, 12L: 12D photoperiod, provided by four fluorescent bulb tubes of model TL-D 58 w/54-756 (Phillips). This was to make sure that T. aripo life stage cohorts were not negatively affected by more or less light duration in the new environment. The three plastic containers were used as the mother cultures for providing all T. aripo life growth stages needed for the experimental units in the subsequent rearing experiments. For the lower RH regime of 40 %, an incubator mounted with a temperature and control thermostat and a fan for aeration was used. A 40 Watt bulb (Phillips) was inserted from the top to provide 12hours of light daily. At night the bulb was switched off. The temperature of $27 \pm 2^{\circ}$ C was maintained throughout the experiment.

2.2.2 Determination of Effects of RH regimes on Growth and Development

Three relative humidity saturation regimes were arrived at for observing the relationship of RH to the life history and growth of *T. aripo* under laboratory conditions. The selected levels were as follows: 45 ± 6 %, 67 ± 6 % and 90 ± 3 % relative humidity regimes. *T. aripo* life stages from egg through larva, protonymph, deutonymph and adult were reared under these relative humidity regimes, observing and recording their growth and life cycle measured as period taken to change from one

stage to the next stage. The fecundity level was used as measure for normal development together with total life span. The choice of 27 ± 2 ° C experimental temperatures was based on the work done by Yaninek *et al* (1989). Throughout the experiments an electronic device (battery-powered) (Model QA-CE, made in Britain) of combined instant recording of temperature and relative humidity was used. The constant temperature of 27 ± 2 ° C was maintained throughout the experiments by monitoring it with a maximum and minimum thermometer. This enabled observations for twelve hours fluctuations recorded as maximum and minimum values reached in the given periods for recording.



Fig.2.1: The type of 8cm-diameter x 10cm-height plastic containers with mesh wire 0.5cm length x 0.5cm width for suspending cassava leaf for T. aripo rearing

2.2.3 Observation for Eggs, Larvae, Protonymphs, Deutonymphs and Adults time period (in days) and number surviving to next life stage

Using a camel hair brush (type 00), 25 newly laid egg cohorts, (and newly 25 emerged larvae, protonymphs, deutonymphs and adults) were placed on the underside part of the leaf portions. This leaf part of cassava is where phytoseiids lay their eggs and the prey cassava green mite feed (by sucking cell sap) and lay their eggs. Fresh detached leaves of the improved cultivar Mucericeri (820058) of pubescent leaves, were cut with a pair of scissors at 4-cm radially from the petiole mid rib point of the leaf lobes and placed into plastic containers of 8 cm-diameter x 10 cm-height. The leaf portions were rested on wire mesh (0.5 x 0.5 cm) above water bath of one cm depth with the long petioles deep inside the water to ensure that the cassava green mite-infested leaves stayed fresh for longer period of time (Fig. 2.1). Leaf quality was maintained by addition of fresh ones once deterioration was noticed. The experimental units were replicated four times for each life stage, in each of the 45, 67 and 90 % relative humidity regimes. Daily observations were carried out and recorded on: (1) number of life stage cohorts that grew to the next life stage, and (2) time period in days taken for the development of one life stage to the next. For the adults 15 newly emerged females were added to 10 males to make up the number of 25 individuals. The observations on the adult cohorts were on the fecundity and survival of mite T. aripo in the different relative humidity regimes. Each life stage experiment unit was replicated four times. Another set of four replicates of newly laid egg cohorts was set in the three different RH regimes (45, 67 and 90 %) and observed for 36 days. Once the eggs reached adulthood and started laying eggs the progeny were recorded and removed each time. The data on the (1) number of eggs and juveniles were used to calculate intrinsic rate of increase (rm) per unity time period over the initial number of 25 individuals in each of the three RH regimes following the procedure by Yaninek et al(1989). (2) The egg to adult longevity period (generation time, Tg) was also calculated from the means on the replicates. (3) The doubling time (Td) was computed for each RH regime.

These observations enabled to demonstrate the: (i) effects of different selected relative regimes on growth of life stages of phytoseiid *T. aripo*, and (ii) determination of the relationship of relative humidity in the environment and the survival of the mite in its entire life cycle.

2.2.4 Test for T. aripo Preference of High Transpiring plant apices

To determine the importance of high relative humidity regime requirement on cassava leaf tissue for normal growth and development of T. aripo, 12 newly detached cassava apices were randomly separated into two experimental sets. Each set was brushed off all cassava green mite actives and eggs to find out how T. aripo survives on the leafy apices without its prey in low and high apex transpiring different apices. One set of 6 apices was oven-wilted for four hours at 34 °C to wilting stage losing at least 50 % of their tissue water content. Within the temperature conditions of 27 ± 2 ° C, the two sets of apices transpiring rate was measured with the same hygrometer-thermometer device described above, inside a plastic transparent paper bag of 8 cm-diameter x 17 cm-height. Later the 12 apices had their stems inserted into wet-spongy material and placed in the T. aripo rearing containers (of 28 cm-diameter x 29 cm-height) in the temperature-relative humidity controlled room of 27 ± 2 ° C and 70 % Relative humidity regime. A total of 100 T. aripo actives of males and females were placed on 10 fresh leaves and introduced into the container of wilted and fresh cassava apices. The settings were replicated four times. Observations and records were taken after

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three days on: (1) number of T. aripo actives on either of the wilted and fresh cassava apices, and (2) number of eggs and juvenile stages on the different treated cassava apices. All the above experiments were repeated three times for reliability of the results.

2.2.5 Data Analyses

Data on the growth of the life stages of *T. aripo* in days was determined by use of oneway ANOVA, comparing the means and standard errors across the three regimes of 45, 67 and 90 % relative humidity at 27 ± 2 ° C. SAS (1999-2001) Version 8 software (PROC GLM) was employed for Least Significant Difference (LSD; Student-Newman Keuls multiple range test) while Ms Excel programme was used to graph for the mortalities recorded against the selected different relative humidity regimes and the corresponding regression results. The significance difference between wilted and fresh leaves was analyzed by PROC T-Test (SAS 1999-2001). Before data analyses, data entries on number of *T. aripo* cohorts, were transformed into square root values $(\sqrt{x} + 0.5)$, to make variates independent of means and remove effects of zero data values. The 5 % significance level (P = 0.05) for biological experiments was used.

2.3 Results

2.3.1 Effects of Different RH Regimes on Growth and Development of T. aripo

By day eight all *T. aripo* life stages had suffered 100 % mortalities at the relative humidity (RH) regime of 45, (Fig. 2.2a). The least mortalities occurred in the 67 % RH regime, for both adult and juvenile stages (Fig. 2.2b). The growth curve peaked exponentially from day seven for the adult stages when laid eggs hatched to larvae as Figure 2.2b shows. The 90 % RH regime had more juvenile mortality than the optimum 67 % RH (cf Fig.2.2b and 2.2c).



Fig2.2a: T. aripo life stage growth and survival in 27 ± 2 °C and at 45 % relative humidity regime

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Fig 2.2b: T. aripo life stage growth and survival in 27 ± 2 °C and 67 % relative humidity



Fig 2.2c: T. aripo life stage growth and survival in 27 ± 2 °C and 90 % relative Humidity

C

The general growth and development was well demonstrated as Figure 2.3 shows. This shows that at 45 ± 6 % relative humidity regime there was high mortalities of both adult and juvenile stages of the phytoseiid of the earlier set 25 individuals of each cohort. The optimum condition of 67 ± 6 % RH had the highest adult and juvenile survival of 40 and 34 actives, respectively (Fig.2.3). The 90 % RH had similar adult survival of approximately of 40 actives but less juvenile survival of 20 individuals. This indicates that this RH had some negative effects on the juvenile stages of *T*. *aripo*.

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Fig2.3: Mean number of T. aripo adult and juvenile growth rate in 7 days at different RH at $27 \pm 2^{\circ}C$.

There was no significant difference in growth period (days) of egg to larva (P=0.010) across the three RH regimes of 45, 67 and 90 % (Table 2.1). Also there was no significant difference in growth period for larva to protonymph across the three different RH regimes (RH). Likewise there was no significant difference for protonymph to deutonymph growth period (P = 0.023), as well as deutonymph to adult (P = 0.010). However, there was significant difference of female fecundity in the eight days across the three different relative humidity regimes (P=0.101 and LSD =15). The indication is that the three relative humidity regimes had varied effects to the female *T. aripo* reproductive potential. Table 2.1 shows the mean number of eggs laid by females in the observed 45, 67 and 90 % regimes as 6.6, 61 and 40, respectively, in the eight days period.

RH (%)	Egg to	Larva to	Protonymph	Deutonymph	Adult fecundity in
Regime	larva	protonymph	to deutonymph	to adult	8 cumulative days
45 ± 6	$2.5 \pm 0.28a$	$1.2 \pm 0.47a$	$1.5 \pm 0.28a$	1.4 ± 0.19a	6.6 ± 0.88a
67 ± 6	2.2 ± 0.44a	0.7 ± 0.16a	$1.3 \pm 0.36a$	1.3 ± 0.39a	61 ± 11.60b
90 ± 3	2.3 ± 0.44a	1.2 ± 0.16a	1.1 ± 0.70a	1.8 ± 0.15a	$40.3 \pm 15.20c$
F, P	0.50, 0.010	0.50, 0.010	2.33, 0.023	1.00, 0.010	10.08, 0.101

Table 2.1: Mean (\pm SE) growth period in days of T. aripo life stage in different relative humidity regimes at $27 \pm 2^{\circ}$ C and the respective adult fecundity in 8 days

Means within the same columns marked with same letters are not significantly different (p < 0.05, df = 2, 6) (Student-Newman-Keuls multiple range test)

T. aripo development rate was shown by the resultant varied intrinsic rate of increase (rm) at different relative humidity regimes with the highest being in the 67 % RH regime (Table 2.2). Doubling time (Td) was shortest in the same relative humidity regime, while the highest generation time (Tg) of 28 days was also observed at this regime. From Table 2.2, Td and Tg at 45 % RH were not included due to the high mortality of the phytoseiid in this particular RH regime which gave unreliable values.

Table 2.2. T. aripo achieved values for intrinsic rate increase (rm), Doubling time (Td) and Generation time (Tg) in days at 45, 67 and 90 % relative humidity regimes at $27 \pm 2 \circ C$

RH (%)	r m	Td	Tg	
45	0.0600	-	-	
67	0.2625	5.0	28.3	
90	0.2085	5.5	26.0	

The relationship between *T. aripo* mortalities in various relative humidity regime levels were depicted in the linear, Y = a + bx, where y = the expected mortality (%) of *T. aripo* adult cohorts, b slope of regression and a being y-intercept which represent particular RH regime level causing the mortality of *T. aripo* predatory mite (Fig. 2.4).



Fig. 2.4: Regression of relative humidity on the mortality of *T. aripo* adults at $27 \pm 2 \,^{\circ} C$

From the regression line the 50 % mortality of *T. aripo* adults occurred at 68 % RH regime. This was the vapour saturation deficit (SD) level causing mortality level of 50 %; which was the SD₅₀ for the *T. aripo* adults, as observed. When this factor (RH) increased, higher survival of *T. aripo* actives increased resulting to lower mortalities.

2.3.2 T. aripo Preference of High Transpiring plant apices

According to the T-test results there was significance difference between fresh and wilted cassava apices. The transpiring rate was greater in the fresh apices, hence releasing more water (t = 135.0, P = 2.70). The number of *T. aripo* as observed was significantly higher in the fresh apices than the wilted ones (t = 7.87, P = 0.154). This was approximately 6.8 and 7.0 per apex, for fresh and wilted apices, respectively
(Table 2.4). Female fecundity in the fresh apices was significantly higher at 3.7 eggs per apex as compared to 0.2 per apex in the wilted ones (t = 5.65, P = 0.113). There was significantly higher number of juveniles in the fresh apices, which was approximately 0.2 juveniles per apex (t = 2.48, P = 0.049). Some of the wilted apices had individual *T. aripo* found feeding from the tender injured parts.

Table 2.3: Mean \pm SE of parameters showing T. aripo preference of high transpiring apices as compared to wilted ones

Plant apex	Transpiring	No. of	Female fecundity	No. of	
Treatment	rate in ul/min	T. aripo	cum. in 3 days	juveniles	
T1: Fresh apices	0.32 ± 0.01a	6.83 ± 0.18a	3.67±0.11a	$1.00 \pm 0.10a$	
T2: Wilted apices	0.06 ± 0.01b	0.67 ± 0.06	b 0.17 ± 0.03b	0.18 ± 0.04b	

The different letters within the columns show significance difference of parameters considered (P = 0.05, n =6 per sample).

2.4 Discussion

2.4.1 Influence of Relative Humidity on Growth and Development

The low relative humidity (RH) regime of 45 % was found to cause high mortalities of both adult and juvenile stages of the phytoseiid *T. aripo*. This effect caused elimination of the phytoseiid within duration of eight days. The moderate RH regime of 67 % was found to be the optimum regime for *T. aripo*, causing the highest growth within the mite's life stages and general development leading to increased number of the phytoseiid. Eggs and juvenile stages had the highest growth recorded in this regime than the other two of highest and lowest regimes of 90 and 45 %, respectively. The highest RH regime of 90 % was, however found to have similar adult survival like the moderate regime of 67 %. The juvenile stages of the phytoseiid at this RH were found to suffer some mortality. Bakker (1993) found that most phytoseiid eggs were vulnerable to low relative humidity regimes, as this study has concluded. For the phytophagous mites like cassava green mite, they exponentially increased their populations in the drier conditions (Yaninek *et al*, 1989). Boudreaux (1957) reported that ovipositing phytophagous spider mites lay more eggs at near dry conditions than in a near saturated atmosphere. This finding is similar to what Yaninek *et al* (1989) found about increased feeding habit of cassava green mite in dry field conditions after wet season of the Sub-Sahara region of Africa.

This study also found that there was no significant difference (p<0.05) in growth rates between life stages across the three different relative humidity of 45, 67 and 90 %. This contrasted sharply with female fecundity across the same three regimes (with LSD =15). This could be attributed to some physiological effect to the reproduction of the phytoseiid with negative results of reduced fecundity in the low RH regime (Chaudhury 1994). The optimum RH regime was the moderate one of 67 ± 6 % where also increased growth of all life stages was observed. This was within the range of what was determined by Yaninek *et al* (1989) for most exotic phytoseiids of South American origin. The overall *T. aripo* life history growth and development was found to be exponential in the moderate RH regime of 67 % with highest intrinsic rate of increase, shortest doubling time and longest generation time of 28.3 days. Considering the relatively similar results from the highest RH regime of 90 %, it reflected well the possible similar field conditions of most areas of Sub-Sahara African climate conditions, inclusive of Eastern Kenya mosaic of agro-ecological zones (Zundel et al 2007; Kariuki personal communication).

2.4.2 Preference of High Transpiring cassava apices and field implications Zundel et al (2007) reported that T. aripo disappears in the dry season of the Sub-Sahara Savannah regions when the dry period prolong over five months. This prolonged dry period results in leaf drop of most cassava plants. This leaf drop occurs faster where there is heavy M. tanajoa infestation (Yaninek et al 1989; Yaninek and Gnanvossou 1993). The evaluation study on the type of cassava apex preferred by T. aripo phytoseiid has demonstrated that the mite prefers most high transpiring plant tips over the less transpiring ones (O'Dowd and Wilson, 1989). This could explain why few T. aripo actives are found on the wilted plant apices in the field. The field study by Zundel et al (2007) in the Central African Countries concluded that T. aripo could be taking a refuge in the soil or on the plant stem. This apex study has made observations that T. aripo individual phytoseiids were found feeding on injured tender parts of the apices when drier environmental conditions advanced, thus confirming that T. aripo has special relationship with cassava plant for its survival in advance dry conditions (Bakker and Klein 1992; Magalhaes and Bakker 2002; Gnanvossou et al 2005).

From this study it can be concluded that one of the reasons for *T. aripo's* preference for the plant apex is due to the acarodomatia features present at that plant stratum as Bakker and Klein (1992) reported. Probably there are some nutritious compounds found at the apex supportive to the survival of *T. aripo* similar to the findings of cassava exudates on the tender leaf petioles supporting *Typhlodromalus limonicus*

Garman and McGregor, by Toko et al (1994). Whether this is the reason T. aripo prefers the apices which are likely rich in such plant compounds could be investigated further (Bakker and Klein, 1990; Bakker and Oduor 1991). Work by Magalhaes and Bakker (2002) found that T. aripo survived longer on cassava plants than other predatory mites. With the findings that even juvenile T.aripo cohorts were found higher in number within the fresh apices than the wilted ones it can further be hypothesized that T. aripo inhabits cassava apices during the day time due to the favourable more humid conditions within the folded young leaves besides the nutritious substrates at the growing plant shoot. At the apex, is where the juvenile phytoseiids can get the extra-foliar domatia for their survival during the day and night fluctuating weather conditions (Onzo et al 2003b, 2005; Bakker and Klein 1992). This could explain why T. aripo is usually found persistent in cassava plant cultivars which do not shed their leaves in dry conditions, while the phytoseiid is usually absent on tips which have shed the young apex leaves. It also explains the reason why T. aripo reappears in a field several weeks after rain on set (Zundel et al, 2007).

Chapter 3

3.0 REARING OF THE PREDACIOUS MITE *TYPHLODROMALUS ARIPO* (DE LEON) IN GREENHOUSE FOR BIOLOGICAL CONTROL OF CASSAVA GREEN MITE, *M. TANAJOA* BONDAR, IN KENYA

3.1 Introduction

The phytoseiid mite, T. aripo De Leon is a predator of the cassava green mite pest, Mononychellus tanajoa (Bondar), and has been reported as an effective biological control agent (Onzo et al 2005; Yaninek and Hanna 2003). It is for this reason that it was released in the cassava fields in the Sub-Sahara Africa on farmers' fields (Zundel et al 2007; Onzo et al 2003a). This predatory mite has been reared in situ in the fields since its introduction into the African Continent from the Latin America region of its origin (Yaninek and Hanna 2003; Hanna et al 2005). While M. tanajoa prefers young leaves of the mid to uppermost part of the cassava plant, T. aripo inhabits cassava apices and at night leaves the apices to feed on M. tanajoa on the cassava leaves (Yaninek et al 1989; Bakker 1993; Onzo et al 2003b). However, one of the major ways to implement biological control is the successful mass-rearing and release of the predator against the pest (Friese et al, 1987). The key factors for this exercise are thorough knowledge of the physical environment and the biology of both the predator and prey (Schroeder 2000; Onzo et al 2005). Mass rearing is the insectary propagation of large numbers of natural enemies for release against a selected pest(s) at strategic times (Megevand et al, 1987). In view of the inherent expenses involved, mass rearing is usually restricted to situations in which both the natural enemy (in this case T. aripo) and its host (M. tanajoa) can be easily cultured. Production of large numbers of T. aripo is dependent on food availability and optimum environmental conditions

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(Gnanvossou et al 2005; Cuellar et al 2001). In view of the heavy infestations of *M. tanajoa* pest on cassava crop as earlier recorded in most fields in Kenya (Kariuki et al, 2000), this investigation was made as a case study of *T. aripo* predacious mite in mass-rearing in a greenhouse using its native prey of the *M tanajoa* from the field. The prey is the preferred food for the phytoseiid *T. aripo* which naturally and easily inhabits the cassava apices predating on its host *M. tanajoa* and multiplying in numbers depending on the prevailing conditions (Yaninek et al, 1989).

From the onset, it was assumed that a successful greenhouse experiment of mass rearing of *T. aripo* would provide the large numbers required for biological control treatments. This is because a greenhouse acts as a simple field shelter where the temperature and humidity within and during a 24-hour period fluctuate and closely parallel the outdoor air temperature and humidity of the farmers' cassava fields where the two mites live (Schroeder, 2000). The objectives of the greenhouse *T. aripo* mass rearing was to: (1) determine suitability of an open greenhouse for mass production of large numbers of the predatory mite *T. aripo* on its prey *M. tanajoa* in eastern region local conditions, (2) compare population density ratio of prey and predator growth in the greenhouse, and (3) measure the effective predator-prey ratio in a given time period, for *T. aripo* on *M. tanajoa*, from a known starting *M. tanajoa* population density.

3.2 Materials and Methods

3.2.1 Laboratory Mass Rearing of T. aripo

The 50 (or so) apices in the plastic container from KARI-Mtwapa were divided into three portions to give aerated environment to minimize fast rotting and drying up in the laboratory's climate-controlled rooms. Each of the three plastic containers was divided by wire-mesh of 0.5 x 0.5 cm, partitioning the containers into three sections. A total of about 16 apices were placed on the wire-mesh sections in the containers so that saprophytic micro-organisms would not cause fast rotting of the cassava apices. Fresh cassava leaves, heavily infested with M. tanajoa from KARI-Katumani cassava field were placed on the wire-mesh with the cassava apices infested with T. aripo. These were then placed on the bench of each of the temperature-relative humidity controlled climatic chambers adjusted at 70 % relative humidity and temperature of 27 ± 2 ° C (Yaninek et al, 1989). The room had automated timer set to allow 12 hours light and 12 hours darkness, 12L: 12D photoperiod, provided by four fluorescent bulb tubes of model TL-D 58 w/54-756 (Phillips). This was to make sure T. aripo life stage cohorts were not negatively affected by more or less light duration in the new environment. The three plastic containers were used as the mother cultures for providing all T. aripo actives needed for the experimental units in the subsequent repeated glass greenhouse experiment.

3.2.2 Simulation for Suitable Agro-ecological Zones for Release of Mite T. aripo

The agro-meteorological data for Eastern and Coast regions were acquired from the respective meteorological stations for the 2007/2008 years. This was to determine the natural conditions in the field that affect *T. aripo* establishment and dispersal and the

present population density status since release of the predator in 1995 and 2007 at Coast and Eastern Provinces, respectively. Simulation regression analyses were carried out for the greenhouse for mass rearing of *T. aripo* on the phytophagous mite *M. tanajoa* on potted cassava plants. A method to calculate effective predator-prey ratio for suppression of *M. tanajoa* population density below economic injury level (EIL) was deduced from an initial *M. tanajoa* population in relation to the number of individual *T. aripo* actives released.

A cassava cuttings-cropping system of 100 pots of sizes 40 cm-diameter x 43 cmheight, was established in a greenhouse during the experiments. The plants were regularly watered and care taken to ensure normal plant growth, without application of any pesticide. The improved cassava cultivar Mucericeri (820058) was selected for the experiment partly because it is the preferred variety grown by farmers in Eastern Province and partly it has been found to be easily infested by the *M. tanajoa*, a suitable prey for the predacious mite *T. aripo*.

Each cassava plant at 30 cm height (one month since sprouting) was artificially infested with about 30 *M. tanajoa* actives on cassava leaves from the Centre's cassava field. This was done by placing the *M. tanajoa*-infested leaves on the upper cassava leaf canopy. This phytophagous colony was allowed to multiply in numbers in the greenhouse conditions for three weeks reaching about 40 *M. tanajoa* actives per leaf. To establish a predator-prey system, 100 actives of the predacious mite *T. aripo* were introduced on 10 randomly selected plants in the greenhouse after three weeks at which time the plants were about one metre high. Since these plants were found to have a mean of 20 leaves, this translated to predator-prey ratio of approximately 0.05:40 or 1:800. To introduce *T. aripo* on the 10 plants, fresh *M. tanajoa*-infested

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leaves were detached from each plant, and with a camel hair brush, individual phytoseiids were placed on the leaves of 10 randomly selected plants in the greenhouse. This means that each of the 100 cassava plant was to have one *T. aripo* per apex. The *T. aripo* actives were assumed to be in 50:50 ratios of males and females which would mate and reproduce, growing in numbers as they foraged on *M. tanajoa* (Bakker and Klein, 1992). In the greenhouse the upper plant canopy leaves were allowed to be touching thus enabling faster dispersal of the prey and predator among the plants.

Sampling was carried out from the first week after release of *T.aripo* until the sixth week. The sampling method adopted was the International Institute of Tropical Agriculture (IITA) protocol, which included: (1) counting the number of *M. tanajoa* per second mature leaf of the plant shoot tip and recording the prey density of randomly selected 30 plants, and (2) counting the number of *T. aripo* per plant apex of the main shoot, from the 30 plants.

3.2.3 Data Analyses

Regression analyses were carried to determine relationship of the predator-prey ratio and time period taken by the predator to eliminate the prey. Time period was taken as the independent variable while *M. tanajoa* and *T. aripo* populations at specific time period were the dependent variables. The functional relationship between the dependent variable Y and the independent variable X was represented by the equation Y = A + BX.

3.3 Results

3.3.1 Mass Rearing of T. aripo in an open Greenhouse

The greenhouse temperature and humidity were monitored during the 24-hour period and compared with those of the meteorological data at Katumani Station (Table 3.1 and Table 3.2). The greenhouse conditions closely paralleled the outdoor air temperature and humidity recorded in some cassava fields in Eastern Kenya Province. However, in this study the outdoor mean daily temperature was lower than the greenhouse temperature which was 19.8 ° C and 27.4 ° C, respectively (Table 3.1). Conversely, the relative humidity was higher in the outdoor conditions than in the greenhouse, at 57.9 and 52.2 %, respectively.

Table 3.1: Mean environmental factors recorded in glass greenhouse at KARI-Katumani in the months where T. aripo was mass reared

Time of	Mean ± sd	Mean \pm sd	Saturation vapour deficit		
the day	temp (°C)	RH (%)	range in KiloPascals (KPa)	n	
Night	9.7 ± 3.1	64.1 ± 10.9	0.58 1.09	37	
Day	35.0 ± 1.9	40.3 ± 6.8	3.00 — 3.75	33	

Daily mean 27.35 ± 10.8 52.2 ±16.8 1.70 - 2.42

(n= number of times records taken in the green house).

Table 3.2: Mean environmental factors from the Meteorological Station at Katumani (for the months of the experimental period)

	Mean ± sd temp (° C)	Mean ± sd RH (%)	SVDs range (KPa) N	
Min.	14.9 ± 2.3	41.2 ± 10.1	0.53 - 0.83	90
Max.	24.7 ± 4.1	74.6 ± 11.8	0.41—1.87	90
Daily mean	19.8 ± 6.9	57.9 ± 23.6	0.47 — 1.35	

N= number of days in the 3 months of meteorological data recording.

For the determination and indication of how the predator-prey population densities grew on the cassava plants, it would depend on the initial populations of the prey and that of the predator. In this case the *M. tanajoa* population density was 40 mites per leaf, on the estimated 20 leaves per plant giving a total mite density of approximately 800 actives.

3.3.2 Comparison of Prey and Predator Mites Populations Reared in an open Greenhouse

The initial introduction of one *T. aripo* per plant tip on the approximately on 800 M. tanajoa enabled comparison of how the population of the prey would be affected by the predator. The weekly sampling on the population densities indicated the effect of *T. aripo* on *M. tanajoa* in the greenhouse conditions. From Figure 3.1, it is apparent that *T. aripo* was able to multiply fast in numbers and effectively suppressed *M. tanajoa* population below one mite per leaf within 4.5 weeks. The suitability of the greenhouse conditions with the minimal fluctuations is credited to the fast multiplication of *T. aripo* population growth in a week's time (Fig. 3.1).



Fig. 3.1: The trend of changes in the M. tanajoa population following the introduction of T.aripo

3.3.3 Effective Predator-Prey ratio of T. aripo on M. tanajoa

The effectiveness of T. aripo in controlling M. tanajoa given the right conditions has been demonstrated in this study. The predator was able to bring down the population of M. tanajoa from 40 mites per leaf while its density increased to three actives per apex in only one week (Fig 3.1). However, the number of both mites decreased rapidly until there was none by the sixth week (Fig 3.1). The regression analysis of the populations of the two variables over time, that is, T. aripo and M. tanajoa population changes yielded two linear lines in relationship with time representing negative correlations as indicated in Figure 3.2. This is for the linear regression equation Y = a + bx, on *M. tanajoa* where y = the expected *M. tanajoa* diminishing population, b slope of the regression equation, and a = y-intercept representing particular population of *M. tanajoa* at given weekly time period. Over the given time of 6 weeks, increase of the predator *T. aripo* resulted to decrease of *M. tanajoa* density, effectively suppressing the latter within the 4.5 weeks (Fig. 3.2).



Fig 3.2: Regression of T. aripo actives on M. tanajoa population densities over time in an open greenhouse

A less linear equation was observed on regression of time period taken for the M. tanajoa pest on leaves of cassava plant to be eliminated by T. aripo, where y = is the diminishing M. tanajoa population in a given time period, and b, the negative slope of the regression equation and a = y-intercept representing particular population of M. tanajoa at given weekly time period (Fig 3.3). From these results the time taken for T. aripo actives to reduce M. tanajoa population to zero is indicated by the part the regression line that cuts the X-axis, which is 4.5 weeks from the time of introducing the predatory mite. To shorten this period of control to a one day it would need hypothetically increasing *T. aripo* by 25 times, to a new ratio of 1:32. This calculation involves dividing the 800 *M. tanajoa* by days in 4.5 weeks, that is, 31.5 days. For a week effective control ratio would be adjusted to 1:224.



Fig3.3: Regression of time period for M. tanajoa population density control by T. aripo

3.3.4 Yearly prevailing Temperature and Relative Humidity conditions at Coast and Eastern regions

Coast region was found to have higher mean relative humidity regimes than Eastern by 10 % margin. Mean temperature at the Coastal strip was higher than Eastern region. While relative humidity range at Coast was 71.1 \pm 4.4 % at Eastern region was 61.6 ± 4.7 %. The comparison of the temperature yearly mean values for Mtwapa and Kiboko was 26.2 ± 1.4 ° C and 24.0 ± 1.9 ° C, respectively. The temperature range difference was relatively small, by 2 ° C compared to the relative humidity margin of 10 % between Coast and Eastern regions of the two different agro-ecological zones





Fig. 3.4: Relative humidity and temp regimes prevailing through out the year at eastern and coast regions of Kenya.

3.4 Discussion

The greenhouse study has enabled evaluation of open greenhouse conditions for rearing *T. aripo* for release to some parts of Kenya like Eastern Province which is a mosaic of varied agro-ecological zones of hilly and low land areas where the predator is not prevalent. This greenhouse experiment for *T. aripo* mass rearing was found faster for *en masse* production of the predator than *in situ* field rearing (Onzo *et al*, 2005; Gutierrez *et al* 1987). The variations of the night temperatures in comparison to the day ones indicated that *T. aripo* would not be eliminated by the adverse effects. The greenhouse was found to retain and maintain higher temperatures of the day with

less extreme fluctuations. A similar case was found for the humidity regime, where the greenhouse conditions indicated lower but fewer fluctuations than the outdoor conditions, thus providing more stable conditions of near optimum for both prey and predator growth as was also shown by Yaninek *et al* (1989) and Onzo *et al* (2003a).

The predator-prey system density ratio of T. aripo and M. tanajoa indicated that M. tanajoa population decreases as its predator T. aripo increases (Yaninek et al 1989; Bakker and Klein 1992). In this study the initial predator-prey ratio was approximately 1:800, and it was likely that the prey growth would be affected by other underlying conditions like cassava leaf nutrient quality level and prevailing climatic conditions (Yaninek et al, 1989). However, the exhaustion of prey numbers was slightly over a month. The high consumption rate of M. tanajoa eggs by T. aripo (about 100 eggs per day) explains why M. tanajoa population density levels were declining so fast (Cuellar et al 2001; Onzo et al 2005). In an open cassava field in Eastern Kenya the results would have probably been different. The extreme temperature and humidity fluctuations would have probably lowered the effective suppression of M. tanajoa numbers by T. aripo, that is, it would have taken longer time to reduce the prey's population densities to near zero. What it means is that T. aripo would still have effected certain degree of control of M. tanajoa in Eastern Kenya's cassava fields though at lower level in comparison to the more humid and warm Coast region of the country. The usually prolonged hot and dry conditions of Eastern Kenya would translate into lower T. aripo population densities in the field in contrast to the Coastal fields (Zundel et al 2007; Onzo et al 2005). Consideration and comparison of the agro-climatic data from Coast and Eastern Kenya showed little mean yearly temperature difference with Eastern having a mean of 24 ° C and Coast having 26 ° C. However the relative humidity regimes showed a range difference of 10 %. This could not be considered a big difference were it not for being away from the optimum of 70 % for most phytoseiids (*Yaninek et al*, 1989). The Kenya Coast region has yearly mean relative humidity range of 71.1 % while that of Eastern Kenya is 61.6 % indicating the latter being in the threshold of lethal lower relative humidity regimes and probably dropping to even lower levels in most months of the year. Kariuki (personal communication) reports that *M. tanajoa* population densities having been reduced by *T. aripo* by between 75 % — 85 % (from high densities between 200— 350 *M. tanajoa* per leaf), at Coast and some Western Kenya fields.

For effective predator-prey ratio the greenhouse study has established that it would depend on the prevailing conditions in the field. If higher mortalities due to abiotic factors are expected then higher predator numbers would need to be released (Gichini et al 2008; Yaninek et al 1993). In this greenhouse study the introduction of T. aripo to M. tanajoa-infested plants in a ratio of 1:800 led to elimination of the prey within 4.5 weeks. Though this ratio was chosen for convenience any ratio could be analyzed for the required time for the predator to suppress the prey. Yet for this to be found effective consideration should be emphasized on the economic injury level (EIL) of M. tanajoa population density on particular cassava cultivars grown. Breeders and agronomists explain that the most critical stage of cassava crop root yield accumulation occurs within the first five months (Yaninek et al 1989; Mackame 1995). Thus the effective predator-prey ratio for introduction or release of T. aripo should be considered on the age of the crop, and the M. tanajoa population density present. Most classical biological control experts do not bother to consider the quantity of T. aripo numbers to be released in a field but are usually convinced that

with the right agro-climatic conditions matching those of the region of origin, the predator would grow in numbers in the presence of prey and suppress the pest (Yaninek et al 1989; Zundel et al 2007).

The results from this study have also shown that T. aripo was able to eradicate M. tanajoa from low introduction of one predator per plant apex in a short period of time. This led to controlling M. tanajoa from about 40 mites per leaf to zero within 4.5 weeks. The work by Cuellar et al (2001) on effective prey consumption showed T. aripo being more effective than most phytoseiids of Columbian origin. What would need to be measured is the time period a certain M. tanajoa population density causes damage of economic nature to a particular cassava variety, especially those being preferred by farmers in Kenya. This would lead to adjusting the predator-prey ratio of T. aripo on M. tanajoa pest at the time of release of the phytoseiid mite. In a hypothetical situation where such 40 M. tanajoa per leaf cause damage in a week's time period a strategy would be needed to increase predator-prey ratio to 25:800 (x 7) or simply by 1:224 to deter M. tanajoa damage to the cassava crop. In classical biological control situation, where prey and predator co-exist in the field effective control would be below economic injury levels. In most parts of the African Continent this is reported as having been achieved (Yaninek and Hanna 2003; Zundel et al 2007).

Chapter 4

4.0 GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

4.1 General Discussion

The studies in the laboratory on the effect of relative humidity on the growth and development of *T. aripo* have shown that where environmental relative humidity is low (\leq 40 %) high mortalities occur if the exposure is prolonged. The same study has shown that the optimum RH condition for the phytoseiid is moderate to < 90 % regimes (cf. Bakker 1993; Yaninek *et al* 1989).

The greenhouse experiment presented a situation of fluctuating conditions of hot day conditions and cold nights with RH ranges of 38—75 %. *T. aripo* multiplied by three times within a week and mortalities started occurring when prey numbers diminished. This was indicative of the fact that the open field conditions of most parts of Eastern Kenya paralleled by the greenhouse conditions were suitable for growth and development of *T. aripo* even if not as suitable as Western and Coast conditions of Kenya. What could be expected probably is lower numbers of the phytoseiid in Eastern Kenya in comparison to the more optimum conditions of Coast strip region which showed a less fluctuation trend of RH conditions.

The determination of an effective predator-prey ratio of *T. aripo* on *M. tanajoa* population density showed that starting with an individual *T. aripo* active and practically determining the control (elimination) period of a *M. tanajoa* population, it would enable estimation of a desired ratio of predator-prey system when the control

period is pre-determined. While classical biological control options is effective for long term period over seasons, the short term benefits occurring might not be clear from the beginning (Yaninek *et al* 1993; Onzo *et al* 2005). The long term benefits occur from one year and over stretching several years later covering both wet and dry seasons of the year (Yaninek and Schuthess 1993; Yaninek *et al* 1989).

T. aripo was released in Kenya Coast region in 1995 and Western region in 1996. Since the releases there is marked reduced populations of *M. tanajoa* pest in Kenya's Coast and Western regions. The persistence of this predatory mite in cassava fields in those regions has lead to higher yields (Kariuki personal communication) reported. The Eastern Kenya region cassava crop was reported to suffer high *M. tanajoa* damage levels of this pestiferous mite (Kariuki *et a*l, 2000). While one reason for dispersal of this predatory mite could be due to few cassava fields within a particular area, long periods of dry conditions of low relative humidity regimes could be a major reason (Zundel *et al* 2007; Onzo *et al* 2005). Such low altitude dry conditions for long periods results in low relative humidity in the absence of rainfall. This could lead to an arthropod organism like the phytoseiid *T. aripo* suffering high mortalities in the increased saturation vapour deficits (Chaudhury1994, Bakker 1993).

Though *T. aripo* is reported to be able to survive and persist in most agro-ecological zones cutting across the African Continent's tropical and sub-tropical region, it is not yet known how physiologically this phytoseiid mite copes with the challenge of body water loss in dry and hot sub-Sahara regions (Zundel *et al* 2007; Gaede 1992; Chaudhury 1994). The physiological adaptations suggested as helping the phytoseiid group of spider mites in coping with advance conditions of low relative humidity include increased feeding on the abundant prey of *M. tanajoa*, conservation of

metabolic water waste and most important: absorption of water from the air as suggested by other workers (Zundel *et al* 2007; Gaede 1992). The absorption of water from the air by *T. aripo* integument is possible when ambient humidity is sufficiently high. The Coast region of Kenya is known to be warm and humid throughout the year and *T. aripo* has since continued to persist on cassava plants in farmers' fields (Kariuki *et al*, 2002). The eastern region of the country presents a mosaic of different agro-ecological zones of different rainfall amounts and of varied frequency of rainfall in the two different bio-modal rainfall seasons. Generally the eastern region is hot and dry in most months of the year. Depending on the seasons of the different months of the year, each region exhibit different relative humidity regimes, depending on the rainfall amount and frequency.

The phytoseiid group of the order Acari to which T. aripo belongs have been found to have a shorter saturation vapour deficit tolerance spectrum than their prey of the phytophagous group of the family Tetranychidae (Bakker, 1993). This explains why most phytoseiids shipped from Latin America and released on the African continent cassava fields to control M. tanajoa of the Tetranychid group were not able to get established at the release sites and disperse to other regions where cassava is grown and the pest present (Yaninek and Schuthess 1993; Yaninek et al 1993). From the initiation effort of classical biological control by the International Institute of Tropical Agriculture (IITA), in collaboration with other international institutions like Empressa Brasieleira Pesquisa Agropecuaria (EMBRAPA), of Brazil, and Centro International de Agricultura Tropical (CIAT) of Columbia. Earlier phytoseiid strains from African Continent Columbia did establish in the the not and Brazilian strains showed a higher tolerant ability on the African Continent agroclimatic conditions with species like T. limonicus reportedly established in Burundi

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and Benin (Yaninek et al, 1993). All this classical biological control approach was based on climate matching of the source of origin of the predatory mite from South America to the African Continent areas to be released. As of today *T. aripo* (De Leon) is reported as the most successful of all phytoseiids released from 1980s to 1990s to control *M. tanajoa* pest in Africa (Zundel et al 2007; Onzo et al 2005; Yaninek and Hanna 2003). Only that *T. aripo* seemed to disperse at lower pace in the Eastern Kenya region where cassava crop suffers heavy damage from *M. tanajoa* causing leaf defoliation in the dry months of the year (Githunguri et al 1984; Kariuki et al 2000; Yaninek et al 1989). More releases of *T. aripo* to any other parts of the country where *T. aripo* is not present and where cassava fields are isolated will be expected to indicate some level of establishment of the predator. Survey work carried out 1999-2003 by Kariuki et al (2004) showed *T. aripo* was not fully established in most cassava fields in Kenya (Fig. 4.1).



Fig 4.1: Map of Kenya showing T. aripo prevalence areas in surveys of 1999-2003 (Source: Kariuki et al 2004)

Of all reasons given for slow dispersal and less persistence of T. aripo the unfavourable climatic factors like relative humidity in the hot and dry low land Savannah region stands out as the most tangible (Zundel et al, 2007). The report of this study in Chapters 2 and 3 has evaluated relative humidity phenomenon and found that indeed relative humidity has critical effect on the survival of T. aripo. Laboratory study in Chapter 2 of this report has shown that T. aripo life stage growth was not found to be much affected by low or high relative humidity regimes. But at least the fecundity level of T. aripo was negatively affected by low relative humidity of less than 45 %. This ended up not only lowering egg-laying by females, but also high mortalities of the adult T. aripo within a short period of time. While optimum conditions were identified within the moderate relative humidity regime of 67 %, still T. aripo was found to increase in numbers in near saturation levels of equal or less than 90 %. Only that the juvenile stages suffered some mortalities as compared to the moderate relative humidity levels. This could be naturally taken care of by the field conditions unlike the laboratory ones where the experiment was carried out (Zannou et al 2007; Gnanvossou et al 2005). The results, of T. aripo mass rearing in greenhouse has proved that the Eastern Kenya colder Machakos areas are able to support the predatory mites development and growth on suitable cassava varieties and that the determining factor is food availability on the cassava plants. This also highlighted a fact that the prevailing relative humidity regimes can still support T.aripo persistence in cassava fields of the region.

The evaluation of an effective predator-prey ratio in the greenhouse has shown that any choice of *T. aripo* initial introduction number in the field would dictate the time period it would take to control *M. tanajoa* populations already in that particular field. It also quantified the need for the person implementing the biological control by *T. aripo* to have an idea of *M. tanajoa* population density capable of causing injury of economic importance to a particular cassava variety. This is one area which is not much explored and possibly each cassava variety would likely have a different population level for certain economic injury level (EIL) from other varieties. This is by assuming that each variety has some level of *M. tanajoa* resistance or tolerance different from other varieties. Since *T. aripo* is already effecting control of *M. tanajoa* in Kenya cassava fields, what could improve its performance in the fields is planting of cassava cultivars with preferred attributes to enhance longer *T. aripo* numbers on the cassava plants.

The greenhouse study has enabled hypothesizing that by adjusting predator-prey ratio to about 25 times, that is, 1:224, of *T. aripo* to *M. tanajoa* of a population would be eliminated within a week and probably stop damage on cassava plants reaching economic injury levels. A more representative picture would be established, once *T. aripo* is released in most cassava fields in the varied mosaic of agro-ecological zones of Kenya and beyond (Fig.4.2).



Fig. 4.2: Map of East Africa showing the Agro-ecological zones (green) for cassava cultivation potential areas and where T. aripo dispersal is possible in effecting biological control of cassava green mite (Source: Kariuki et al, 2004)

From this study the generated information on the environmental requirement for the mite *T. aripo* indicate that Kenya cassava field areas like Eastern Kenya will likely continue to suffer some *M. tanajoa* damage, reducing root yields even in the presence of the predator due to the low relative humidity regimes which affects its population build-up. Still some level of control will be expected where *T. aripo* is present due

to reported high prey consumption (Cuellar *et al*, 2001), To decide on the right area or region for *T. aripo* release in any part of the country, yearly meteorological data can be collected and its range considered matching it with the laboratory results in Chapter 2, and more suitably with the predatory mite's place of origin, the North eastern Brazil. The greenhouse experimental experience has further demonstrated that relative humidity fluctuations enables *T. aripo* to recover from water loss unlike the continuous prolonged laboratory conditions. This indicates that *T. aripo* is likely to establish in most marginal areas of Kenya though probably in lower density levels in comparison to warmer Coast and Western regions.

4.2 Conclusions

This study on effects of relative humidity on the growth and development of *T. aripo* has demonstrated that this climatic factor is important in considering the choice of this predatory mite for control of *M. tanajoa* on the cassava fields in Kenya. This became clearer due to the fact that Kenya cassava agro-ecosystems fall in the large context of cassava crop being able to grow in most parts of the country where moisture is adequate as in most of the tropics (Yaninek and Schuthess, 1993). Kenya's agro-ecological zones from Coast region across the highlands to the Western lake region mainly are able to accommodate production of cassava crop. The major pest, cassava green mite, *Mononychellus tanajoa* Bondar, *sensu lato*, is able to develop and grow increasing in high populations within the allowable dry and hot / warm short spells possible due to the phytophagous mite's higher fecundity rate of 60 eggs as compared to its predatory mite *T. aripo's* 48 eggs and a shorter oögenesis of one day while the predator takes four days (Yaninek *et al*, 1989).

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Since some cassava cultivars are able to show tolerant characteristics to the phytophagous pest attack it is possible for the farmer to always reduce losses by planting a good number of such varieties (Yaninek and Schuthess, 1993). The Eastern Kenya farmer would benefit a lot by being informed well of the most suitable cassava varieties whose plant apices harbour *T. aripo* and have tolerance to *M. tanajoa* attack throughout the year of production. This service is possible through well trained entomologists, breeders and agronomists in local and international institutions within the country.

The fact that *T. aripo* can be mass reared in green house with no humidifiers or no heaters present is an easier *T.aripo* multiplication alternative for large numbers to release to Kenya's cassava fields. The findings that the varied and fast fluctuating conditions of Eastern Kenya gives some positive expectation of *M. tanajoa* populations density reduction by *T. aripo* even if not yet reaching below economic injury levels are encouraging. At least *M. tanajoa* individuals on cassava plant upper stratum region will be suppressed to some level, giving less damage to cassava plants which fall under heavy damages in the dry-hot seasons of the year. Breeders of cassava would be expected to include *T. aripo* supportive plant characteristics to new cultivars so that the predatory mite persists and disperses in the region. In this regard, some principles have been learned in the use of predators in the biological control management of pests such as the eastern region of Kenya. These guidelines are:

 Know the life cycles and biology of both natural enemies and pests, so all cultural and other control practices can be as beneficial to natural enemies and as harmful to pests as possible.

- 2. The need to keep up to date on pest populations in relation to changing economic injury levels, and on parasitization / predation rates and predator prey ratios, so that the proper measures can be taken to keep them favourable.
- 3. Biological control is not the answer to every thing, but the opportunity exists to do much more than has been done to date with cassava pests in Africa.

4.3 Recommendations

There is need to mass rear T. aripo phytoseiid mite and release it in areas where it has not been found persistent inclusive of some areas in Eastern Kenya. This should target different agro-ecological zones of eastern region and evaluate its persistent for a reasonable duration of at least over three years to determine performance of the predatory mite on the hill masses, low altitude areas and mid altitude region of the province and other marginal areas. Drought tolerant cassava varieties would probably sustain high T. aripo numbers in the field. The study on T. aripo population densities on wilted and fresh cassava apices has demonstrated that T. aripo prefers fresh tips due to higher transpiration rate of the cassava plant, creating suitable microclimatic conditions. Cassava crop being one of the crops which can give reasonable yield with erratic rains as global warming increases there is need to take care of constraints of seed unavailability and other socio-economic hindrance there upon. More farmers' need to be encouraged to grow cassava crop so that T. aripo predatory mite is able to disperse within and across cassava fields in eastern province. Later a survey on the persistence of T. aripo would be able to give more reliable estimate values of the persistence or non establishment of T. aripo in Eastern Kenya varied agro climatic conditions experienced across the landscapes. What needs also to be measured is how

much yield loss will be expected from the area per each cassava variety as compared to Coast and Western Kenya regions.

Being a drought resistant / tolerant crop cassava would always be able to give the farmer a good seasonal yield unlike other crop types like cereals and legumes in times of erratic rain seasons, hence the need for extension personnel to encourage farmers in Kenya to grow the crop. Cassava varieties found to have unique characteristic like tolerance to diseases and having extra-floral and acarodomatia suitable for *T. aripo* harbouring should be encouraged for adoption by farmers in Eastern Province and beyond the country's cassava fields for conservation of biodiversity of beneficial biocontrol agents.

If farmers fully adopt growing cassava crop in Eastern Kenya and marginal areas then food security would be achieved with food rations from Government and Non government organizations being a thing of the past. This will be possible with *T. aripo* maintaining *M. tanajoa* below economic injury level status, resulting to higher root yields of cassava crop. Farmers will be able to process the root produce to various products like oil roasted chips and gari for flour which has several immediate uses as whole or proportions with other cereal or legume flour ingredients for ugali, cakes and bread products.

A good number of farmers complain of not getting the right cassava seed. This is where researchers and extension people, need to come in to help in identification, of varieties with the desired agronomic and *T. aripo* supportive-attributes. Seed is a basic starting point to increase cassava production and should be solved effectively for the

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benefit of the farmers. A strategy to come up with a higher seed production of the right varieties will lay the foundation for higher cassava production. A system where farmers are contracted to produce large quantities of cassava seed to supply to others willing to engage in cassava production will solve the problem of seed scarcity. This calls for some money budgeted and acquired for this initial activity towards sustainable cassava production in most parts of the country. Sourcing for and establishing reliable market within the agro-industry will ensure cassava entrepreneurial production with the crop as a permanent feature in Kenya fields and *T*. *aripo* giving protection against *M. tanajoa* damage.

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