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**Seasonal abundance and diversity of mites in
Coffea arabica L. at Beaver Creek Coffee Estate,
South Africa**

By

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DECLARATION

I, Nontobeko N. Chikomo declare that this dissertation is my own, unaided work. It is being submitted for the degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

A handwritten signature in black ink, consisting of a series of loops and a long horizontal stroke extending to the right.

(N. Chikomo)

Dedication

I dedicate my dissertation work to my family and friends. A special feeling of gratitude to my loving parents, Mr. Dumezweni and Mrs. Sibonakele Chikomo, whose words of encouragement and push kept me going. My brother Kukhanya Chikomo and to my daughter Leano Mikayla Chikomo who is very special to me.

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Abstract

The presence of multiple species of mites inside the leaf domatia of *Coffea arabica* is well documented by various studies. This study examined the influence of seasonal changes on the abundance and diversity of mites in the leaf domatia of *Coffea arabica*. The study furthermore documented the species of predatory mites that were associated with coffee. The results of the study showed that there was a significant variation in the abundance of mites due to changes in season. Mite counts were significantly higher in spring followed by autumn and lowest in summer. There was no correlation between the number of mites and temperature and relative humidity. Therefore, this study could not establish what drives the seasonal changes in the mite populations and we postulate that this was because we did not measure the microclimate of the individual trees we sampled. This would have given us more accurate data on the temperature and relative humidity experienced by these mites. The Shannon-Weiner Diversity Index was found to be highest in summer and lowest in winter. The Phytoseiidae, Tydeidae, Stigmaeidae, and Tenuipalpidae were found to be the predominant families in this study. This study is one of the few studies in South Africa to directly investigate the effects of seasonal changes in mite abundance, and could potentially open avenues for further research, particularly on what seasonal parameters drive the mite population changes. We recommend that future studies use Ibuttons to get a true measure of the climatic variables that are experienced by the mites sampled at a tree level.

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Definition of terms

Predaceous	: Habitually hunting and killing other animals for food, preying on other animals.
Arthropods	: Animals that are invertebrates and have appendages with paired joints, a segmented body, and an exoskeleton.
Phytophagous	: Species that feed on plants, and herbivores.
Aeroplankton	: These are life forms that float and drift in the air.
Morphotypes	: Any group of individuals of various kinds belonging to the same species that make up a population.
Translucent	: Semi-transparent, allowing some light to pass through.
Mycophagous	: Organisms that feed on fungi.

CHAPTER 1: GENERAL INTRODUCTION AND LITERATURE REVIEW

Introduction

Leaf domatia, also known as acarodomatia; are found on the underside of leaves and are described as very small structures present in the veins of axils of angiosperms (Romero et al., 2011). Agrawal et al. (2000) describes leaf domatia as tiny structures produced by many plants that typically protect arthropods that may be beneficial to the plant (Figure 1). These structures are populated by mostly mites, especially the predaceous ones. Several studies have shown that the existence of leaf domatia on plant leaves has a bearing on the number of mites and diversity found on its leaves (O'Dowd, 1994; Situngu et al., 2020). Furthermore, according to Matos et al. (2006) natural enemies of phytophagous insects form mutualistic relationships with plants. This is also the case in coffee trees, the domatia act as important sites for mite reproduction and development (O'Dowd, 1994); Situngu et al., 2020). Studies by Mineiro et al. (2006) and O'Dowd (1994) observed that, despite the presence of phytophagous mites, most of the mites in coffee leaf domatia were predatory. The leaf domatia of coffee has well-developed pit-type domatia that has been observed to house more predatory than pest mites (Mineiro et al., 2008; Ferreira, 2011). However, the mite *Oligonychus ilicis* McGregor (Trombidiformes: Tetranychidae) can also be found and is the most prevalent pest in many countries that cultivate coffee. (Romero et al., 2011; O'Dowd, 1994). Most studies that recorded predatory mites in *Coffea arabica* were carried out in Brazil and other parts of the world with few in Africa and South Africa in particular. Predatory mites are of so much interest as they are a beneficial group due to their key role in integrated pest management (IPM) as they help in keeping the pest population under control (Sadanandan, 2006).



Figure 1: Leaf domatia found on the underside of leaves. The domatia in this picture are whitish hair-tufts.

Sudo et al. (2010) carried out a study in Kyoto, Japan to investigate the Seasonal variations in the population of foliar mites on *Viburnum erosum* Thunb (Dipsacales: Viburnaceae), a deciduous shrub, the results showed that the phytoseiid mites were found in the domatia of the plant from May to November (Summer to Autumn). While the eriophyid mites were found only in spring and autumn. In an earlier study conducted in Northeastern Italy, Duso et al., (2004) observed changes in the phytoseiid mite population over the course of the year, with a high population in hedgerows from mid-spring to early summer (April to late June) and a low population in Autumn in Italy (September and October). The hedgerows were a combination of secondary hedgerows and natural ones and the study noted that there was more abundance of pollen on the natural hedgerows and so was the population of the phytoseiid mites. The population densities of mites rely upon temperature and rainfall. However, whose results do not permit us to reach a conclusion regarding any seasonal patterns in general (Kamczyz, 2022). The above results and assertions suggest the existence of seasonal changes, though narrow, in mite abundance in a wide range of plants. In this study, we hypothesize that climatic factors like temperature and relative humidity influence mite. To date no study on South Africa has directly investigated seasonal changes in mite abundance in *Coffea arabica*. Hence this knowledge gap that this research seeks to

fill. This study also investigates whether there are any changes in the diversity of mites due to changes in season.

1.1 *Coffea arabica*

Coffea arabica Linnaeus (Rubiaceae) originates from Ethiopia in East Africa (Ferreira et al., 2020). This plant is of economic importance as the coffee beverage is consumed all over the world (Ferreira et al., 2020; Krishnan, 2017). Currently, Brazil is the world leader in coffee production with approximately 212 million kg of which 70,5% is *Coffea arabica* (Peixoto et al., 2017). In comparison with Brazil, South Africa lags far behind in terms of coffee production to an extent that by 2014, the national yield stood at only 3500 bags (Situngu et al., 2020; Agricultural Research Council).

Coffee is believed to be one of the most valuable export commodities worldwide, and it is argued that it ranks second behind petroleum products in the world market (Philippe et al., 2009; Krishnan, 2017). The only two coffee species that are believed to be important economically are *Coffea canephora* and *Coffea arabica*. L (Melese & Kolech, 2021; Krishnan, 2017). *Coffea arabica* is a dicotyledonous tropical bush tree that is evergreen and can grow to a height of 8 to 10m (Melese & Kolech, 2021). The optimum temperature for the growth of Arabica coffee is between 18°C and 21°C, while the optimum rainfall ranges between 1500 mm and 2000 mm per year/growing season. In view of these climatic requirements of the crop and its association with mites, there is need for further investigation to determine in which seasons of the year the mites are more abundant in *Coffea arabica*.

Among some 90 species of the genus *Coffea*, two of those species dominate the world coffee trade and these species are *Coffea arabica* and *Coffea canephora*. Both coffee species share similar growth requirements with numerous forest trees and crops making them more susceptible to growing in agroforestry ecosystems. *Coffea arabica*, which is the focus species for this study, has elliptical leaves which bear a distinct pit-type domatia in their veins of axils (Romero et al., 2011; Situngu et al., 2017). According to the Department of Agriculture, Forestry & Fisheries, Coffee has white pinkish flowers that are arranged in glomerules of 3 to 16 and are grouped together in the axis. According to Pohlen et al., (2010) coffee plant is

a tropical bush tree, with a main stem that is upright growing, and horizontal branches. For successful production, coffee requires extremely specific environmental conditions, but the crop can grow under both tropical humid/sub humid highlands and humid lowlands.

1.2 Plant mites

Predatory mites are distinct species of minute arthropods important for biological control of insects and other mites (Zhang, 2003). Mites are minute in size with an average body length ranging from 100 μ m to 5mm. They are worldwide in distribution and are considered the second most diverse group of living organisms after insects (Nazar et al., 2020; Salmane & Brumelis, 2010). Mites are easily distinguishable from other arthropods because of their lack of antennae, mandibles, and maxillae (Finch et al., 2014). The life cycle of mites depends to a substantial extent on the availability of food and temperature (Nazar et al., 2019).

Mites colonize most abiotic and biotic habitats (Nazar et al., 2020; O Connor, 2009) and they are a major component of the fauna of both forests and cultivated crops (Kiefer et al., 1982; Gerson et al., 2008). They are abundant in aeroplankton and there is a great variation in the diversity of species and the nature of their assemblages (Gwiazdowicz, 2021). According to Nazar et al. (2020) unlike insects, mites have received less attention from biologists because of their body size, for example at the time of Linnaeus, only 30 species were described. However, by 2019, there were an estimated 500,000 different species of mite, with only about 50,000 having been described (Nazar et al., 2020).

1.3 The plant-mite association

Predatory mites inhabiting leaf domatia provide benefits such as feeding on herbivores and pathogens which may attack the plant species, and this is called a plant-mite defense mutualism (Romero and Benson, 2005; Situngu, 2018). Romero et al. (2011) state that principal members of the leaf domatia are predaceous mites, primarily of the Stigmaeidae and Phytoseiidae families, and fungivorous mites. These mites decrease plant damage which may be caused by pathogenic fungi or phytophagous mites. It has been found that mites

provide some relief by reducing the coffee leaf rust fungus (*Hemileia vastatrix*) which leads to increased overall fitness of the plant.

Plants with leaf domatia benefit by getting protection and reduced damage from herbivory caused by phytophagous mites and reduced disease from pathogens. Other benefits that plants with leaf domatia receive include an increase in fruit and seed production. Agrawal et al. (2003) conducted an experiment in which a simulated leaf domatia was added to the plant and the host plant performance was manipulated by inducing resistance by carefully exposing seedlings to spider mite herbivory in the early season. The experimental leaf domatia-treated plants had improved reproductive performance and developed resistance. Agrawal (1997) revealed that cotton plants which were supplied with artificial domatia had a greater population of predatory mites, a decrease in the number of herbivores, and a higher cotton yield as compared to plants that did not have acarodomatia. Romero et al. (2011) state that leaf domatia do not have any physiological functions. However, a study by Tilney et al. (2012) concludes that physiological function and facilitate the exchange of compounds between plants and mites.

It has been hypothesized that plants with domatia also provide a nursery and a place to molt. Predatory mites' survival is said to increase because of this interaction, which increases herbivore predation and even of the hyphae of plant-pathogenic fungi. (Ferreira et al., 2010). According to Ngondya *et al.* (2011), mites inside domatia are usually less visible to enemies and less vulnerable to diseases. They experience more hospitability in the domatia (Ngondya et al., 2011). Romero et al., (2011) indicated that one other benefit of the leaf domatia was that they function as a barrier between predator-prey oscillations. Leaf domatia cause phytophages mite to increase in number and when they increase, they then spread out onto the surface of the leaf in a continuous flow, which, in turn, provides predators with dependable food (Romero et al., 2011). It was also found that eggs of predaceous mites in domatia did not experience any parasitism (Ngondya et al., 2011).

It is also said that there is an interaction between predatory mites and entomopathogenic fungi and these are incredibly significant in the control of insect pests (Wu et al., 2016). It was also revealed that *Beauveria bassiana* Balsamo (Cordycipitaceae: Hypocreales) can also

be used as a substitute to the regular pest management to be biologically compatible with predatory mites, as *B. bassiana* has been shown to have no pathogenicity to predatory mites (Wu et al., 2016).

Duso et al., (2003) revealed that when Downey mildew symptoms appeared on many leaves, the population densities of *Amblyseius andersoni* Chant (Mesostigmata: Phytoseiidae) and, to a lesser extent, *Typhlodromus pyri*, increased. The study further showed that *A. andersoni* populations were much higher on leaves with Downey mildew symptoms than on leaves without symptoms. Evidence further suggests that *A. andersoni* and *T. pyri* can develop and reproduce by feeding on both pollen and fungi (Pozzebon et al., 2005).

Tydeidae mite densities were also found to increase with the spread of downey mildew (Duso et al., 2003). When this occurs, it is then concluded that domatia contributes to the survival chances of these mites, which in turn results in an increase in the consumption of plant-pathogenic fungi, which also benefits the plant (Ferreira et al., 2009). Matos et al. (2005) found that domatia enhance predatory mite reproduction in low-humidity conditions and increases predatory mite consumption of phytophagous mites, thereby reducing attacks. While there have been studies that state that there is high reproduction of predatory mites in low humidity, some studies said otherwise. Messelink and Leman, (2020) suggested that extremely low humidity levels, about 50% of the predatory mites' eggs, particularly *Phytoseiulus persimilis* Athias-Henriot and *Neoseiulus californicus* McGregor (Phytoseiidae), die. Similarly, a report by Dutch cucumber growers also agreed that indeed the spider mites control often fails in spring when they experience low humidity (Messelink and Leman, 2020).

1.4 Types of mites associated with leaf domatia.

Phytoseiidae are abundant in domatia and are usually associated with phytophagous mites (Matos et al., 2006). Most mites belong to the Phytoseiidae, Bdellidae (Trombidiformes) and Stigmaeidae families (Trombidiformes) (O'Dowd, 1994). Predatory mites like *Euseius citrifolius* Denmark (Mesostigmata: Phytoseiidae) and *Euseius concordis* Chant (Mesostigmata: Phytoseiidae) are associated with coffee in Brazil. (Mineiro et al., 2008). In a study by Grostal and O'Dowd (1994), a total of two thousand seven hundred and twenty-one

mites were found on the leaves of the *Viburnum tinus* shrub (Dipsacales: Adoxaceae), and the predators that were found included Phytoseiidae (*Euseius elinae* and *Typhlodromus dossei*), Stigmaeidae (*Agistemus* sp. and *Zetzellia* sp.), Anystidae family indet., and the Cunaxidae (*Rubrascirus* sp.). In an experiment that was conducted on a *Cupania vernalis* forest tree, 522 arthropods were found inside the domatia of those leaflets, 98.5% being mites, of these arthropods 12,3% were predacious from the Phytoseiidae and Stigmaeidae families, the other 3.6% were fungivores. Eriophyidae were also found and lastly 1.3% of the arthropods were identified to be omnivores (Romero and Benson, 2005).

1.5 Seasonality of mite populations in plants with leaf domatia

It has been observed that mite communities that live in plants are impacted by several environmental factors such as maximum and minimum temperature, precipitation, relative humidity, and sunshine. (Rosado et al., 2015; Rezende, 2016). An investigation was made into how temperature affected the number of predatory mites on some cotton plants. (Waqas et al., 2014). The findings revealed that the number of phytoseiid mites increased with the temperature. Kolokyatha et al., (2011) revealed that elevated temperatures shortened the developmental time of the mites while low temperatures lengthened the developmental time of the mites. This, therefore, implies that in seasons of elevated temperatures, the phytoseiid mites are expected to be in abundance.

The survival of predatory mites during the dry seasons, in the tropics is negatively influenced by low relative humidity (Zundel et al., 2009). In their study on cassava, they found that the abundance of predatory mites was greater in humid areas. Similarly, a study by Mutisya et al. (2017); carried out in Kenya; investigated the effectiveness of the predatory phytoseiid *Typhlofromalus aripo* DeLeon., in the management of cassava green mite (CGM), *Mononychellus tanajoa* (Trombidiformes: Tetranychidae), and found that the phytoseiid *T. aripo* suppressed the population of CGM by 45% in dry hot areas and by 64% in warm humid zones.

The presence of fungal flora on leaves was seen to affect the fluctuations in mites seasonally as some of these mites depend on fungi as food source, with high populations of mites

recorded in winter and low populations recorded in spring (Situngu and Barker, 2017). Addison et al. (2000) found a similar and interesting finding and noted that the build-up of the predatory mites *Typhlodromus pyri* and *Zetzellia mali* was correlated with summer abundance of pollen on apple plants.

In a study conducted in Northern Italy, it was discovered that predatory mites of the family Phytoseiidae increased in density in the late summer, when a significant proportion of the leaves displayed symptoms of downy mildew (Duso, 2002). Vermaak (2019) studied the variety and ecology of mites in South Africa's Western Cape vineyards. The study found that only two predatory mites, *Euseius addoensis* and *Typhlodromus praeacutus*, were consistently present in commercial vineyards from November to May. In terms of phytophagous mites, *Brevipalpus lewisi* McGregor, was found to be abundant throughout the seasons. The other interesting observation was that samples from the organic vineyard block were observed to have a high diversity of predatory mites and no herbivorous mites.

A study was also conducted by Sudo et al. (2010) over a period of two years to observe the effect of seasonal changes in mites' communities on a deciduous shrub (*Viburnum erosum*). The results showed that during the sampling season that took place from March to November, fungivorous mites from the Winterschmidtidae and the Tydeidae families were found in the domatia from May to November (spring, summer, autumn) respectively. This appeared to suggest that mites from different families respond differently to seasonality. An investigation on seasonal mite abundance on three plants with leaf domatia in South Africa (Situngu, 2018) revealed that in *Tecoma capensis* (Thunberg) Lindl., there were two peaks of mite abundance, one in April –May (autumn), in November (summer). For *Rothmania globosa* (Hochst.) Keay, (Gentianales: Rubiaceae), the highest population of mites was recorded between October and May, while for *Gardenia thunbergia* L., the peak of mite abundance was observed in spring and summer between October and March. It is also argued that plant structure and leaf surfaces can influence the persistence and effectiveness of predators (Schmidt, 2014) and it may be inferred that leaf structure also play a role in regulating seasonal changes of mites.

A study to assess the effects of rainfall on the occurrence of the *Oligonychus sp.*, *Brevipalpus sp.* and *Polyphagotarsonemus latus* Banks, mite species, results showed that the phytophagous mite *Brevipalpus sp.* was found in abundance on both rainy and dry seasons (Mineiro et al., 2008). The mite *Oligonychus sp.* was found in abundance in the months of low rainfall. The study also noted that predatory mites of the Phytoseiidae family were influenced by rainfall. Results consistent with the above finding were also reported by Mineiro et al. (2008) who in their study of mites on coffee in Brazil, reported that *B. phoenicis* mites were more abundant in the dry periods of the year. However, the influence of precipitation on predacious mites was not as evident as both *Euseius citrifolius* Denmark and Muma *Euseius concordis* Chant were observed to be abundant across seasons (Miniero et al., 2008). Neto *et al.* (2010) also concluded that one of the primary factors that controls pest and predatory mite populations is rainfall. Overall, the mite's population in coffee cultivars differed with seasons, with a greater population recorded in dry seasons than in rainy seasons (Alexandra, 2008).

The results of another investigation on the changes in population of mites on coffee in Brazil (Luiz et al., 2007) showed negative correlation between temperature and the abundance of mites for certain species. The mite species *Zetzellia malviniae* was found to be negatively correlated with temperature (Luiz et al., 2007). Alexandra, (2008) noted that the majority of the variation in spider mite populations may be explained by abiotic factors such as temperature and relative humidity. Rainfall, temperature, and humidity are some of the key parameters used to define seasons in South Africa. The effects of these parameters explain the seasonal population variations of mites.

The literature reviewed provides an understanding of the association between mites and some of the plant species with leaf domatia however, it also arouses further questions. The study aims to investigate any seasonal changes in mite abundance and diversity in *Coffea arabica*. This knowledge is critical as it will provide an understanding of when the predatory mites are likely to be abundant in leaf domatia of coffee in South Africa and this will in turn allow us to forecast seasonality of mite pest explosion in coffee and plan accordingly. Furthermore, this understanding will be used to predict the best season for collecting samples for future research. Secondly, we want to determine which predatory mites are

associated with *Coffea arabica*. This understanding will help future research in that it will guide us on which seasons the predatory mites are in abundance hence enabling us to determine the appropriate season to implement an integrated pest management program.

1.6 Objectives

1. To collect and count the number of mite species found in the leaves of *Coffea arabica* growing at the Beaver Creek Coffee Estate over the seasons.
2. To identify the different mite species found in each season (spring, summer, autumn and winter) of sampling.
3. Survey predatory mites associated with *Coffea arabica*.

1.7 Research questions

1. Does the abundance of mites and their diversity change with season?
2. Is there correlation between seasonal parameters (temperature, precipitation, and relative humidity) and mite population densities and diversity?
3. Which predatory mites are found in abundance in the leaf domatia of *Coffea arabica* at the Beaver creek Coffee Estate?

CHAPTER 2: RESEARCH METHODOLOGIES

2.1 Study area

Beaver Creek Coffee Estate (31°02'39"S 30°10'56"E) which is located in Port Edward, in the province of KwaZulu Natal was my study site for the collection of the coffee plant samples (Figure 2). This farm was originally a banana farm and was changed over to cultivating coffee around 1984. The farm is in an area rich in nutrients, and the soil of this place is deep loamy and well drained. The type of farming methods practiced at Beaver Creek coffee farm include decreased use of herbicides, increased use of ground cover, introduction of more shade practices such as planting indigenous trees and planting the coffee in an east-west direction (Velosa, 2016). Their harvesting occurs over 50 days (about 1 and a half months) from February to October, with the most crops being picked from May to July. The farm started off with four trees and now has about 60000 coffee trees (Van Eeden, 2021).



Figure 2: A Google map of South Africa showing location of the study area. (Source: Google maps).

2.3 Climatic variables

The area generally experiences high temperatures and humidity all year round and approximately 1044mm of rainfall is received a year. For the project's duration, the farm received rainfall throughout the year, with the driest month being June with an average rainfall of about 0.3 mm. The greatest rainfall was received in April (autumn) with an average of about 19.8 mm (Table 1). The warmest month of the year was February with temperatures of about 27°C, while the lowest average temperatures occurred in June at around 12.7°C (Table 1) (South African Weather Service, 2022).

2.4 Field Sampling

Sampling was done in each of the four seasons of the year with the first one commencing in September 2021 to understand the influence of the seasons on mite assemblages and population. To exclude the effects of the edges, two transect lines were laid out at random deep in the cultivars (Figure 3). 20 meters was used to separate the trees chosen for sampling. Twenty individual coffee plants were selected randomly along the transect lines and tags placed on them to make it easy to identify the plants during the subsequent sample collections. From each of the randomly selected plants, ten leaves with properly developed leaf domatia were collected around the plant.



Figure 3 A picture showing my study area, Beaver Creek Coffee Estate farm.

2.5 Processing of leaves and microscopy

The sampled leaves were placed in labelled Ziploc bags, in a cooling container with a few ice packs to keep the mites sessile. On the same day of sampling, before the condition of the samples was affected, the sampled leaves were viewed under a dissecting microscope (Nikon SMZ460, C-LEDS) and the mites were extracted from the leaf domatia (Figures 4a and b) using a paint brush. The collected mite samples were placed on a stub and viewed using a Scanning Electron Microscope (SEM), (Phenom pure G6) for identification purposes and the images taken were processed using Thermoscientific Software. Some of the representative mites were mounted on microscope slides by placing a droplet of Polyvinyl Alcohol (PVA) mounting medium at the center of a clean microscope slide using a thin paint brush (Krantz and Walter, 2009). The air bubbles that were trapped in the medium were left to rise to the surface and dissipated and then using a pair of forceps, a clean coverslip of 12-15 mm in diameter was applied to the edge of the slide droplet and allowed it to fall gently into place.

Mites were identified to species by Professor Eddie Ueckermann of North West university. The slides were then labelled and viewed using a light phase contrast microscope (Olympus CX 23) and the images from the slides were taken using the AxioCam MRc and used in mite identification (Figure 13 and 14). The total number of mites from each plant were recorded by taking individuals of all growth stages. External morphological characteristics, such as dorsal and anal size and shield shape, number of setae on both the dorsal and anal shield. The setae and shape of legs, shapes of spermatheca, structure of sperm dactyl and aedeagus and the cuticle as skin texture were examined.

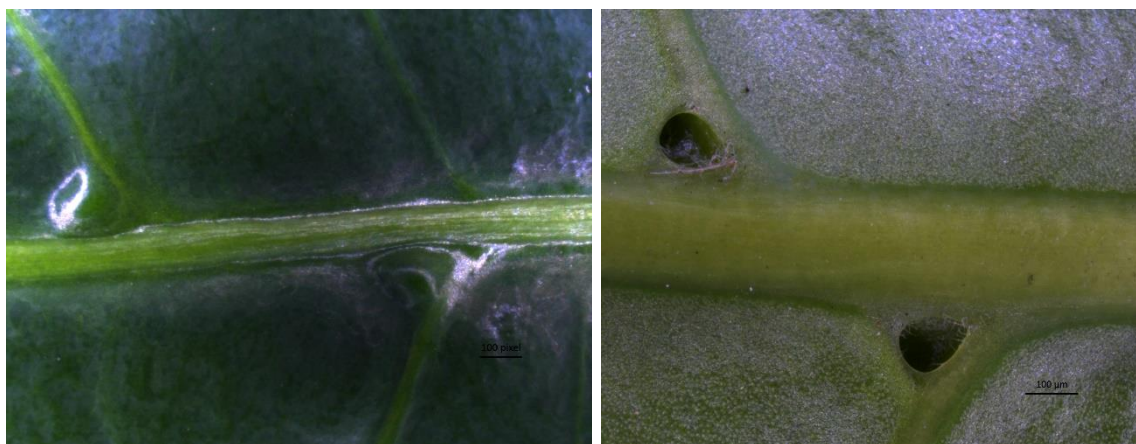


Figure 4: Abaxial side of the leaf showing the leaf domatia (a). Adaxial side of the leaf showing the opening of a leaf domatia (b).

2.6 Data Analysis

To determine whether my data was normally distributed, a Shapiro-Wilk normality test was conducted. I used a Kruskal-Wallis analysis to determine the significant seasonal variation in mite counts because my data was not normally distributed and two post-hoc tests, Tukey HSD test and Dunnett's test were done to determine where the significance lay. Climatic data in terms of the daily maximum temperatures, relative humidity, and precipitation for the days coinciding with the days of sampling was requested from South African weather service. This data was used to establish if there is a correlation between the climatic variables and the number of mite and diversity using a generalized linear model analysis was done to determine the correlation between the mite numbers per season and the climatic variables. Shannon-Weiner diversity index analysis was also conducted to measure the diversity of species per season. All the above-mentioned analysis was conducted on STATISTICA version 14.0.1 as well as software package R version 4.1.3 and R-Studio.

CHAPTER 3: Results

3.1 Mite abundance

Table 1 is a summary of the total number of mites from all the sampled leaves and gives details of average climatic variables of the preceding week of the dates of sampling. The seasons with the most mites were spring and autumn. In summer, the highest was at 23 while the highest for winter was 65 (Table 1). From this data, a box and whisker plot were then used to compare the means of mites from each season. A visual comparison of the medians on the box plots (figure 5) showed that the highest average number of mites was recorded in spring, followed by autumn and the least number was recorded in summer.

To determine whether my data was normally distributed, a Shapiro-Wilk normality test was used. The findings revealed that $W = 0.85281$, with a p-value of 0.007. This indicated that the data were not distributed normally. The number of mites was then compared between the months and seasons of sampling using a Kruskal Wallis test to see if there was a statistically significant difference. According to the findings, there was no statistically significant difference in the number of mites between the sampling months (P-value= 0.183). Even though the number of mites per season varied statistically significantly (P-value = 0.03). A box and whisker plot were then used to compare the means of mites from each sampling season.

Table 1 Summarizes the total number of mites collected from the leaves and the averages of climatic variables (maximum and minimum temperature, relative humidity and precipitation) of the week prior to the day of sampling.

Seasons	Dates	Number of mites	Maximum temperature	Minimum temperature	Relative humidity	Average precipitation
Spring	27/09/2021	67	21,83	16,61	61,14	1
Spring	16/10/2021	62	25,9	16,47	57,86	0,2
Spring	19/11/2021	51	24,58	18,07	67	9,24
Spring	17/12/2021	61	26	20,59	67,86	10,83
Summer	07/01/2022	23	25,33	19,96	78,29	2,11
Summer	26/01/2022	15	26,94	20,44	72,57	2
Summer	23/02/2022	17	26,54	20,93	74,71	2,04
Summer	19/03/2022	16	25,07	18,69	76,86	6,5
Autumn	09/04/2022	60	24,27	19,16	72,43	7,13
Autumn	26/04/2022	48	23,46	16,57	77,14	13,7
Autumn	13/05/2022	57	26,84	15,73	73	8,8
Autumn	25/05/2022	67	22,94	15,09	70,86	16,47
Autumn	15/06/2022	43	23,66	13,16	68,29	0
Winter	29/06/2022	24	21,53	12,69	63,86	0
Winter	13/07/2022	16	22,03	12,81	72	0
Winter	27/07/2022	24	21,29	13,43	65,43	4
Winter	10/08/2022	24	21,9	14,61	63,75	34,5
Winter	24/08/2022	65	22,09	12,03	64	0
Spring	07/09/2022	52	22,64	12,69	73,72	0

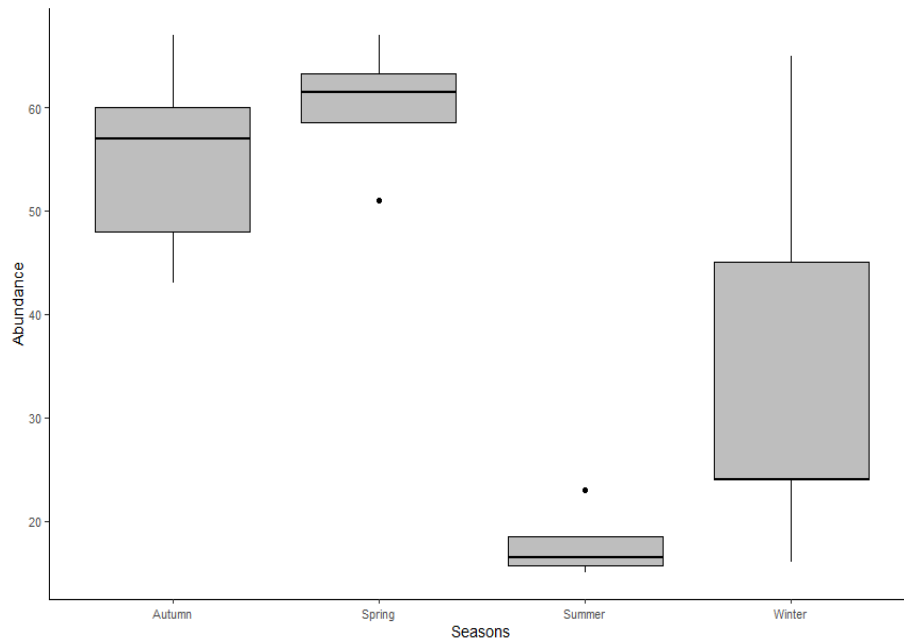


Figure 5: Box and whisker plots comparing the number of mites from each sampling season.

The box and whisker plot reveals that for the autumn month, the minimum number of mites collected was 43 while the maximum was 67. The upper quartile (Q3) for the data on abundance collected in autumn was 60 while the lower quartile (Q1) was 48, giving us an interquartile range (Q3-Q1) of 12. The median (57) was closer to the upper quartile suggesting that the data was negatively skewed. This implies that the mean was less than the median.

For the spring data, the minimum was 51, which was an outlier, while the maximum was 67. However, the median stood at 61.5 and was closer to the upper quartile of 64.5. This again suggests that the summer data was also negatively skewed. The interquartile range for the spring data was 8.5, implying that there was low variability in the data set. The abundance of mites was consistently high throughout, except for the outlier.

The box and whisker plot further shows that for the summer months, the maximum was 23 while the minimum was 15. In this season, the data were positively skewed with an

interquartile range of 4.5. This further suggests that the mite counts were consistently low throughout this season. There was therefore low variability in the data set.

The winter season had the most spread data where the minimum number of mites was 16 and the maximum was 65. These figures imply that in some instances mites were found in abundant populations during this season yet in other instances, they were found in extremely low populations in the same season. The data were positively skewed meaning that the mean of the data was greater than the median.

Table 2_ Dunnett's test showing results for significant differences in seasons of sampling.

Dunnett's test; variable Abundance: df = 15,000				
Seasons	Spring	Summer	Autumn	Winter
Spring		0,001693	1,000000	0,038610
Summer	0,001693		0,003453	0,390346
Autumn	1,000000	0,003453		0,100152
Winter	0,038610	0,390346	0,100152	

Additionally, a Dunn's post hoc analysis test was conducted to determine the significance level. According to the test's outcome (table 2), there was a significant pairwise difference between summer and spring, spring and winter, and summer and autumn.

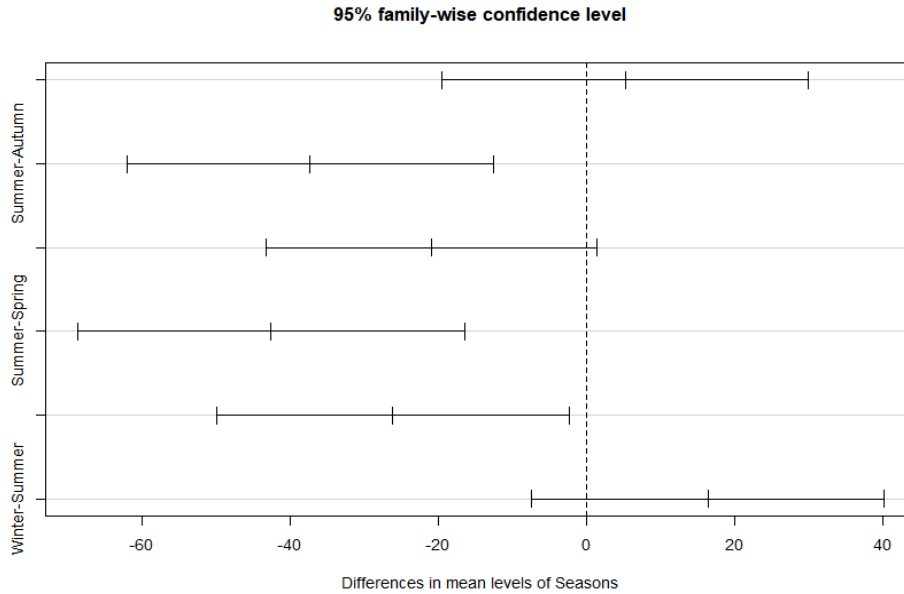


Figure 6 Confidence levels graph showing differences in mean level of seasons.

Tukey test-95% family-wise confidence level was also constructed to determine if there were significant differences in mean levels of seasons. From the graph (Figure 6), the vertical dotted line marks the point where the differences between the means was equal to 0. We note that the summer- autumn, and summer- spring seasons the vertical line does not cut the 95% confidence interval.

A generalized linear model (GLM) analysis was also done to evaluate whether the significant difference of mite counts between the months of sampling were driven by the different climatic variables such as maximum and minimum temperature and relative humidity and average precipitation recorded a week before sampling. Results showed that p-values obtained for minimum and maximum temperature, relative humidity and precipitation were all greater than significant value ($p = 0.05$). The linear regression graph for maximum temperature and abundance (figure 7a) showed no correlation between the two. This implies that maximum temperature had no influence on the abundance of mites.

Similarly, the linear regression graph for minimum temperature and mite abundance (figure 7b), the results also showed no correlation, slightly leaning towards a very weak negative correlation between the two variables. This further suggests that the minimum temperature had no influence on mite abundance.

On the other hand, the linear regression graph between relative humidity and abundance of mites (figure 7c) showed a negative correlation between the two variables. This seems to suggest that as relative humidity increased, the population of mites dropped and vice versa. Lastly a linear regression graph of average precipitation (recorded a week before sampling) and abundance of mites (figure 7d) showed a very weak positive correlation between the two variables. This seems to imply that the higher the average precipitation the higher the population of mites, even though very minor.

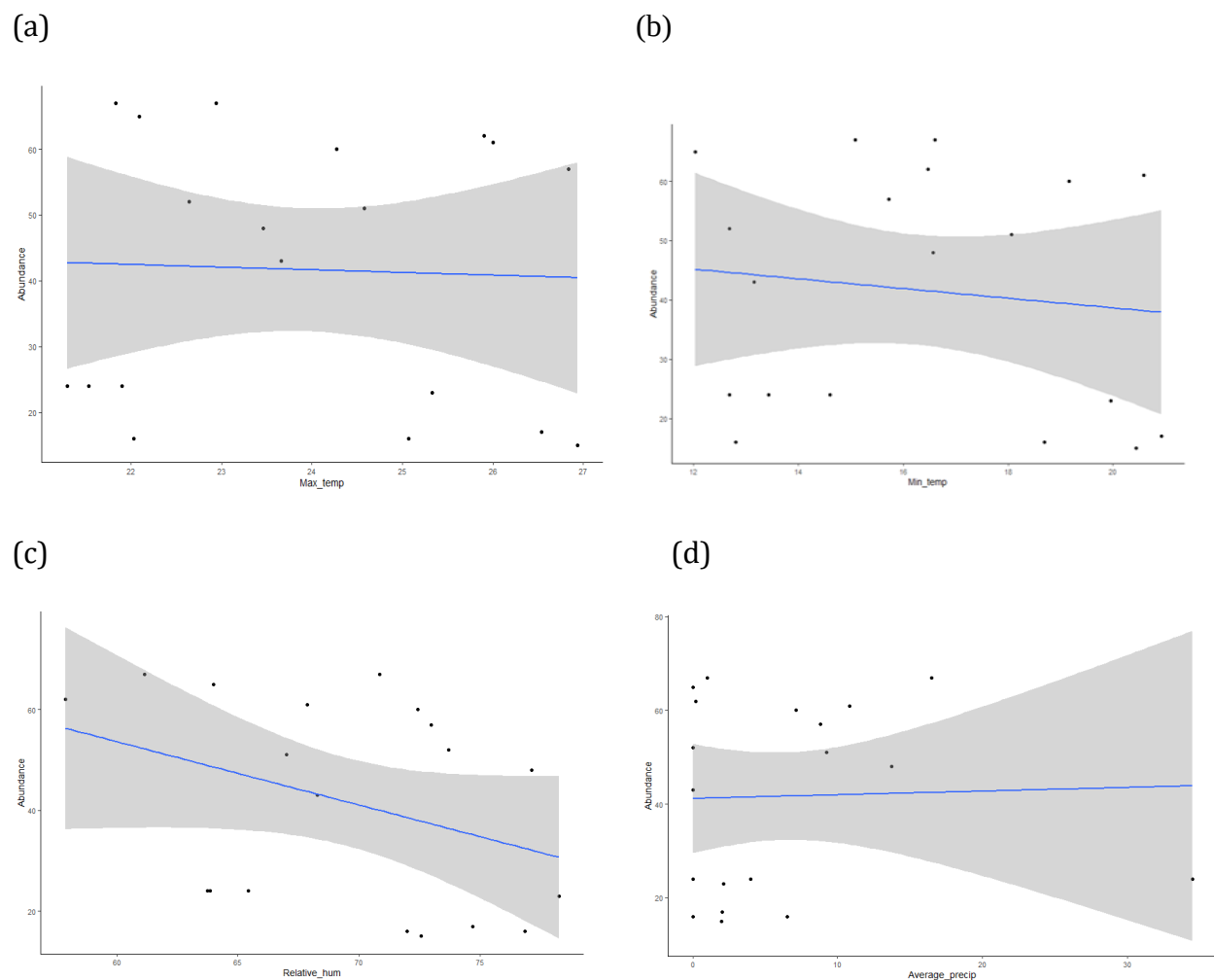


Figure 7a, b, c and d Multiple regression analysis of climatic variables vs number of mites.

3. Mite diversity in *Coffea arabica*.

From the table 4 below it is evident that across all the 4 seasons, mites from the family Phytoseiidae were the most abundant in *Coffea arabica* from my study site. This was followed by the Tydeidae, Tetranychidae, Tenuipalpidae, with the Stigmaeidae coming last.

Table 3 Number of mites per family, collected in each genus.

Family	Genus	Number of mites
Phytoseiidae	<i>Amblyseius</i>	46
	<i>Typhlodromus</i>	57
	<i>Neoseiulus</i>	45
	<i>Galendromus</i>	41
	<i>Phytoseiulus</i>	39
	<i>Euseius</i> (possibly <i>E. tutsi</i>)	35
Tenuipalpidae	<i>Tenuipalpus</i>	62
	<i>Brevipalpus</i>	68
Tydeidae	<i>Lorryia</i>	86
	<i>Tydeus</i>	81
Stigmaeidae	<i>Zetzellia</i>	52
	<i>Agistemus</i>	39
Tetranychidae	<i>Oligonychus</i>	22
	<i>Tetranychus</i>	119

It emerged that under the Phytoseiidae, the *Typhlodromus* was the most abundant genus species (22%) of the Phytoseiidae followed by the *Amblyseius* (17%). The least under the Phytoseiidae was the *Euseius* (13%). Under the Tydeidae family, only two were identified, the *Lorryia* and the *Tydeus* and there was not much of a difference in their abundance. The Stigmaeidae family had two which were identified, and these were the *Zetzellia* and the *Agistemus*. The *Zetzellia* was slightly more than the *Agistemus* in abundance (Table 6). Under the Tetranychidae the *Oligonychus* and the *Tetranychus* were identified. It was observed that the *Tetranychus* far outnumbered the *Oligonychus* with counts of 119 and 22 respectively. The *Brevipalpus* and the *Tenuipalpus* were the two species of mites identified under the Tenuipalpidae family. They were found in almost equal abundance.

A variety of mites were found in the leaves through the sampling period. However, the phytoseiid mites were the most common across all the four seasons. Notably though, was the fact that the Shannon-Weiner diversity index (Figure 8a) had minor variations from September to January. In February (summer) the index dropped to 0 and thereafter, it immediately rose again to about 1.2. From autumn to winter it continued with its minor fluctuations. Nevertheless, it was at its peak during the winter and in spring seasons in the months of June and November respectively. It was at its lowest in summer month of February. This explains why there was no significant difference in the diversity of mites between the sampling seasons according to the results of the Kruskal-Wallis analysis. In terms of seasonality of the different mite families, it can be observed from (Figure 8b) that the Phytoseiidae peaked in September (spring) and April (autumn), the Tenuipalpidae had a peak in August (winter) and March. A general pattern appears to show that in the season where the Phytoseiidae was high the Tenuipalpidae (phytophagous) also appeared to rise. On the other hand, the Tydeidae of mites was found throughout the sampling period. The Stigmaeidae had the lowest number of mites throughout the sampling seasons and the mites were not found in leaves in February (summer). The Tetranychidae, which are phytophages, had the highest peak in April (autumn) and had the lowest number of mites throughout the summer season, from January to March.

Table 4: Groups of mite families and genera and their feeding guild

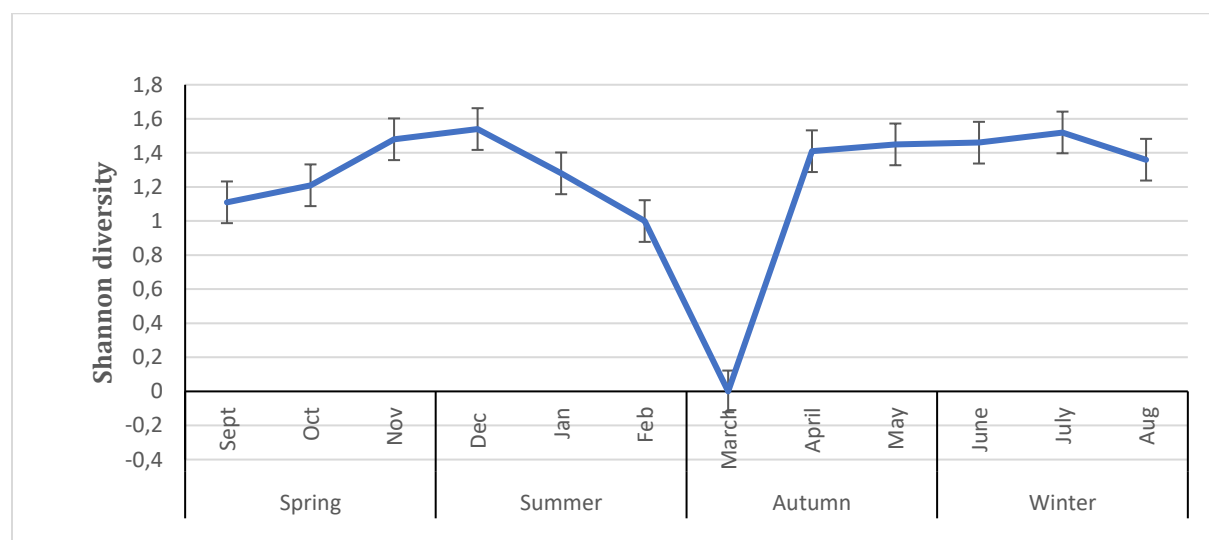
Mite species collected.	Feeding guild
Phytoseiidae	
<i>Amblyseius</i>	Predacious
<i>Typhlodromus</i>	Predacious
<i>Neoseiulus</i>	Predacious
<i>Galendromus</i>	Predacious
<i>Phytoseiulus</i>	Predacious
<i>Euseius (E. tutsi)</i>	Predacious
Tenuipalpidae	
<i>Tenuipalpus</i>	Plant feeding
<i>Brevipalpus</i>	Plant feeding
Tydeidae	
<i>Lorryia</i>	Predacious/fungivorous
<i>Tydeus</i>	Predacious/fungivorous
Stigmaeidae	
<i>Zetzellia</i>	Predacious
<i>Agistemus</i>	Predacious
Tetranychidae	
<i>Oligonychus</i>	Plant feeding
<i>Tetranychus</i>	Plant feeding

It was noticeable that the Tetranychidae had a rapid drop soon after its highest peak, this can be because Phytoseiidae mites had rapidly peaked as well causing them to drop. Once again Tetranychidae was low in abundance from June (winter) up to September (spring). It was nonexistent from January to March (summer to autumn season). The Tetranychidae

population rose sharply between February and March to its peak. The Stigmaeidae family was not found in abundance throughout the sampling period but its peak of approximately 20 mites was observed in December (summer). Its lowest population of zero mites was recorded in February (summer).

The Tydeidae were the only family of mites found throughout the sampling period. It reached its peak in April (autumn). It was not a hugely abundant mite family with its peak around 25 mites. The Tenuipalpidae was low in abundance from August (winter) to October (spring) to summer. In February, and between September and October, the Tenuipalpidae species was not found in the leaves. Its population started to rise from March (autumn), and it approached its peak in April (autumn). As if it were in response to rise in the population of the Tenuipalpidae, the abundance of the phytoseiid also rose sharply between March and April to its peak as well (Figure 8b). We suspect that the Phytoseiidae were predators of the Tenuipalpidae, and this abundance was in response to the availability of food. We suspect that the abundance of Tenuipalpidae, being a plant feeding mite could have been suppressed by predation by the phytoseiid mites (predatory). What remains unclear is why the majority of families of mites except the Tydeidae were not found in leaf domatia in between February and March.

(a)



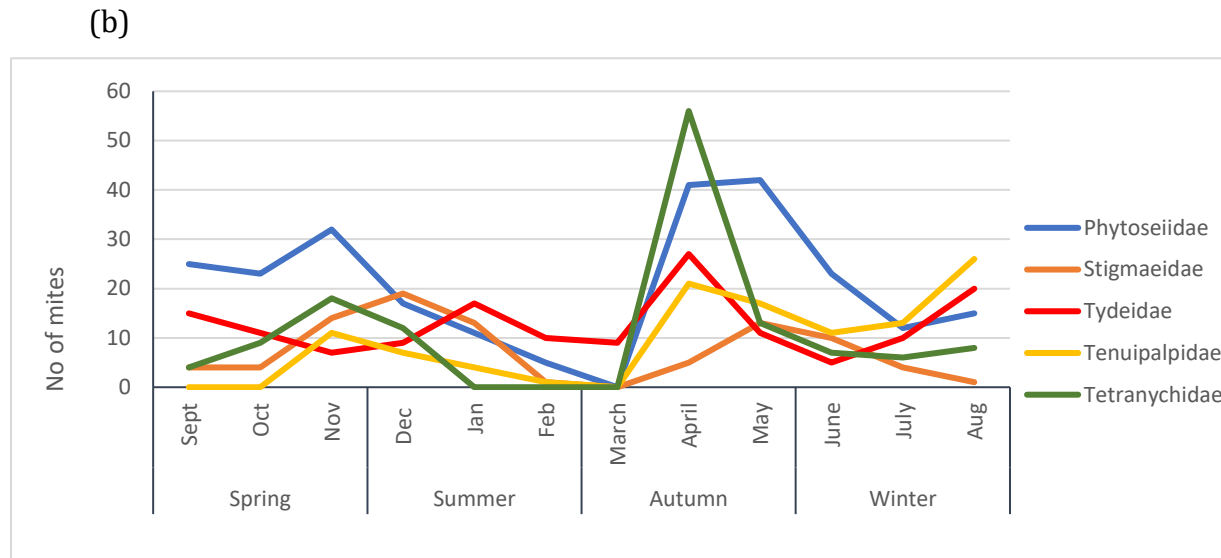


Figure 8 (a) Shannon-Weiner diversity index and abundance of different species types. (b) Different morphospecies abundance.

To determine mite abundance by species or the diversity of mites, a Shapiro-Wilk test was done to evaluate whether my data was normally distributed. The results from the test tell us that $p\text{-value} = 6.346e-09 > \alpha$, which states that the distribution is not normal. A Kruskal-Wallis rank sum test was then used to determine if there was any significant difference in the abundance of mites between the different mite families. The results gave us $p\text{-value} = 0.006117$. A Box and Whisker plots (Figure 9) were drawn to give a picture of the abundance of various species of mites. For the Phytoseiidae family the maximum population recorded was 32 while the minimum was 0. The median was 10.5 while the interquartile range was 17. Data for the Phytoseiidae was positively skewed and more widely spread than the rest of the mite families. On the other hand, the Stigmaeidae family had a maximum of 19, which was an outlier and a minimum of 0. The box and whisker plot for this species showed a near normal distribution with the median centrally positioned. The data for the Stigmaeidae family was more compact suggesting that the data were less spread.

The Tenuipalpidae family had a maximum of 19 a minimum of 0. The maximum for the Tetranychidae was 47, which was an outlier while the minimum was 0. The box plot for the Tetranychidae family shows that data was positively skewed. The other mite family analyzed

was the Tydeidae which had a maximum of 16 and a minimum of 2. In terms of comparison of medians, this mite family was second to the Phytoseiidae family.

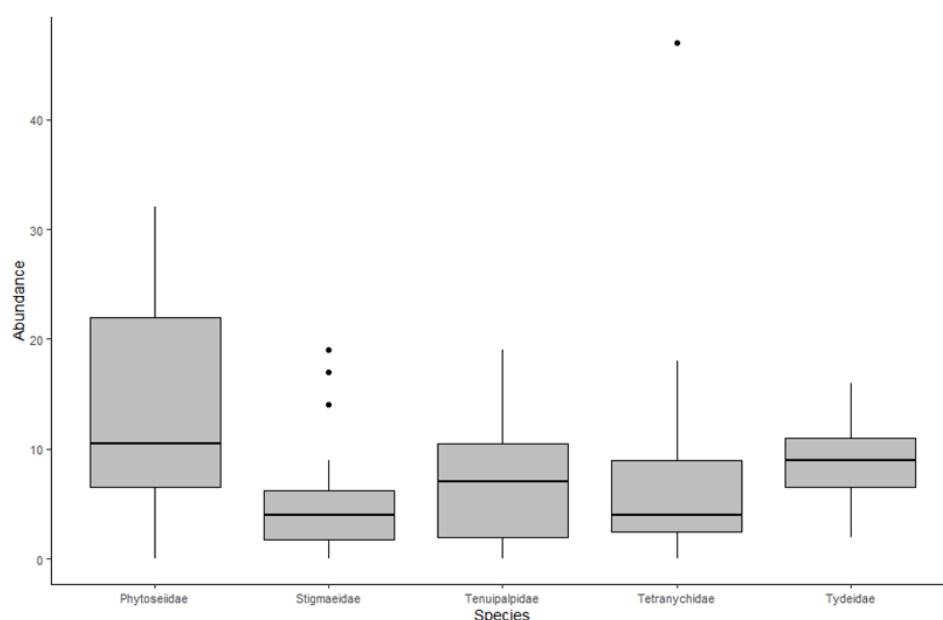


Figure 9 Box and whisker plot showing the number of different mites' species collected.

Whisker plot for the phytoseiid mites shows the widest spread in the population of the Phytoseiidae family. The box and whisker plot for the Stigmaeidae shows that this family had the lowest spread in terms of its population. This family also had some outliers. In terms of the two remaining plant feeding mites, the Tenuipalpidae had a wider distribution than the Tetranychidae suggesting more diversity for the former than the latter.

Table 5: Dunn's Post hoc tests. Kruskal-Wallis multiple comparison

	Comparison	Z	P.unadj	P.adj
1	Phytoseiidae - Stigmaeidae	3.2342546	0.001219607	0.01219607
2	Phytoseiidae - Tenuipalpidae	2.1280710	0.033331194	0.23331836
3	Stigmaeidae - Tenuipalpidae	-1.0950937	0.273475589	1.00000000
4	Phytoseiidae - Tetranychidae	2.8060663	0.005015037	0.04513533

5	Stigmaeidae – Tetranychidae	-0.3989899	0.689900615	0.68990061
6	Tenuipalpidae - Tetranychidae	0.6873474	0.491863845	0.98372769
7	Phytoseiidae - Tydeidae	0.9175730	0.358842450	1.00000000
8	Stigmaeidae - Tydeidae	-2.3379227	0.19391257	0.15513006
9	Tenuipalpidae - Tydeidae	-1.2271953	0.219749184	1.00000000
10	Tetranychidae - Tydeidae	-1.9145427	0.055550846	0.33330508

A Dunnett's post hoc analysis (table 6) test was done to evaluate where the statistically significant differences lay. The results showed us that there were significant differences between Phytoseiidae and Stigmaeidae, Phytoseiidae and Tenuipalpidae, Phytoseiidae and Tetranychidae (figure 10).

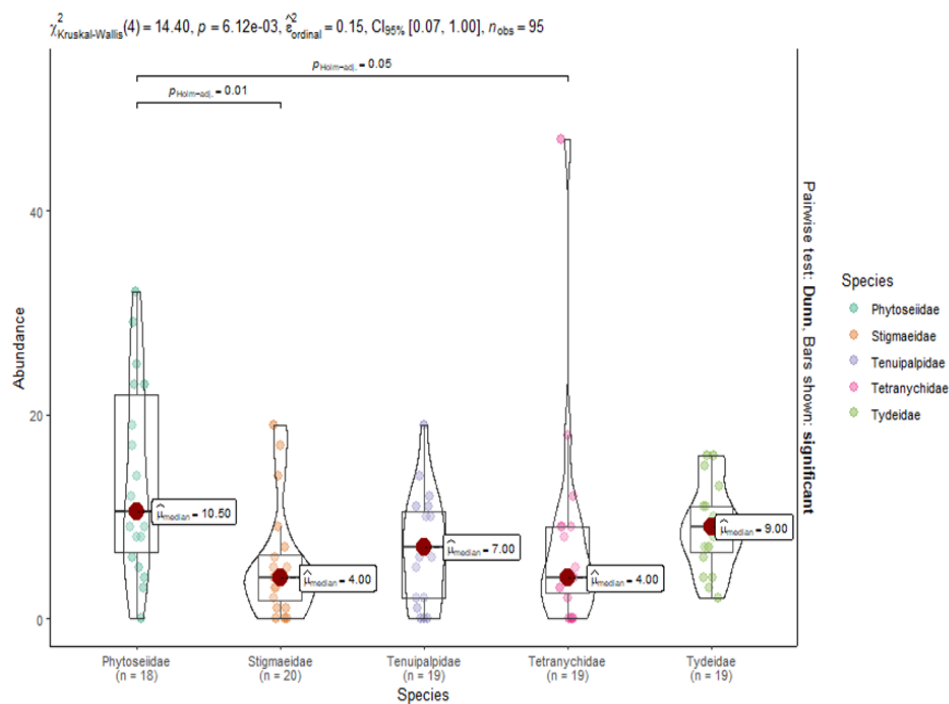


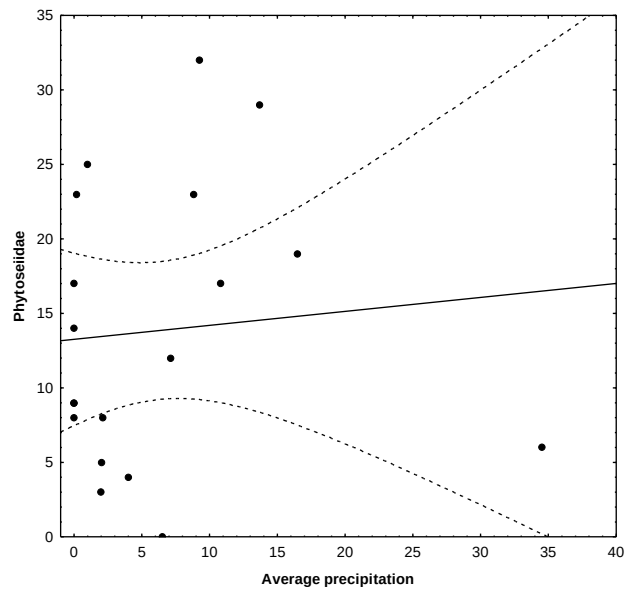
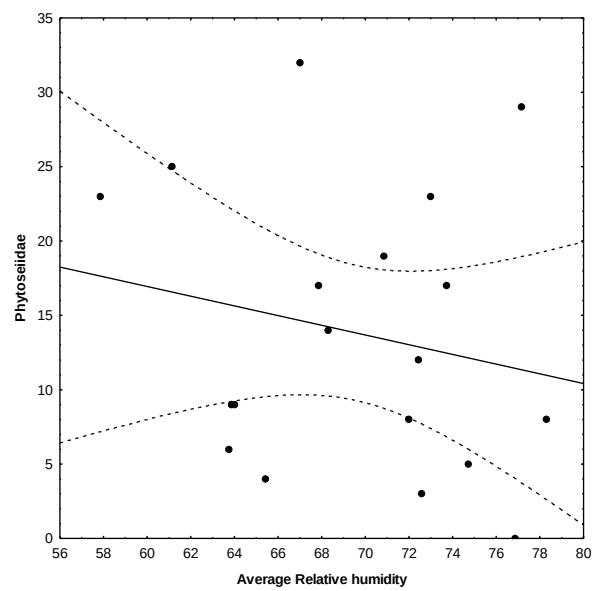
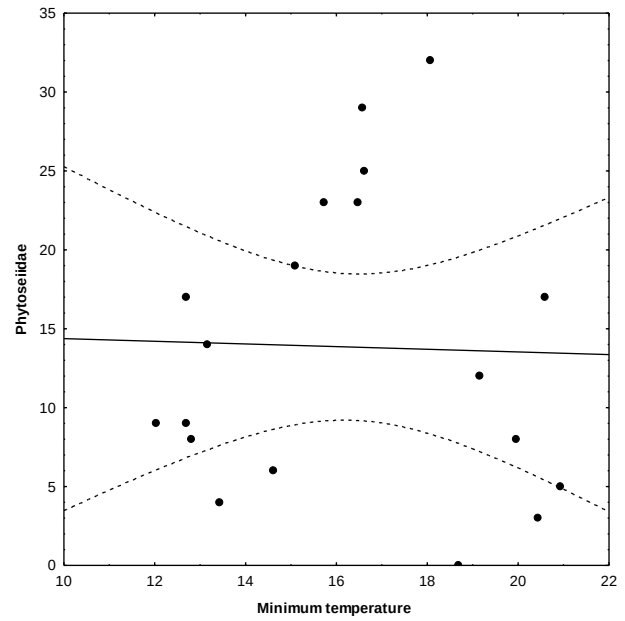
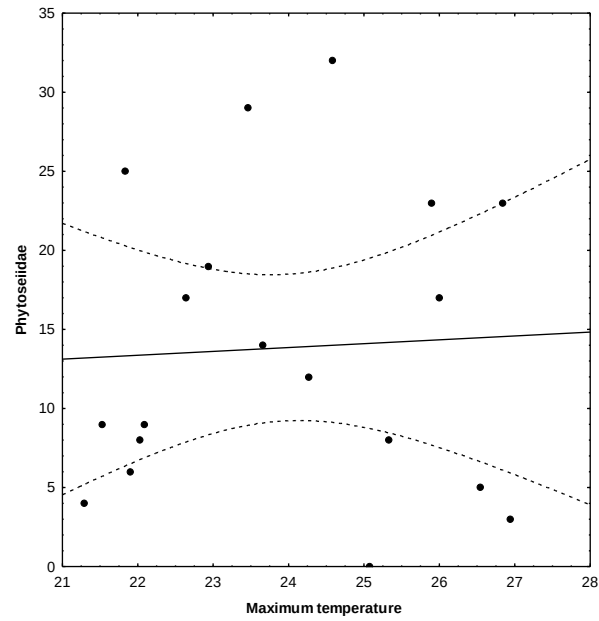
Figure 10 Dunn's pairwise test bars showing significant differences in mite families.

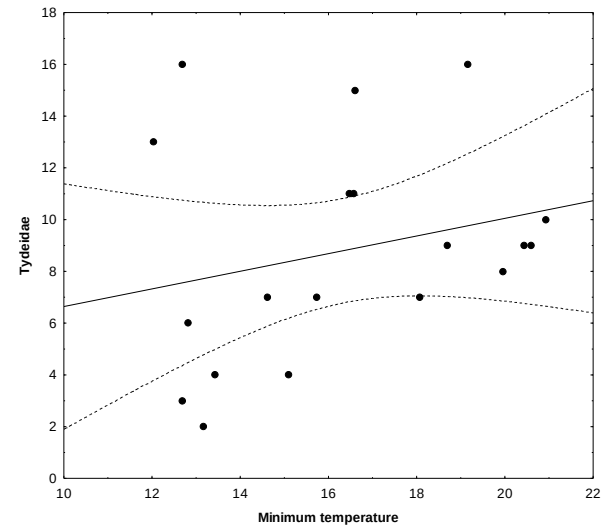
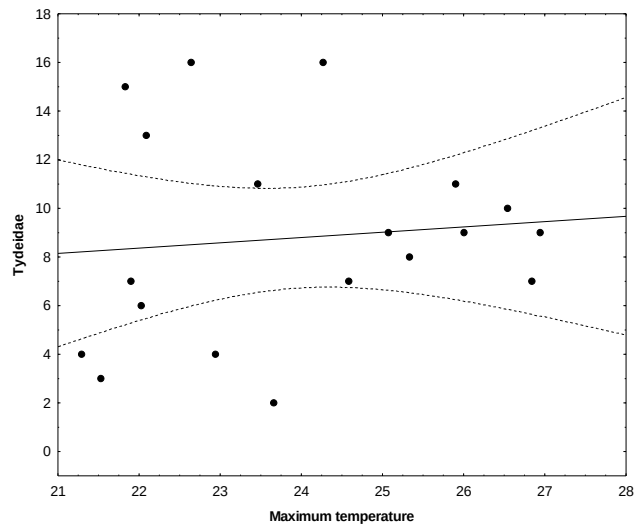
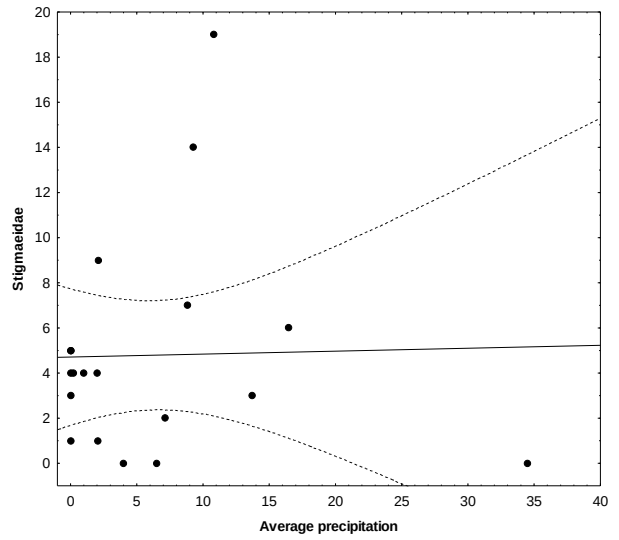
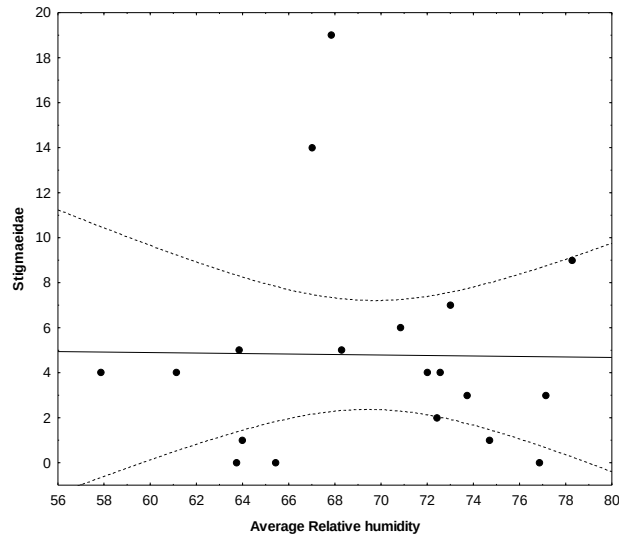
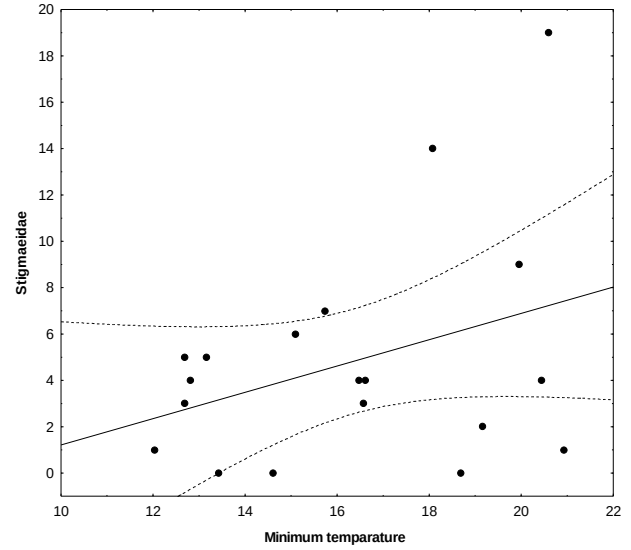
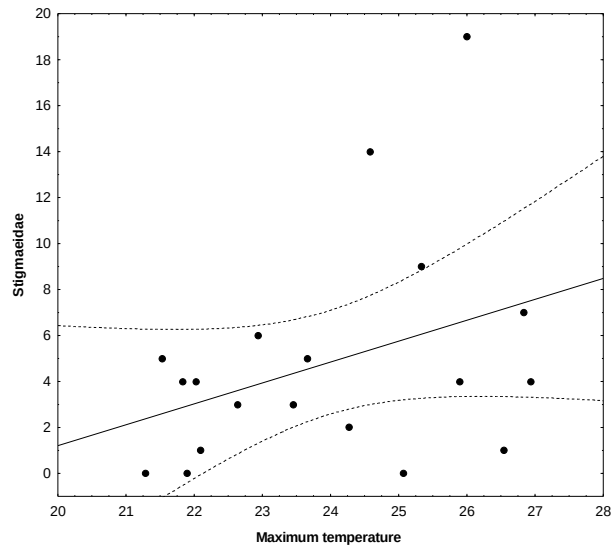
3.3 Correlation between climatic variables and mite diversity.

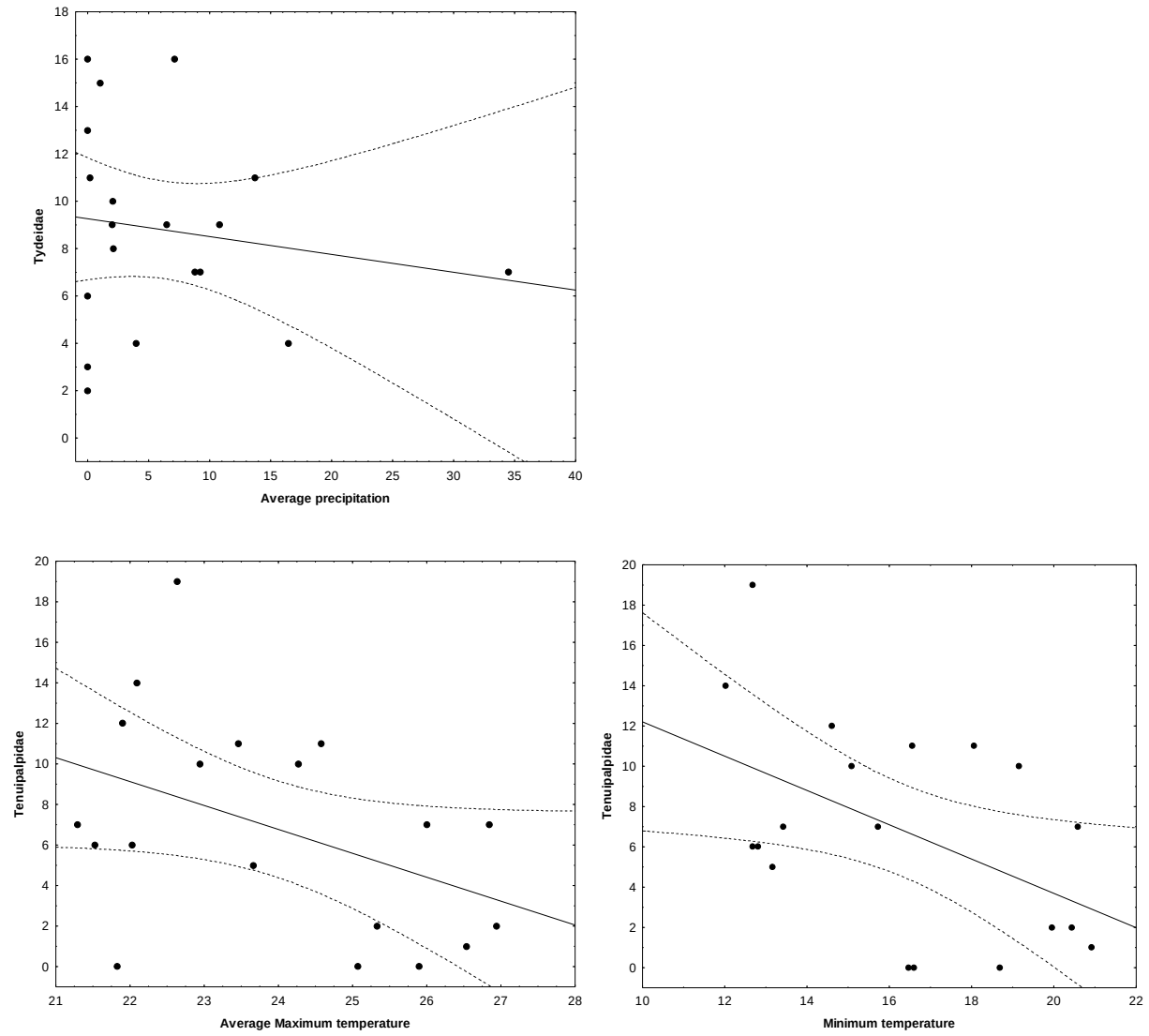
Each of the five diverse families of mites identified were correlated with maximum temperature, minimum temperature, precipitation, and relative humidity to determine if the climatic variables affect the diversity of mites. Generalized Linear model graphs were plotted with lines of best fit (Figure 11) Against minimum temperature, the Phytoseiidae family did not show any correlation, while with maximum temperature it had a weak positive correlation. Phytoseiidae and relative humidity, there was a negative correlation, while in Phytoseiidae and precipitation, there was a positive correlation.

The Stigmaeidae showed no correlation with relative humidity and precipitation. It also showed positive correlation with both minimum and maximum temperatures which were much stronger than that of the Phytoseiidae. The Tydeidae (Figure 12) also showed a positive correlation with maximum and minimum temperature and relative humidity. With precipitation, the Tydeidae had a negative correlation.

The Tenuipalpidae had a negative correlation with maximum temperature and minimum temperature. The Tenuipalpidae then showed a positive correlation with relative humidity and an average positive correlation with precipitation. The Tetranychidae showed a weak positive correlation with maximum temperature and minimum temperature but had no correlation with relative humidity. It showed a positive weak correlation with average precipitation.







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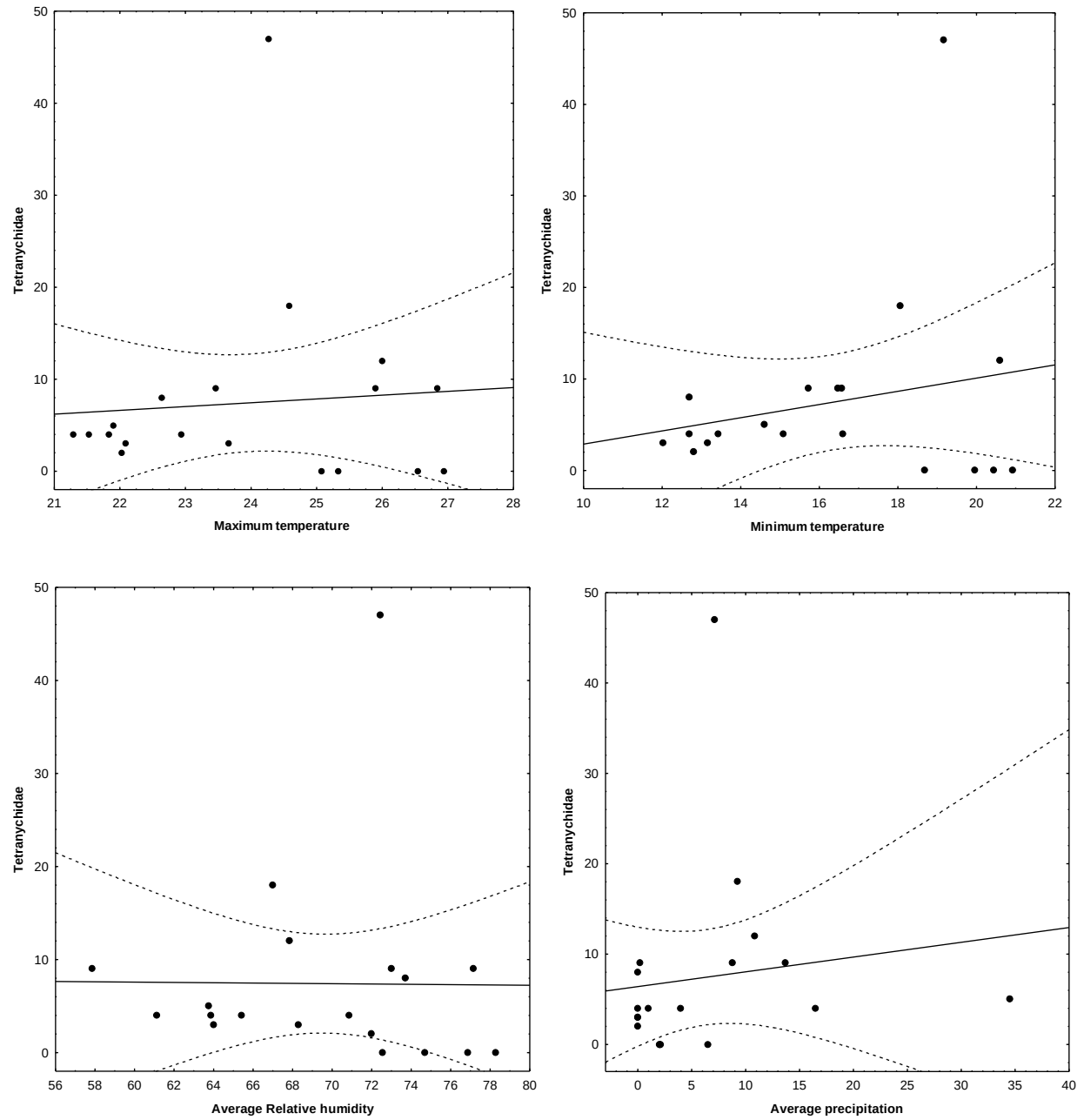


Figure 11 Correlation plots of mite diversity and climatic variables.



Figure 12 Mites associated with Coffea arabica. Images of the Tydeidae mites inside the leaf domatia and on the surface of leaves next to the leaf domatia of Coffea arabica samples.



Figure 13 Light microscope images of a Phytoseiidae mites showing the dorsal (LHS) and ventral (RHS) (sternal and posterior anal) views.

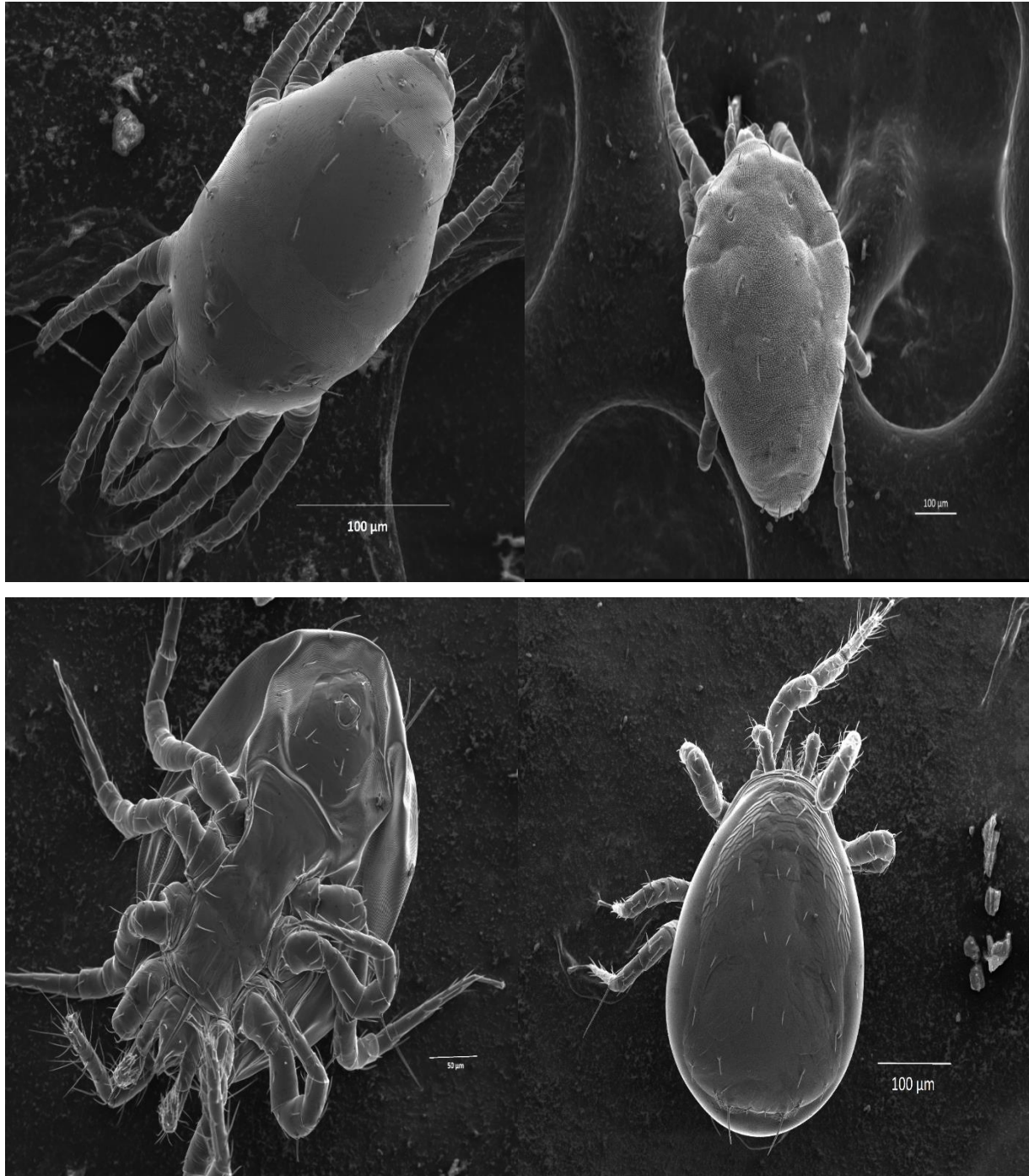


Figure 14 Micrograph of mites from the different families. The dorsal and the ventral view show the setal patterns of mites. Clear view of the sternal shield and the posterior anal shield.

CHAPTER 4

DISCUSSION AND CONCLUSION

4.1 Discussion

The results of this study show that there are seasonal changes in the abundance and diversity of mites in *Coffea arabica*. Comparable results were reported by Romato et al. (2013) who reported that seasonal changes in climate and plant diversity influence the population dynamics of both predatory mites and pest mites, even though their study was conducted on a different plant species (Physic nut plantation). Situngu, (2020) also noted that there were seasonal changes in the abundance and diversity of mites. Other studies (Mendes *et al.* et al.; Duso *et al.*, 2010 observed some seasonal variations in mite abundance even though their studies were based on different plant species (cashew trees and *Viburnum erosum* respectively).

In the current study the seasonal patterns appear to show that mite population increased during spring and autumn (Figure 8), but the mites were present in the leaves in all seasons. This is consistent with Situngu, (2018) who concluded that mites were present in leaves of Coffee across all seasons. While the mite population appeared to increase in spring and autumn, this study could not succinctly pinpoint the exact seasonal parameters responsible for mite abundance. The climatic variables maximum temperature, relative humidity, minimum temperature, and average precipitation were correlated with mite abundance, but not significantly so. The results (Figure 9) also showed that maximum temperature, relative humidity, and minimum temperature had a weak negative correlation with mite abundance. In contrast, Waqas et al., (2014) reported a positive correlation between temperature and the number of mites, in their study of the predatory mites on some cotton cultivars. We predict that the geographical differences between Saudi Arabia (Waqas's study site) and South Africa could be the reason for the slight differences in the results. The plant species as well as the species and diversity of mites for the two studies were also different and that could also be the reason for the differences in the findings.

In most days of sampling, the minimum temperature ranged from 14°C to 18°C and there were only a few days where the minimum temperatures were extremely high. Similarly, the maximum temperatures ranged from 20°C to 28°C suggesting that there was not much variation in maximum temperature. Precipitation in the form of average rainfall, a week before sampling was done, was correlated with the number of mites. The resultant graph from the GLM analysis showed no correlation between precipitation and the mite abundance. Though, in this study we could not pinpoint, the influence of precipitation on mite population. Abreu, (2014) noted that rainfall influenced the occurrence of predatory mites of the Phytoseiidae family. This was a study on the effects of rainfall on mite species in Coffee. The province of my study site (KwaZulu Natal) experienced severe rainfall and floods in April 2022. We suspect that because mites are delicate, their abundance in the season of the floods may have been reduced to an extent that the mite population for the period was not a true reflection of the expected figures of that season. Yannick et al. 1991) also noted in their research on cassava that the main factor contributing to mite losses during the sampling period was rainfall.

In terms of relative humidity, Gomez-Moya et al., (2018) point out that the Phytoseiidae family of predatory mites favors periods of high relative humidity, even though there are variances in the way varied species tolerate low relative humidity. In my current study, relative humidity ranged between 60% to 90% for most of the days during the sampling period leaving only 3 days of sampling period with relative humidity outside that range. We therefore propose that in seasons where mite abundance was low, it was not because of the influence of relative humidity.

4.2 Patterns of mite diversity in response to seasonal changes.

This study gives us a picture of the seasons in which the different communities of mites could be at their peak. Such an idea of the season in which a particular family of mites is in abundance, helps us to predict its population explosion and how best to utilize such knowledge to implement biological control of mite pests Leda, (2017) observed that amongst the predatory mites, the Phytoseiidae (Figure 13) were the highest in terms of abundance

while the, Stigmaeidae were only detected in two management systems. In terms of phytophagous mites, the study. Leda, (2017) detected only two, the Tenuipalpidae and Tetranychidae of which the former was more prevalent in the cropping systems. This was with reference to their study to assess mite densities of the different mite families in *Coffea arabica* in four different cropping systems in Brazil. Situngu *et al.* (2020) reported that only two predatory mite species, *Euseius addoensis* and *Typhlodromus crassus*, were discovered to be the most prevalent in coffee. The results of this current study are consistent with Leda, (2017) as they show that the phytoseiid mites were the most abundant with diverse species across all seasons. The study seems to also concur with numerous studies (Waqas *et al.*, 2014.; Shibao *et al.*, 2004; fang *et al.*, 2009) that found this family of mites prevalent in their studies.

Our results from the Shannon diversity index show that mite diversity was highest in June and November and lowest in February. The results concur with the findings by Teodoro *et al.* (2009) who found that when compared to the rainy season, the diversity of mites in *Coffea arabica* underwent some seasonal changes, with the dry season exhibiting higher densities of species. Despite the possible effects of the heavy rains that fell in my study site on some occasions during the sampling period, our results are still consistent with these of Teodoro *et al.* (2009).

Another interesting aspect was that our results show the presence of the Tenuipalpidae (herbivorous mites) and the Tetranychidae, also a plant feeding mites. It can be observed that throughout the sampling period when the Phytoseiidae (predatory) population rose, both Tenuipalpidae and the Tetranychidae populations also rose. This suggests the existence of a correlation between the phytoseiid population and the population of both the Tenuipalpidae and the Tetranychidae. We predict that Phytoseiidae were feeding on both the Tenuipalpidae and Tetranychidae families.

4.3 Synthesis and opportunities for future research.

The findings of this study indicate that there are seasonal changes in mite abundance. This is consistent with an argument by (Kaczmarek *et al.*, 2011) who states that a population's

abundance dynamics depend on environmental conditions and intra-population parameters. Furthermore, Bloszyk, (1999) stated that factors such as population characteristics, food availability, and climatic conditions directly affect population density. This seems to confirm that environmental or climatic conditions of a place have a key role in the abundance of mites and that mite abundance and diversity vary seasonally. This study however failed to pinpoint which climatic variable was predictive of mite population changes and diversity, but we suspect that temperature and precipitation and relative humidity may all be among the parameters that influence mite abundance. The effects of floods in KwaZulu Natal during this study may have suppressed their significance. The world is currently experiencing climate change, and the effects of climate change are evident in the environment around us. The unique characteristics of each of the four seasons are no longer as clear cut as they used to be. The possible effects of climatic change on the results of this study cannot be overlooked. In South Africa, heavy rainfall and high relative humidity are normally experienced in spring and summer while low rainfall and low humidity are experienced in winter, yet during this study, we witnessed floods in April (autumn), and this may have affected mite abundance and diversity. We also conclude from this study that mites inhabit leaf domatia of *Coffea arabica* across all seasons. It is only the abundance of the different mite families and species that fluctuates according to the seasons. Even though we did not find any statistical evidence to suggest that the environmental parameters temperature and relative humidity had a significant influence on mite abundance and diversity, some studies (Abreu et al., 2014; Kamczyc et al., 2022) the opposite. This study on mite abundance and diversity on *Coffea arabica* offers us an insight summarized below:

- The population of mites changes due to changes in seasons even though temperature and relative humidity had no influence on the changes in the population of mites. Other climatic variables like wind speed were not statistically evaluated in this study, hence at this stage it is still unclear which seasonal climatic variables contribute to changes in population.
- This study found that there were changes in mite diversity due to seasonal changes. This again agrees with Teodoro et al. (2009)'s findings who found that seasonal variations in the mite population that lives on coffee beans led to more species and higher densities in

the dry season than in the rainy season. In this study though, mite diversity was found to not vary much across all seasons except in March (autumn). It is still unclear why mite diversity was low in autumn.

- In terms of mites identified from *Coffea arabica* from my study site, the Phytoseiidae was the most abundant family of mites and other prominent families of mites included the Stigmaeidae and the Tydeidae. The Tenuipalpidae and the Tetranychidae were the most abundant phytophagous mites. In a different study on *Coffea arabica* in Brazil Leda, (2017) found the Phytoseiidae and the Stigmaeidae as the abundant predatory mites and the Tenuipalpidae as the most abundant plant feeding mites. This gives us an insight into how these could be the most common mite species for *Coffea arabica* in different parts of the world.

4.4 Implications for future research

This study was conducted over 12 months and the results we have from this study could not be repeated for each of the seasons, hence more research is needed on the aspect of seasonality of mites.

1. Results suggest that mite abundance changes because of seasonal changes, yet it remains unclear what the key climatic variables that drive the changes in population are. This is a knowledge gap that needs further research.
2. A similar study with sampling conducted over a period of 24 months could help to show if the pattern of the first spring is repeated in the subsequent spring.

In conclusion, the study helped us understand the seasons in which the population of mites could be in abundance. In addition, it has provided us with an insight of which predatory mites and which phytophagous mites we would expect to encounter in *Coffea arabica* in South Africa. Furthermore, the result of this study equips us with the knowledge of when we could employ integrated pest management practices in *Coffea arabica*.

Conclusion

The results have shown that there are variations in the abundance of mites because of seasonal changes. Statistical analysis showed that indeed there was significant difference in the population of mites in *Coffea arabica* between seasons of sampling. The average population of mites was found to be highest in spring followed by autumn and least in summer. It remains unclear though, what characteristics of the different seasons had an influence in the abundance of mites. The climatic variables, minimum temperature, maximum temperature, and humidity were correlated with the number of mites and were found to have no significant effect on changes in mite abundance. Other climatic variables were not utilized for this study and could offer valuable opportunities for future investigation.

The diversity of mites in *Coffea arabica* because of seasonal changes was also assessed. The chapter further examined the predatory mites that were associated with *Coffea arabica*. The results showed that mite diversity changed with seasons in South Africa. Interestingly, was the fact that results from the Shannon Weiner diversity index showed that diversity of mites was higher in the seasons that had lower mite abundance (summer and winter). This seems to suggest that the higher the population of mites, the less the diversity of mites and vice versa. The main families of mites identified were the Phytoseiidae, the Stigmaeidae and Tydeidae. It should also be noted that a family of the plant feeding Tenuipalpidae was also found in *Coffea arabica* at Beaver Creek Coffee estate. In conclusion, the study has shown that the abundance and diversity of mites in *Coffea arabica* change as the seasons change in South Africa. We also conclude that the environmental factors temperature, rainfall and relative humidity could be among the variables that drive changes in abundance and diversity of mites but their effect in this study could have been affected by the effects of climate change. The study has helped to give us some understanding of how the seasons in which the population and diversity of mites could be at their highest. In addition, it has provided us with an insight of which predatory mites and as the plant feeding mites, we would expect to encounter in *Coffea arabica* in South Africa in the different seasons. Finally, the result of this study equips us with an idea of when and how we could employ integrated pest management practices in *Coffea arabica* in South Africa.

References

- Abreu, K.G., Araujo, F.G., de Lima, E.D. and Daud, R.D., 2017. Mites (Arachnida, Acari) on *Astronium fraxinifolium* Schott (Anacardiaceae) from the Cerrado remnants associated with nickel mining areas. *Acarologia*, 57(2), pp.223-232.
- Agrawal, A., 1997. Do leaf domatia mediate a plant-mite mutualism? An experimental test of the effects on predators and herbivores. *Ecological Entomology*, 22(4), pp.371-376.
- Agrawal, A.A., Karban, R. and Colfer, R.G., 2000. How leaf domatia and induced plant resistance affect herbivores, natural enemies and plant performance. *Advancing ecology*, 89(1), pp.70-80.
- Duso, C., Castagnoli, M., Simoni, S. and Angeli, G., 2010. The impact of eriophyoids on crops: recent issues on *Aculus schlechtendali*, *Calepitrimerus vitis* and *Aculops lycopersici*. *Experimental and Applied Acarology*, 51(1), pp.151-168.
- Duso, C., Fontana, P. and Malagnini, V., 2004. Diversity and abundance of phytoseiid mites (Acari: Phytoseiidae) in vineyards and the surrounding vegetation in northeastern Italy. *Acarologia*, 44(1-2), pp.31-47.
- Duso, C., Malagnini, V., Paganelli, A., Aldegheri, L., Bottini, M. and Otto, S., 2004. Pollen availability and abundance of predatory phytoseiid mites on natural and secondary hedgerows. *BioControl*, 49, pp.397-415.
- Duso, C., Pozzebon, A., Capuzzo, C., Bisol, P.M. and Otto, S., 2003. Grape downy mildew spread and mite seasonal abundance in vineyards: evidence for the predatory mites *Amblyseius andersoni* and *Typhlodromus pyri*. *Biological Control*, 27(3), pp.229-241.
- Ferreira, J.A., Pallini, A., Oliveira, C.L., Sabelis, M.W. and Janssen, A., 2010. Leaf domatia does not affect population dynamics of the predatory mite *Iphiseiodes zuluagai*. *Basic and Applied Ecology*, 11(2), pp.144-152.

- Ferreira, J.A., Cunha, D.F., Pallini, A., Sabelis, M.W. and Janssen, A., 2011. Leaf domatia reduce intraguild predation among predatory mites. *Ecological Entomology*, 36(4), pp.435-441.
- Ferreira, J.L., Caixeta, E.T., Caniato, F.F., Setotaw, T., Sant'Ana, G.C. and Ferreira, L.M., 2020. Genetic Diversity of *Coffea arabica*. In *Genetic Variation*. n. pag.
- Finch, S., Samuel, A. and Lane, G.P., 2014. Lockhart and Wiseman's crop husbandry including grassland. 9th edition, United Kingdom, UK: Elsevier.
- Gerson, U., Smiley, R.L. and Ochoa, R., 2008. Mites (Acari) for pest control. *John Wiley & Sons*.
- Gómez-Moya, Cristina Antonia, Manoel GC Gondim Jr, Gilberto J. de Moraes, and Elisangela GF de Moraes. "Effect of relative humidity on the biology of the predatory mite *Amblyseius largoensis* (Acari: Phytoseiidae)." *International journal of acarology* 44, no. 8 (2018): 400-411.
- Grostal, R. and O'Dowd, D.J., 1994. Plants, mites and mutualism: leaf domatia and the abundance and reproduction of mites on *Viburnum tinus* (Caprifoliaceae). *Oecologia*, 97(3), pp.308-315.
- Gwiazdowicz, D.J., 2021. Biodiversity of Mites. 13, 80. <https://doi.org/10.3390/d13020080>
- [Hardinge, B.F., 2020. https://getitmagazine.co.za/highwayberea/blog/2020/04/24/beaver-creek-generations-of-love-in-a-cup/](https://getitmagazine.co.za/highwayberea/blog/2020/04/24/beaver-creek-generations-of-love-in-a-cup/)
- Kamczyc, Jacek, Marcin K. Dyderski, Paweł Horodecki, and Andrzej M. Jagodziński. "Temperature and precipitation affect seasonal changes in mite communities (Acari: Mesostigmata) in decomposing litter of broadleaved and coniferous temperate tree species." *Annals of Forest Science* 79, no. 1 (2022): 12.
- Krantz, G.W., 1978. A manual of acarology (No. Ed. 2). Texas tech university, Texas.
- Krishnan, S., 2017. Sustainable coffee production. In *Oxford research encyclopaedia of environmental science*. Predatory mites (Gamasina, Mesostigmata). *Agriculture, Ecosystems & Environment*, 74(1-3), pp.395-410.
- Kolokytha, P.D., Fantinou, A.A. and Papadoulis, G.T., 2011. Temperature and diet effects on immature development of predatory mite *Typhlodromus athenas* Swirski and Ragusa (Acari: Phytoseiidae). *Environmental Entomology*, 40(6), pp.1577-1584.

- Matos, C.H., Pallini, A., Chaves, F.F., Schoereder, J.H. and Janssen, A., 2006. Do domatia mediate mutualistic interactions between coffee plants and predatory mites? *Entomologia Experimentalis et Applicata*, 118(3), pp.185-192.
- Melese, Y.Y. and Kolech, S.A., 2021. Coffee (*Coffea arabica* L.): Methods, objectives, and future strategies of breeding in Ethiopia. *Sustainability*, 13(19), p.10814.
- Mendes, J.A., Lima, D.B., Monteiro, N.V., Gondim Jr, M.G. and Melo, J.W.D.S., 2021. Phytoseiid mites in cashew trees: diversity and seasonality. *International Journal of Acarology*, 47(4), pp.339-345
- Messelink, G.J. and Leman, A., 2020. Are low humidity levels a limiting factor for spider mite control by phytoseiid predators under fluctuating climatic conditions? In WG" *Integrated Control of Plant-Feeding Mites*" (Vol. 149, pp. 101-102).
- Mineiro, J.L.D.C., Sato, M.E., Raga, A. and Arthur, V., 2008. Population dynamics of phytophagous and predaceous mites on coffee in Brazil, with emphasis on *Brevipalpus phoenicis* (Acari: Tenuipalpidae). *Experimental and Applied Acarology*, 44(4), pp.277-291.
- Mineiro JL, Sato ME, Raga A, Arthur V, Moraes GJ, Sarreta FD, Carrijo A. Diversity of mites (Arachnida: Acari) on *Coffea arabica* L. cv.'Mundo Novo'in Jeriquara and Garça counties, state of São Paulo. *Biota Neotropica*. 2006;6.
- Mutisya, D.L., El Sayed, M.E.B., dos Santos, V.V., Kariuki, C.W., Khamala, C.P. and Tixier, M.S., 2017. Predatory phytoseiid mites associated with cassava in Kenya, identification key and molecular diagnosis (Acari: Phytoseiidae). *Acarologia*, 57(3), pp.541-554.
- Nazar, M.Z., Freed, S., Hussain, S., Sumra, M.W., Shah, M.S. and Naeem, A., 2020. Characteristics of biochemical resistance mechanism of novel insecticides in *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae). *Crop Protection*, 138, p.105320.
- Ngondya, I.B., Kim, B.G. and Ibrahim, R.I.H., 2011. Life on leaves: Which type of domatia in *Cornus* species is most Preferred by foliar mites? *Journal of Agriculture & Life Science*, 45(3), pp.19-23.
- O'Dowd, D.J., 1994. Mite association with the leaf domatia of coffee (*Coffea arabica*) in north Queensland, Australia. *Bulletin of Entomological Research*, 84(3), pp.361-366.

- O'Dowd, D.J. and Willson, M.F., 1991. Associations between mites and leaf domatia. *Trends in Ecology & Evolution*, 6(6), pp.179-182.
- Peixoto, M.L., Fernandes, L.G., Carvalho, M.A.C., Oliveira, M.L.D., Putti, F.F. and Reis, A.R.D., 2017. Assessment of mite fauna in different coffee cropping systems in Brazil. *Biocontrol Science and Technology*, 27(3), pp.424-432.
- Philippe, L., Benoît, B. and Hervé, E., 2009. Breeding coffee (*Coffea arabica*) for sustainable production. *Breeding plantation tree crops: Tropical Species*, pp.525-543.
- Pohlan, H.A.J. and Janssens, M.J., 2010. Growth and production of coffee. *Soils, plant growth and crop production*, 3, p.101.
- Pozzebon, A., Duso, C. and Malagnini, V., 2005, October. Predatory mite population dynamics in vineyards: the role of alternative foods. In *Proc 2nd 'Colloque Internat sur les Acariens des Cultures', Association Française de Protection des Plantes* (pp. 24-25).
- Rezende, J.M., Verona, R.L. and Lofego, A.C., 2016. Mites (Acari) inhabiting *Jatropha curcas* L.(Euphorbiaceae) crops: the role of seasonality and weeds. *Systematic and Applied Acarology*, 21(11), pp.1515-1524.
- Romero, G.Q. and Benson, W.W., 2005. Biotic interactions of mites, plants and leaf domatia. *Current Opinion in Plant Biology*, 8(4), pp.436-440.
- Romero, G.Q., Daud, R.D., Salomão, A.T., Martins, L.F., Feres, R.J.F. and Benson, W.W., 2011. Mites and leaf domatia: no evidence of mutualism in *Coffea arabica* plants. *Biota Neotropica*, 11(1), pp.27-34.
- Rosado, J.F., Picanço, M.C., Sarmento, R.A., Da Silva, R.S., Pedro-Neto, M., Carvalho, M.A., Erasmo, E.A. and Silva, L.C.R., 2015. Seasonal variation in the populations of *Polyphagotarsonemus latus* and *Tetranychus bastosi* in physic nut (*Jatropha curcas*) plantations. *Experimental and Applied Acarology*, 66(3), pp.415-426.
- Salmane, I. and Brumelis, G., 2010. Species list and habitat preference of Mesostigmata mites (Acari, Parasitiformes) in Latvia. *Acarologia*, 50(3), pp.373-394.
- Sadanandan, M.A., 2006. A new species of predatory mite, *Amblyseius* (Acarina: Phytoseiidae) from stored coffee berries. *Journal of Bioscience*, 14, pp.39-41.

<https://www.weathersa.co.za/>

- Schmidt, R.A., 2014. Leaf structures affect predatory mites (Acari: Phytoseiidae) and biological control: a review. *Experimental and Applied Acarology*, 62, pp.1-17.
- Situngu, S., 2018. *Studies in leaf domatia-mite mutualism in South Africa*. <https://core.ac.uk/download/pdf/158296174>, Rhodes University, pp. 1-166.
- Situngu, S. and Barker, N.P., 2017. Position, position, position: Mites occupying leaf domatia are not uniformly distributed in the tree canopy. *South African Journal of Botany*, 108, pp.23-28.
- Situngu, S., Barker, N.P. and Vetter, S., 2020. A Snapshot of Domatial Mite Diversity of *Coffea arabica* in Comparison to the Adjacent Umtamvuna Forest in South Africa. *Diversity*, 12(2), p.79.
- Sudo, M., Nishida, S. and Itioka, T., 2010. Seasonal fluctuations in foliar mite populations on *Viburnum erosum* Thunb. var. *punctatum* Franch. et Sav. (Adoxaceae) and sympatric shrubs in temperate secondary forests in western Japan. *Applied Entomology and Zoology*, 45(3), pp.405-415.
- Teodoro, A.V., Klein, A.M. and Tscharrntke, T., 2009. Temporally mediated responses of the diversity of coffee mites to agroforestry management. *Journal of Applied Entomology*, 133(9-10), pp.659-665.
- Tilney, P.M., van Wyk, A.E. and van der Merwe, C.F., 2012. Structural evidence in *Plectroniella armata* (Rubiaceae) for possible material exchange between domatia and mites. *Plos One*, 7(7), p.e39984.
- Vega, F.E., Ochoa, R., Astorga, C. and Walter, D.E., 2007. Mites (Arachnida: Acari) inhabiting coffee domatia: a short review and recent findings from Costa Rica. *International Journal of Acarology*, 33(4), pp.291-295.
- Waqas, M.S., Aqueel, M.A., Afzal, M., Raza, A.B.M., Kamran, M., Mustafa, I. and Bakar, M.A., 2014. Influence of temperature on the seasonal abundance of predatory mites *Euseius scutalis* in few cotton cultivars. *Int. J. Agric. Appl. Sci. Vol*, 6(1).
- Wu, S., Zhang, Y., Xu, X. and Lei, Z., 2016. Insight into the feeding behavior of predatory mites on *Beauveria bassiana*, an arthropod pathogen. *Scientific reports*, 6(1), pp.1-5.

- Yaninek, J.S., Baumgaertner, J. and Gutierrez, A.P., 1991. Sampling *Mononychellus tanajoa* (Acari: tetranychidae) on cassava in Africa. *Bulletin of Entomological Research*, 81(2), pp.201-208.
- Zhang, Z-Q. 2003. Mites of greenhouses: Identification, biology and control. *CABI Publishing, Oxon, UK*. pp.1-244.
- Zundel, C., Nagel, P., Hanna, R., Korner, F. and Scheidegger, U., 2009. Environment and host-plant genotype effects on the seasonal dynamics of a predatory mite on cassava in sub-humid tropical Africa. *Agricultural and Forest Entomology*, 11(3), pp.321-331.