



Article

Assessing *Panonychus ulmi* (Acari: Tetranychidae) Infestations and Their Key Predators on *Malus domestica* Borkh in Varied Ecological Settings

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Abstract: This study investigates the infestation dynamics of *Panonychus ulmi* McGregor 1916 and its associated predators in *Malus domestica* borkh orchards across three towns in Morocco: Midelt, Ait Sebaa, and Imouzzzer-Kender, situated in the Fez-Meknes and Draa-Tafilalt regions. Ait Sebaa (Fez-Meknes region), characterized by high temperatures and a lower altitude, exhibited a substantial increase in *P. ulmi* and its predators. In contrast, Midelt (Draa-Tafilalt region), with the highest altitude, demonstrated lower mite counts. Imouzzzer-Kender (Fez-Meknes region), at an intermediate altitude, showed moderate mite levels. Detailed findings reveal a positive correlation between *P. ulmi* and temperature, as well as with phytoseiid mites. Conversely, a negative correlation exists between *P. ulmi* and altitude. Additionally, a positive correlation between phytoseiid mites and temperature is identified. Overall, this study provides valuable information on the ecological interactions between mites, temperature, altitude and humidity in distinct Moroccan regions, highlighting the need to take regional specificities into account in pest management strategies.

Keywords: phytoseiid; mites; European red mite; infestation; humidity



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1. Introduction

Malus domestica, commonly known as the apple tree, is a deciduous tree that belongs to the Rosaceae family. It is widely cultivated for its fruit, apples, which come in various colors, flavors, and textures [1]. Its probable origins trace back to the mountainous regions of Central Asia, thriving at altitudes between 1200 and 1800 m [2,3]. It is cultivated on every continent, excluding Antarctica. Its significance is underlined not only by its widespread cultivation but also by its nutritional richness [4]. Flourishing in temperate zones worldwide, the apple holds a paramount position as one of the most economically and culturally valuable species [5]. Today, it stands as one of the most extensively cultivated fruit trees globally, ranking as the fourth-most produced fruit worldwide, trailing behind bananas, oranges, and grapes [6]. The global production of apples reached approximately 63 million

tonnes (MT) in 2016, with China holding the title of the world's leading producer [7]. In India, apple cultivation spans 315,000 hectares (Ha), yielding a production of 2.544 MT [8]. Among Indian states, Jammu and Kashmir take the lead, with 16,100 Ha dedicated to apple cultivation, contributing 1.647 MT to the total production. This region commands a substantial 70.39 percent share of the national market [9]. The apple industry significantly bolsters the economy of Jammu and Kashmir, contributing approximately USD 8 million and serving as a cornerstone of the state's economic framework [9].

In Morocco, the projected apple production for the 2023–2024 season ranges between 900,000 and 1,000,000 tonnes, boasting a national average yield of 20 tonnes per hectare [10]. Encompassing a total area of 50,590 hectares, apple cultivation is predominantly concentrated in the Drâa-Tafilalet and Fès-Meknès regions, collectively constituting 39% and 28% of the national cultivated area, respectively. Notably, the Drâa-Tafilalet region contributes approximately 60% to the overall national apple production, with the province of Midelt alone representing 90%. This notable expansion is credited to strategic initiatives implemented since 2008 under the Green Morocco Plan (GMP) and Generation Green [11,12].

To fortify and perpetuate this positive trend, proponents of the plan advocate for the adoption of the “Green Generation 2020–2030” strategy. This forward-looking approach places paramount importance on nurturing human capital and fortifying logistics infrastructure to facilitate the promotion and marketing of the apple product [2,11,13]. Despite these advantages, national production remains comparatively low when compared to that of other European and American countries. Several constraints contribute to this limitation, including diminished access to cold storage, reduced water resources, susceptibility to frosts and hail, and pest outbreaks, notably by *Tetranychus urticae* and *P. ulmi* [14–18]. The latter is an insidious mite that poses a significant problem to apple cultivation; within the realm of arthropod pests, this mite manifests as a destructive entity, showcasing considerable morphological and ecological diversity within the class Arachnida (alongside spiders and scorpions), the subphylum Chelicerata, and the phylum Arthropoda [19–25]. The European red mite acquired pest status after the 1993 infestation in apple orchards in the Kashmir Valley, emerging as a significant threat to apple production [19]. First recorded in Oregon in 1911, it has since become the predominant apple pest in recent times [17]. The infestation of apple trees by *P. ulmi* led to significant changes in fruit set and a decrease in dry matter content. Notably, the population of this pest reached its maximum levels during periods characterized by elevated average temperatures and relative humidity [26–28]. Concurrently, in response to the presence of phytophagous mites, predatory mites exhibited an increase in their populations [28,29]. This interplay between *P. ulmi*, environmental conditions, and the response of predatory mites underscores the complex dynamics influencing apple orchard ecosystems and warrants a comprehensive examination for effective pest management strategies [26,29,30]. The immature and adult stages of *P. ulmi*, along with other mite pests, induce a decline in photosynthesis, leading to reduced fruit size. This, in turn, prompts premature fruit drop and adversely affects the fruiting in the subsequent season [3,31]. Phytoseiids play a major role as essential biological control agents against pest mites, making them integral components of applied biological control programs (Lindquist et al., 1996; McMurtry and Croft, 1997). Among these, *Neoseiulus californicus* McGregor (Phytoseiidae) stands out as a globally distributed predatory mite, widely employed in the applied biological control initiatives that target tetranychids in diverse settings such as grapevines, apple trees, greenhouse legumes, and strawberry crops [21,32,33]. *Amblyseius swirskii*, a predatory mite indigenous to the Mediterranean region, exhibits exceptional adaptation to warm climatic conditions. This versatile predator is known for its efficacy at all life stages, making it a prevalent choice in the biological control of spider mites and thrips [34,35]. This study aims to investigate the variations in pest infestation levels and the population density of its primary predators in response to diverse environmental parameters, including altitude, temperature, and humidity. The research involves a comparative analysis of *P. ulmi* outbreaks and its key phytoseiid predators, *Neoseiulus californicus* (McGregor) and *Amblyseius swirskii* (Athias-Henriot), across three

distinct regions (Ait Sbaa, Imouzer-Kender, and Midelt). These regions exhibit different conditions in terms of altitude, temperature, and humidity, providing valuable insights into the interplay between environmental factors and the dynamics of *P. ulmi* infestation and predator abundance.

2. Materials and Methods

2.1. Study Area

This study was conducted in three distinct towns in Morocco: Midelt, Ait Sbaa, and Imouzer-Kender, situated in two different regions—the Fez-Meknes region (Ait Sbaa and Imouzer-Kender) and the Draa-Tafilalet region (Midelt). Ait Sbaa town ($33^{\circ}43'48''$ N $5^{\circ}00'36''$ W) is positioned at a lower altitude of 950 m above sea level compared to the other two towns, Imouzer-Kender ($33^{\circ}43'48''$ N $5^{\circ}00'36''$ W) at 1440 m and Midelt ($32^{\circ}40'48''$ N $4^{\circ}43'48''$ W) at 1600 m (Figure 1). The Draa-Tafilalet region is characterized by an average annual rainfall of 156.9 mm, boasting an agricultural area of approximately 270,910 hectares; it is known for its diverse local produce, featuring over nine prominent products, including the Midelt apple. The region's semi-desert climate is characterized by a scarcity of natural water resources across expanses of sparsely populated land. Hot winds from the Sahara contribute to very high summer temperatures, reaching up to 42°C , and harsh winters with temperatures ranging from -7°C to -1°C [30]. The Fez-Meknes region, covering an expansive agricultural area of 1,235,521 hectares, is abundant in quality local produce, particularly apples, which are grown on more than 300 hectares [31]. The climate in the Fez-Meknes region differs significantly, marked by cold and wet conditions in mountainous areas. Winters are very cold and snowy, while summers are temperate. The region experiences average annual rainfall exceeding 700 mm, with the occurrence of hail and flooding following intense downpours. These diverse climatic and geographical characteristics contribute to the unique agricultural conditions in each region, influencing the cultivation of specific crops and shaping the overall environmental context for this study [32].

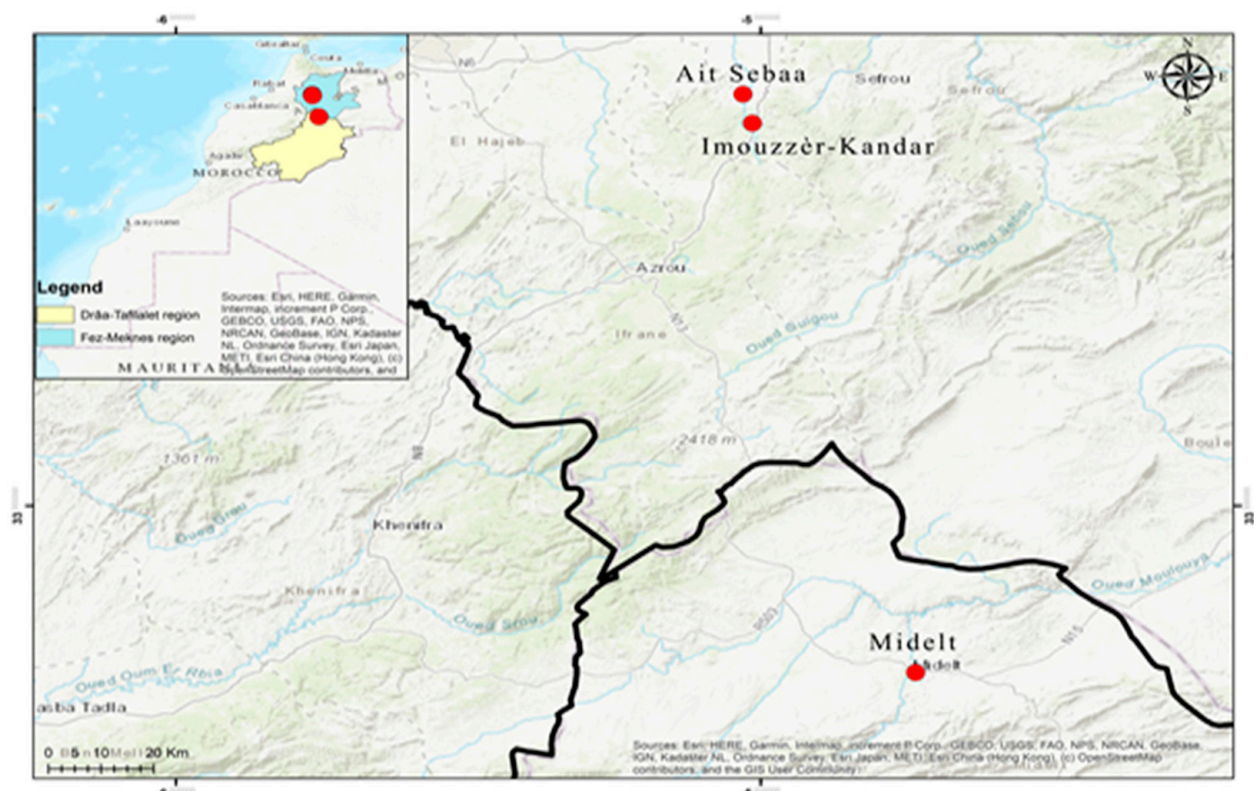


Figure 1. Geographical localization of the three studied regions.

2.2. Sampling Design

For this study, three separate plots were chosen, each featuring the Golden Delicious variety and situated in different towns. No cultural soil practices or chemical treatments were employed, and uniform conditions, including tree spacing and planting age, were upheld consistently throughout the three regions. In Ait Sebaa, the trees were 22 years old, ranging in size from 2.80 m to 3.3 m and spaced 3×4 m apart. In Imouzzzer-Kender, the trees were 23 years old, displaying a similar size and spacing to those in Ait Sebaa. Meanwhile, in the Midelt region, trees were aged 22 years, had dimensions ranging from 2.90 m to 3.5 m, and were spaced 3×4 m apart. In our monitoring, we refrained from employing chemical interventions in the plots where our study was conducted to mitigate the potential influence of chemical acaricides on the mite proportions. Over a two-year period, we closely monitored the activity of the *P. ulmi* and its predators, the phytoseiid mites. The surveillance took place on specific dates: 23 June, 17 July, 23 July, 30 July, 6 August, 12 August, 19 August, 27 August of the year 2022, and 22 June, 13 July, 20 July, 29 July, 12 August, 17 August, 25 August, 31 August of the year 2023. The selection of these specific dates is justified by the fact that they correspond to the period of maximum activity of the pest on apple trees. In contrast, during other seasons in Morocco, the presence of *P. ulmi* on trees is seldom observed.

In the orchards under investigation, apple trees typically underwent foliation in early May and experienced complete defoliation by the end of November. To comprehensively study the dynamics of mite populations, we implemented a systematic sampling approach. Weekly collections of leaf samples were conducted from June to the conclusion of August during the *P. ulmi* infestation period. In each of the 3 regions under examination, we selected and observed 10 trees on the aforementioned dates within each plot. From each tree, we collected 10 leaves, amounting to a total of 100 leaves per plot. The leaves were gathered from diverse directions (north, east, south, and west) and various heights of the tree. The entire process was independently replicated 10 times. Throughout these inspections, we recorded the total count of predators and *P. ulmi* found on the 10 leaves of each plot, documenting the findings separately [31,36]. The diverse mobile forms of the mites on each leaf were methodically determined and counted on both surfaces, utilizing a professional $10\times$ magnifying glass. Subsequently, the collected leaf samples from each marked tree were carefully placed in separate labeled paper bags enclosed within translucent plastic bags and stored in a cooler for preservation. Upon arrival at the laboratory, the mites present on each leaf underwent identification, sorting, and counting under a binocular microscope. Evaluations were performed for each individual tree, and, subsequently, the mean mobile mite numbers per leaf were calculated for each orchard. Additionally, we recorded temperature and relative humidity (RH) data in the field, employing a Davis Instruments Vantage Pro2 (Davis Instruments, Hayward, CA, USA).

2.3. Statistics

The dataset is presented featuring means and percentages accompanied by standard deviation values. Subsequent to an examination of the effects of different study regions (climatic conditions), monitoring dates, and year, along with their interactions using a univariate general linear model (GLM), a Tukey post hoc test at a significance level of $p < 0.05$ was conducted. To ensure the robustness of the subsequent statistical analyses, the normality and homogeneity of variance for all variables were thoroughly evaluated using the Kolmogorov–Smirnov test.

Delving into a more comprehensive understanding of the relationships among key variables, a Principal Component Analysis (PCA) was employed. This analysis encompassed Phytoseiid mites, *P. ulmi*, temperature (T°), relative humidity (RH), and altitudes. The PCA not only assessed the variability within these variables and their correlations but also unveiled patterns of similarities and differences within samples pertaining to towns, years, and monitoring dates.

The execution of PCA was carried out using JMP Pro 14 software from the SAS Company, Cary, NC, USA, ensuring a nuanced exploration of the multidimensional dataset and yielding insightful perspectives on the complex dynamics inherent in the study parameters.

3. Results

3.1. Distribution of the Mites Studied in Relation to the Three Studied Towns

Over the course of the two-year monitoring period, the orchard in Midelt (1600 m) exhibited relatively lower numbers of mites under study. Specifically, the proportion stood at 21% ($n = 7236$) for *P. ulmi* and 23% ($n = 5538$) for phytoseiid mites. In contrast, Imouzzzer-Kender trees, located at 1440 m, presented an intermediate count of mites, with 28% ($n = 9584$) attributed to *P. ulmi* and 37% ($n = 8593$) to phytoseiid mites (Figure 2).

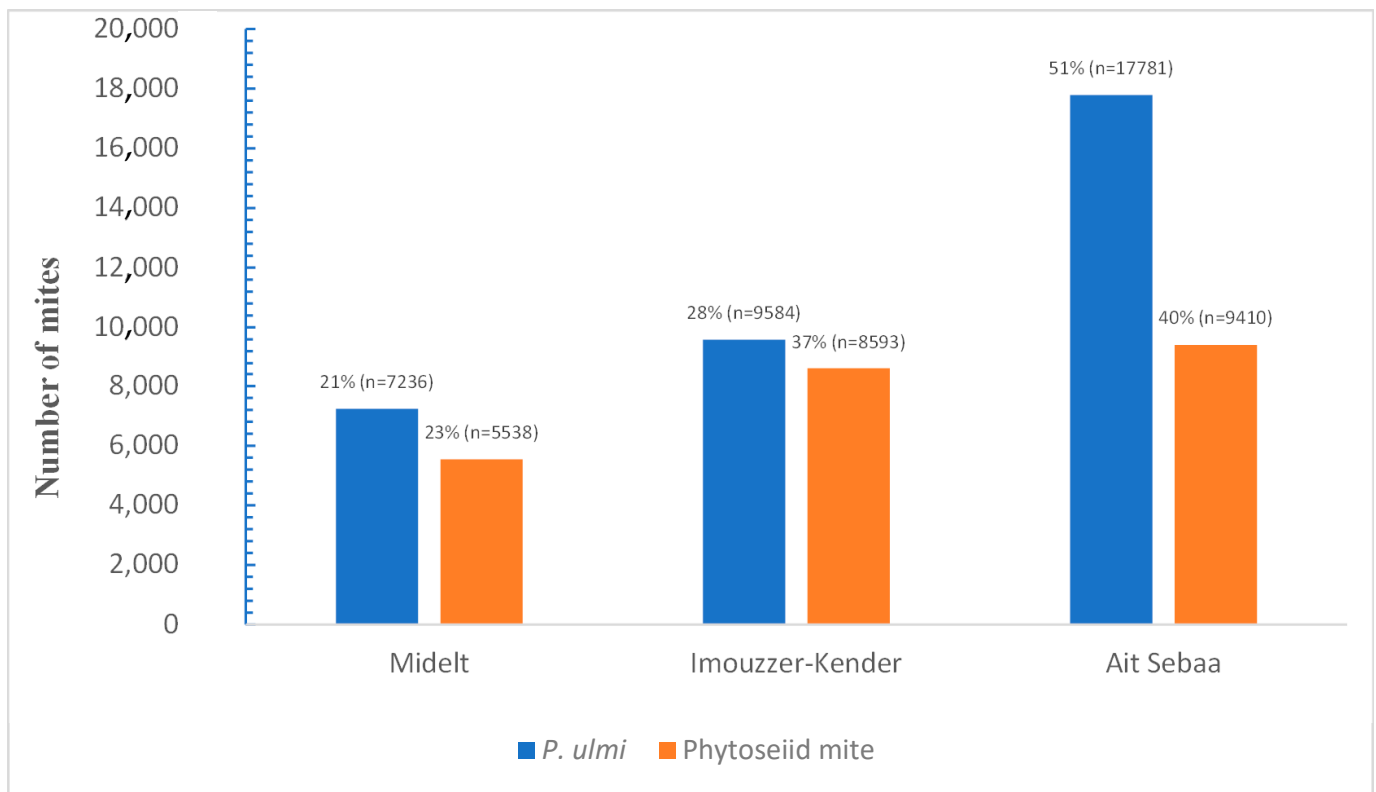


Figure 2. The comparative abundance (%; n) of the phytophagous mite *Panonychus ulmi* and phytoseiid mites in three distinct regions (Midelt, Imouzzzer-Kender, and Ait Sebaa) throughout the entire monitoring period.

Remarkably, Ait Sebaa (950 m) witnessed a significant surge in the number of *P. ulmi* and their predators. Notably, there were 17,781 mobile forms of *P. ulmi*, constituting 51% of the count, and 9410 mobile forms of phytoseiid mites, accounting for 40% of the total (Figure 2). This discernible increase in *P. ulmi* and their predators in Ait Sebaa suggests a notable ecological shift at this lower altitude, emphasizing the impact of altitude on the abundance and dynamics of these mite populations. Between 2022 and 2023, there was a rise in the number of mites studied, encompassing the pest and the phytoseiid mites, except for *P. ulmi* in the Ait Sebaa region, where a decline was observed from 2022 to 2023 (Figure 3).

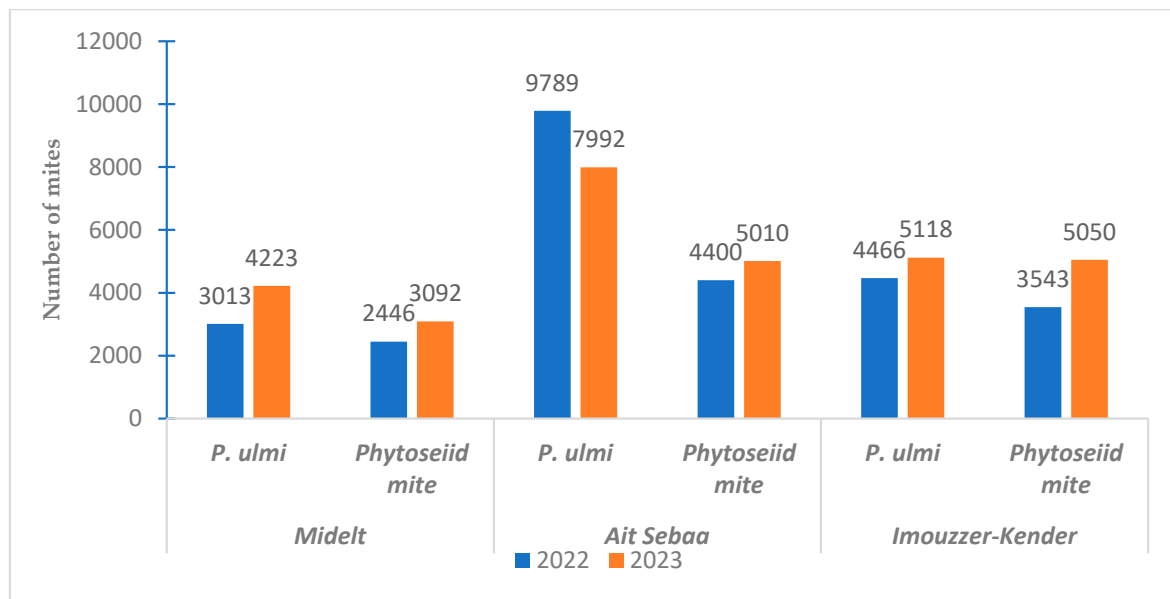


Figure 3. The abundance of *P. ulmi* and phytoseiid mites observed per region over the two years of monitoring.

3.2. Influence of Climatic Conditions, Geographical Region, and Monitoring Dates on the Mite Populations

Tables 1 and 2 comprehensively depict the impact of location, monitoring dates, and years, as well as their interactions, on the averages of the mite diversity. Our observations underscore that the location, representing variations in climatic conditions such as altitude, temperature (T°), and relative humidity (RH), alongside the monitoring dates, exerted a significant influence on the variations in *P. ulmi* and phytoseiid mites (Table 3). Intriguingly, the year of collection did not exhibit a discernible impact on the fluctuations in these mite populations. Furthermore, our analysis revealed that the sequential interactions among the studied factors collectively played a significant role in shaping the variations in the populations of both *P. ulmi* and phytoseiid mites.

Table 1. The analysis of variance for *Panonychus ulmi* and phytoseiid mites, employing the general linear model (GLM) to assess the impact of region, year, monitoring dates, and their interactions.

Species	Source	DF	Adj SS	Adj MS	F-Value	p-Value
<i>Panonychus ulmi</i>	Town	2	383,127	191,563	7485.86	0.000
	Year	1	9	9	0.34	0.558
	Dates	7	254,939	36,420	1423.20	0.000
	Town*Year	2	31,981	15,991	624.88	0.000
	Town*Dates	14	32,650	2332	91.14	0.000
	Year*Dates	7	7459	1066	41.64	0.000
	Town*Year*Date	14	30,295	2164	84.56	0.000
	Year	1	15,905	15,904.5	775.52	0.000
<i>Phytoseiid mites</i>	Town	2	52,069	26,034.3	1269.46	0.000
	Dates	7	331,590	47,370.1	2309.82	0.000
	Town*Dates	14	29,394	2099.6	102.38	0.000
	Town*Year	2	3223	1611.7	78.59	0.000
	Town*Year*Dates	14	4562	325.8	15.89	0.000
	Year*Dates	7	1654	236.3	11.52	0.000
	Year	1	15,905	15,904.5	775.52	0.000

Table 2. The average population sizes per tree of the various mites studied (*Panonychus ulmi* and *Phytoseiid mites*) across the three studied regions.

Region	<i>Panonychus ulmi</i>	<i>Phytoseiid mites</i>
Ait Sebaa	111.13 A $\pm$ 20.33	58.81 A $\pm$ 10.84
Imouzzzer-Kandar	59.90 B $\pm$ 10.20	53.71 A $\pm$ 10.65
Midelt	45.23 C $\pm$ 8.54	34.61 B $\pm$ 6.45

Means with a different letter in each column are significantly different by Tukey's test ($p < 0.05$).

Table 3. Temperature, altitude and relative humidity recorded during the monitoring period.

Midelt Town 1600 m (Altitude)	Follow-up dates (2022)	23 June	17 July	23 July	30 July	6 August	12 August	19 August	27 August
	Temperature	30	35	34	36	36	35	37	36
	Relative humidity	48%	22%	23%	24%	20%	21%	22%	27%
	Follow-up dates (2023)	22 June	13 July	20 July	29 July	12 August	17 August	25 August	31 August
	Temperature	33 °C	37 °C	36 °C	36 °C	36 °C	37 °C	35 °C	36 °C
	Relative humidity	60%	20%	21%	20%	22%	23%	20%	35%
Imouzzzer-Kender 1440 m (Altitude)	Follow-up dates (2022)	23 June	17 July	23 July	30 July	6 August	12 August	19 August	27 August
	Temperature	30 °C	35 °C	36 °C	39 °C	38 °C	39 °C	39 °C	37 °C
	Relative humidity	60%	29%	33%	35%	27%	35%	33%	51%
	Follow-up dates (2023)	22 June	13 July	20 July	29 July	12 August	17 August	25 August	31 August
	Temperature	34 °C	34 °C	35 °C	33 °C	37 °C	38 °C	38 °C	38 °C
	Relative humidity	62%	27%	27%	30%	25%	22%	25%	40%
Ait Sebaa 950 m	Follow-up dates (2022)	23 June	17 July	23 July	30 July	6 August	12 August	19 August	27 August
	Temperature	33 °C	38 °C	39 °C	43 °C	41 °C	44 °C	43 °C	41 °C
	Relative humidity	55%	25%	25%	28%	25%	35%	29%	50%
	Follow-up dates (2023)	22 June	13 July	20 July	29 July	12 August	17 August	25 August	31 August
	Temperature	36 °C	36 °C	39 °C	38 °C	40 °C	43 °C	40 °C	42 °C
	Relative humidity	60%	20%	25%	30%	20%	21%	22%	36%

To provide a more detailed perspective and highlight distinctions among them, our study unveiled that the three regions studied markedly influenced the abundance of *P. ulmi*. Specifically, Ait Sebaa exhibited the highest average (111.13) of *P. ulmi*, followed by Imouzzzer-Kender (59.90) and Midelt (45.23).

In examining the means of the phytoseiid mite populations across different towns, notable distinctions emerged. Imouzzzer-Kender and Ait Sebaa, with a mere 15 km difference between them, exhibited statistically similarly means (58.81 and 53.71, respectively). In contrast, the predators in Midelt exhibited a significantly different mean (34.61) compared to both Imouzzzer-Kender and Ait Sebaa.

To enhance precision and establish correlations among the studied variables, particularly linking climatic conditions with the populations of *P. ulmi* and phytoseiid mites, Table 4 and Figure 4 present the principal component analysis results. The loading diagram, in particular, offers a visual representation of how well each variable is captured by the principal components. In this analysis, the first principal component emerged as a potent

factor, effectively encapsulating 58.90% of the variability inherent in the data. This significant proportion suggests that the first principal component serves as a comprehensive summary of the interrelationships among the variables, showcasing its central role in explaining the observed patterns. The second principal component, although contributing a slightly smaller fraction, still plays a substantial role, accounting for an additional 22.50% of the variability. The collective contribution of the first and second components amounts to approximately 82%, indicating that these two components alone provide a robust understanding of the total information embedded in the dataset (Figure 4).

Table 4. Correlation matrix among variables (temperature, altitude, relative humidity, *P. ulmi*, and phytoseiid mites).

	<i>P. ulmi</i>	Phytoseiid Mites	Temperature	Relative Humidity	Altitude
<i>Panonychus ulmi</i>	1.0000	0.7472	0.7803	−0.0013	−0.7125
Phytoseiid mites	0.7472	1.0000	0.6628	−0.1548	−0.2761
Temperature	0.7803	0.6628	1.0000	−0.3079	−0.6151
Relative humidity	−0.0013	−0.1548	−0.3079	1.0000	−0.0891
Altitude	−0.7125	−0.2761	−0.6151	−0.0891	1.0000

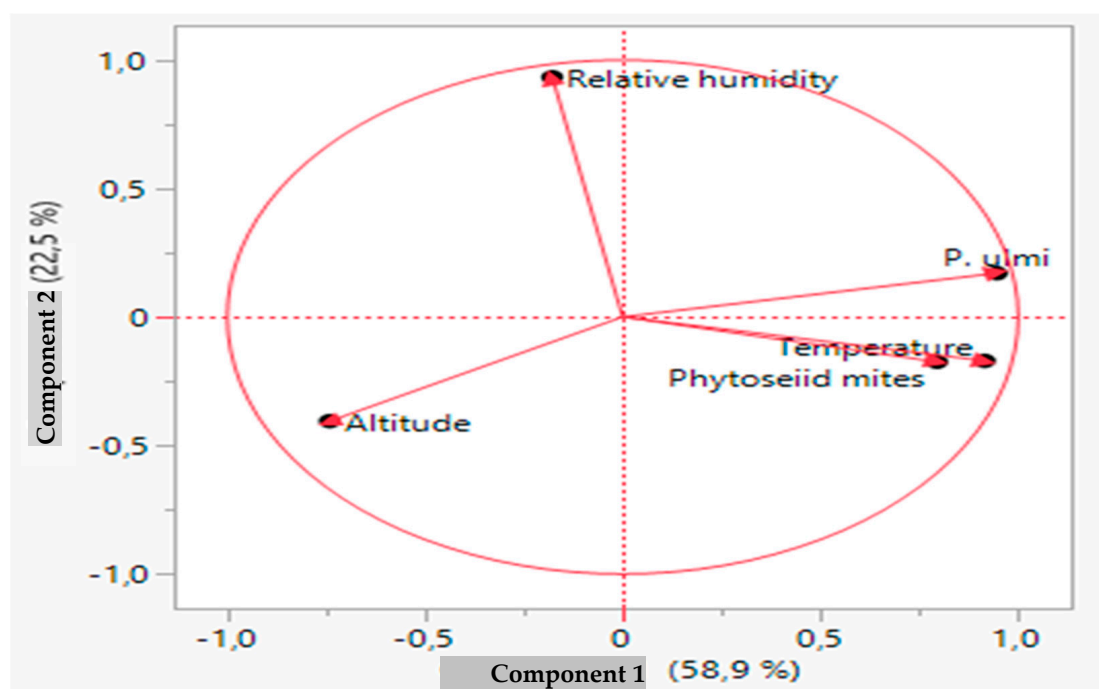


Figure 4. Loading plot that represents the projection of the variables on the PC1 and PC2. PC: principal component.

These findings reveal a robust positive correlation between *P. ulmi* and temperature, as well as with phytoseiid mites, suggesting that an increase in the pest population directly corresponds to an increase in the number of predators. Conversely, a negative correlation is observed between *P. ulmi* and altitude, whereas the study did not reveal a correlation between the number of *P. ulmi* and relative humidity (Table 4).

Furthermore, a notable positive correlation is evident between phytoseiid mites and temperature (T°), with no discernible correlation observed between phytoseiid mites and altitude or relative humidity (RH). These insights, derived from the principal component analysis, provide a nuanced understanding of the interrelationships among climatic factors and mite populations in the study.

The biplot illustrated in Figure 5 and the data presented in Table 3 unveil distinct groupings based on altitude levels in the studied regions. Specifically, one group encompasses the highest altitudes (Midelt at 1600 m and Imouzzzer-Kender at 1440 m), while the second group is characterized by the lowest altitude (Ait Sebaa at 950 m). The graph further delineates these groups, with a red circle representing lower temperatures and a sparse density of mite populations, especially in the initial four-week period. In contrast, the green circle marks the other group, marked by elevated temperatures and a substantial presence of mite populations, notably in the latter four samples.

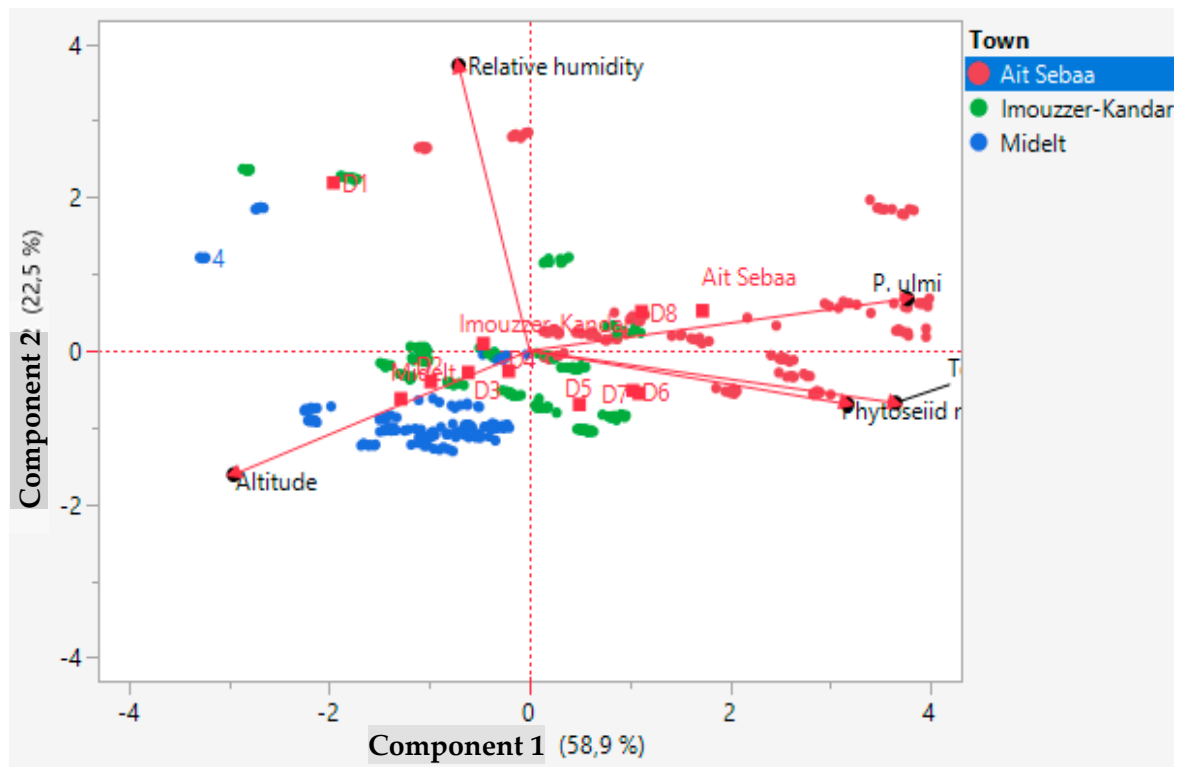


Figure 5. Biplot that represents the projection of the individuals and variables on PC1 and PC2 according to the region and monitoring dates.

In summary, the figure illuminates that regions characterized by high temperatures and low altitudes exhibit a pronounced presence of mites, while areas with lower temperatures and higher altitudes display a diminished mite incidence. These findings contribute to a comprehensive understanding of the interplay between climatic variables and mite population dynamics in the studied regions.

3.3. Variability in Mite Populations Observed across Diverse Regions and Monitoring Dates

In the Ait Sebaa region, during the initial year of observation (2022), a distinct pattern in the average *P. ulmi* population emerged. Notably, the first four samplings reflected a comparatively lower average, exhibiting a modest rise from 66.00 on 23 June to 91.30 mites on 30 July (Figure 6). This increase in pest abundance can be attributed to the temperature surge from 33 °C on 23 June to 43 °C on 30 July, concomitant with a decline in relative humidity from 55% to 28% (Table 3). Between the fifth sample on 6 August and the final sample on 27 August, characterized by temperatures between 41 °C and 44 °C and relative humidity ranging from 25% to 50%, there was a substantial surge in the average *P. ulmi* population. The average escalated significantly from 122.60 to 190.90. Concurrently, the average for phytoseiid mites in the Ait Sebaa region increased from 7.00 to 94.00 per 10 leaves, spanning the first sample to the last.

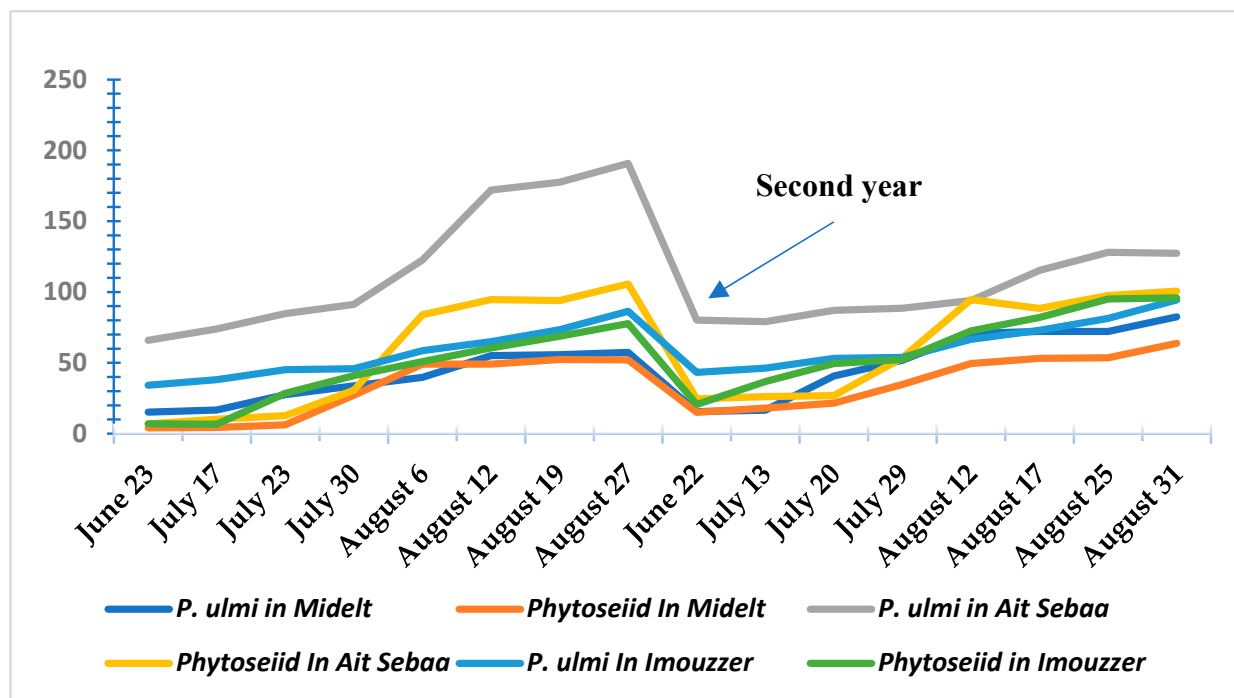


Figure 6. The average of diverse mites identified in apple trees in various Moroccan regions across different monitoring dates (2022–2023).

In the subsequent year (2023), a similar trend persisted. For *P. ulmi*, the mean increased from 80.1 during the first sampling on 22 June (36 °C, 60%) to 127.3 at the last sampling on August 31 (42 °C, 36%). Likewise, the mean for phytoseiid mites rose from 24.6 during the first sampling to 100.6 at the last sampling date. These observations highlight consistent patterns in the population dynamics of *P. ulmi* and phytoseiid mites in the Ait Sebaa region over the two-year monitoring period.

In the Imouzzer-Kender and Midelt regions, a parallel trend is evident, where the rise in temperature from the initial to the final sampling facilitated an increase in the average population of *P. ulmi*. However, it is noteworthy that this increment in average was comparatively modest in comparison to the pronounced increase observed in the Ait Sebaa region. Similarly, the averages of Phytoseiid mites exhibited a notable upturn from the first to the last week of monitoring in both regions.

4. Discussion

This study represents the first national survey, in which we systematically explore the impact of diverse climatic conditions across three distinct regions, characterized by variations in altitude, temperature (T°), and relative humidity (RH), on the infestation levels of the spider mite (*Panonychus ulmi*) and the fluctuations in the density of beneficial phytoseiids. Our findings present the first dataset in Africa that draws comparisons regarding the dynamic behavior of mites on *M. domestica* in different regions of Morocco. This holds implications for future comparative research, aimed at discerning infestation patterns and the rate of pest propagation in response to varying climatic conditions. By contributing these insights, our study lays the foundation for a comprehensive understanding of the ecological dynamics between pests and beneficial phytoseiids in agroecosystems, with broader implications for pest management strategies and agricultural sustainability.

Ait Sebaa, positioned at a lower altitude of 950 m compared to Midelt (1600 m) and Imouzzer-Kender (1440 m), experienced a pronounced upsurge in the population of *P. ulmi* and their corresponding predators. Specifically, a noteworthy 17,781 mobile forms of *P. ulmi*, constituting 51% of the total count, and 9410 mobile forms of phytoseiid mites, comprising 40% of the total count, were observed (Figure 2). This conspicuous rise in both pest and

predator populations in Ait Sebaa suggests a notable ecological shift at this lower altitude, underscoring the significant impact of altitude on the abundance and dynamics of these mite populations. The findings illuminate the intricate interplay between altitude and the ecology of mites, offering valuable insights for understanding and managing mite populations in diverse geographical contexts. A comprehensive investigation of non-native walnut pests in Italy confirms our results, specifically focusing on the leafminer *Coptodisca lucifluella* and the carpophagous *Rhagoletis completa*, both originating from America; samples were systematically collected from 219 *Juglans regia* trees across various altitudes in the Friuli Venezia Giulia region (FVG). *C. lucifluella* was identified in 55 sites, exhibiting a distribution that inversely correlated with altitude, notably absent from sites exceeding 600 m above the sea. *R. completa* was detected in 89 sites, displaying heightened infestation in lowland areas and a notable absence above 700 m. The influence of altitude emerged as a significant factor, shaping the presence of these two pest species [37]. Our findings highlight that the town, reflecting variations in climatic conditions, including altitude, temperature (T°), and relative humidity (RH), along with the monitoring dates, played a crucial role in influencing the fluctuations in both *P. ulmi* and phytoseiid mites. A research investigation spanning the East and Central African countries of Burundi and Rwanda examined banana fields distributed across three altitude ranges in Burundi and 99 fields situated across two altitude ranges in the watersheds of Rwanda. The study revealed significant associations between the incidence and prevalence of Banana Bunchy Top Disease (BBTD) and *Fusarium* wilt (FW) with temperature and altitude in Burundi. This underscores the likelihood that rising temperatures could contribute to the upward progression of banana diseases [38]. Our findings also find support in multiple studies demonstrating that climatic conditions wield either a positive or a negative influence on the infestation rates by mites or insect pests [30,39–44]. Additional research validates that elevated temperatures and increased relative humidity typically expedite the development and reproduction of *P. ulmi* and its predators. Elevated temperatures can expedite life cycles and amplify egg-laying rates, potentially resulting in population growth [30,45,46].

Our observation certainly corresponds to a well-established understanding in the fields of agriculture and entomology. The influence of climatic conditions on the rate of infestation by mites or insect pests is a widely recognized phenomenon that is crucial to understanding the dynamics of pest populations in various ecosystems [47]. Temperature is a critical factor affecting the development, reproduction, and behavior of mites and insect pests. Warmer temperatures often accelerate the life cycle of pests, leading to increased reproduction rates and more rapid population growth [41]. Relative humidity is another important climatic factor. Some pests thrive in humid conditions, while others fare better in drier environments. Humidity levels have an impact on the availability of breeding sites and the ability of certain pest species, particularly mites, to survive [30,44]. The seasonal trends as climate varies from one season to the next also play a crucial role [30,47]. Certain pests may be more frequent during specific seasons because of conditions that favor their life cycle [48]. For example, spring and summer may see increased pest activity and higher infestation rates [49]. Also, the impact of climatic conditions on pest infestation can vary across different geographical regions. Pests may exhibit different behaviors and adaptability to climatic factors, depending on the local environment [42,50].

In essence, these outcomes underscore the multidimensional nature of the interactions among mites, climatic variables, and plants. This comprehensive understanding not only enriches our current knowledge but also calls for further exploration in the pursuit of advancing our comprehension of these intricate ecological relationships. As researchers venture into future investigations, these insights stand as guideposts, directing attention towards avenues that hold the potential for deeper revelations and a more nuanced grasp of the complexities inherent in the studied ecological network. In addition, understanding the correlation between climatic conditions and pest infestation is fundamental to devising effective Integrated Pest Management strategies. Farmers and pest control professionals can use this knowledge to implement targeted and sustainable approaches to pest control. By

acknowledging the influence of climatic conditions on pest infestation rates, researchers and practitioners can better tailor pest management strategies, making them more adaptable and resilient in the face of changing environmental conditions. This interdisciplinary approach contributes to sustainable agriculture and ecosystems.

5. Conclusions

The concluding remarks succinctly encapsulate the findings extracted from the study, shedding light on important insights and paving the way for critical considerations in future research within the realm of mite–plant–climate interactions. The following elaboration delves into the primary points of emphasis: (1) Altitudinal Impact on Pest Dynamics: The foremost finding underscores the impact of altitude on the distribution and abundance of pests, exemplified by the case of *P. ulmi* and its predators. This revelation serves as a cornerstone for understanding the intricate dynamics of mite populations and their ecological counterparts in varying altitudinal gradients. (2) Temperature and Humidity Influences on Mite Infestation: The second finding accentuates the paramount role played by temperature and relative humidity in shaping the levels of infestation and the rapidity of mite proliferation. This insight underscores the nuanced interplay between climatic conditions and mite behavior, providing a crucial foundation for comprehending the intricacies of mite-related ecological phenomena.

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