

Article

Population Fluctuation of Phytophagous Mites and Their Impact on the Quality Properties of Wild and Cultivated Blackberry Fruits (*Rubus* spp. L.) in Jalisco, Mexico

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Abstract

Phytophagous mites are considered pests in fruit crops, such as blackberries (*Rubus* spp. L.). These pests affect fruit quality and commercial value. This study aimed to evaluate the fluctuation of phytophagous mite populations and their impact on the quality of cultivated and wild blackberries in Jalisco, Mexico. Monthly sampling was carried out from November 2023 to May 2024. Mite families such as Diptilomiopidae, Eriophyidae, Tydeidae, Tarsonemidae, Tenuipalpidae, and Tetranychidae were identified, with a total of 6438 mites in the samples. An increase in mite populations was observed in March on cultivated blackberries and in April on wild ones, coinciding with the onset of plant development. The Eriophyidae family showed the highest relative abundance, with 34.2% in cultivated blackberries and 31.7% in wild ones in 2024. Quality parameters were evaluated in healthy and damaged blackberries. Damaged cultivated fruits showed lower weight (4.49 ± 1.44 g), smaller diameter (18.11 ± 2.00 mm), lower vitamin C content (4.76 ± 1.53 mg/100 g), and higher acidity ($80.07 \pm 19.10\%$). This study enabled the identification and monitoring of different mite families in blackberries, as well as an understanding of their population dynamics and impact on fruit quality.

Keywords: phytophagous mites; population dynamics; blackberry; fruit quality; cultivated and wild varieties



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1. Introduction

Blackberry (*Rubus* spp. L.) is a fruit that belongs to the *Rosaceae* family. It is marketed together with other small fruits known as “berries”. These small fruits are very popular in American and European markets due to their flavor and bioactive properties. Blackberry cultivation in Mexico is an important agricultural sector due to its economic importance. More than 11,000 hectares are in production throughout the country, with Michoacán and

Jalisco being the main producers' states. Both states produce 17,000 tons of blackberries annually, with profits exceeding 200 million dollars [1,2]. Despite the favorable agroclimatic conditions in Mexico, there are some limitations in the cultivation of blackberries in terms of yield and fruit quality, mainly due to biotic factors, especially pests. Among the most important pests of this crop are phytophagous mites. These microscopic mites are widely distributed in different agricultural areas and affect crops by damaging some physiological processes of the plant, such as photosynthesis and plant morphology, thereby acting as vectors of pathogens [3–5]. The families Tenuipalpidae, Tarsonemidae, and Eriophyidae have been recognized for their economic importance as vectors of plant viruses, such as the citrus leprosis virus and the coffee ringspot virus, which are transmitted during feeding [4,6,7]. A species of mite that affects 100% of blackberry crops in Mexico and other countries is *Acalitus essigi* (Eriophyidae) due to its feeding behavior on shoots and fruits [8]. Despite the considerable damage caused by these mites, there are few studies on phytophagous mites in blackberry. In addition, most of the studies have been carried out on commercial cultivars [9,10] and none on wild plants.

Around 7000 species of phytophagous mites have been detected worldwide, belonging to the Eriophyoidea and Tetranychidae families [11–13]. The species that act as disease vectors are found in the Tenuipalpidae and Tarsonemidae families [4,6,7]. Within the agricultural sector, natural mites represent limited diversity; however, these arthropods are relevant due to their relative abundance, which causes damage to different crops and consequently incurs significant economic losses [14]. Currently, 39 species of mites have been recorded as associated with blackberries, and among the most relevant phytophagous species are *Acalitus essigi* Hassan, *Phyllocoptes gracilis* Nalepa (Acari: Eriophyidae), *Brevipalpus phoenicis* Geikskes (Acari: Tenuipalpidae), and *Tetranychus urticae* Koch (Acari: Tetranychidae) [15–17]. This information shows a significant set of phytophagous mites that in turn constitute a phytosanitary problem in blackberries and other similar fruits that must be investigated and evaluated. To date, *Tetranychus urticae* has been identified as the sole agent responsible for damage to blueberries [18]. The order Trombidiformes, a group of mites with remarkable morphological diversity, includes 21 species recognized worldwide [19–21]. Within the families of phytophagous mites, such as the Eriophyidae family, eriophyids are the smallest known arthropods and are distributed at all latitudes except the poles. They are strictly phytophagous and are associated with a wide variety of hosts, causing damage such as leaf curl; abnormal foliage growth; the development of papillary projections on the underside of leaves, known as “erinea;” and the formation of galls. They can also act as vectors of viruses and other pathogens [22].

The Tydeidae family comprises a group of mites with diverse feeding habits, including phytophagy, mycophagy, and, in some cases, predatory behavior. There are approximately 374 species grouped into 58 genera. The Tarsonemidae family has 530 species grouped into 40 genera. The Tenuipalpidae family, known as “flat mites” or “false red spiders,” are phytophagous, with approximately 800 species grouped into 30 genera. The Tetranychidae family is strictly phytophagous. The family is represented by 1000 species grouped into 70 genera, with the genera *Tetranychus*, *Eotetranychus*, *Oligonychus*, and *Panonychus* being the most common [6]. Research on mite families is limited to blackberry crops, and studies on mites associated with wild blackberry plants are even scarcer. In a study conducted in Brazil on blackberry varieties, Marchetti and Juárez-Ferla [15] documented 12 families, with the Diptilomiopidae and Tetranychidae families being the most prevalent. In Mexico, Ayala-Ortega [22] mentions 10 families of mites associated with this crop in two municipalities of Michoacán, including Tenuipalpidae, Diptilomiopidae, Phytoseiidae and Tetranychidae, the families that presented the highest number of mites. Vargas-Madriz et al. [23] mention 13 families of mites found in blackberries in Jalisco, and Tetranychidae, Eriophyidae,

Phytoseiidae, and Diptilomiopidae were the families with the highest abundance. Studies conducted in Mexico and Brazil report Tetranychidae, Diptilomiopidae, and Eriophyidae the prevalent families in cultivated blackberry varieties [9,10,16]. However, little information is available regarding the population dynamics of these families throughout the agricultural cycle of this crop and their distribution within different layers of the plant. Moreover, it remains unknown whether the presence of these mites negatively affects the physicochemical properties of the fruit, such as firmness, color, and vitamins, of wild and cultivated blackberries. Studies have reported that *Tetranychus urticae* causes negative effects on the physicochemical properties of the fruit [24]. The aim of the present study was to determine the population fluctuations of phytophagous mite families in wild and cultivated blackberries (*Rubus* spp. L.) and assess their impact on fruit quality parameters.

2. Materials and Methods

2.1. Plant Material and Study Area

The study was conducted in two locations in the state of Jalisco, Mexico. Wild blackberry samples were collected in Telcruz, Municipality of Cuautitlán de García Barragán (19°34′33.2″ N, 103°44′31.9″ W; 1659 m.a.s.l.). Cultivated blackberry samples were collected in Rancho Tecamo, Municipality of Sayula (19°52′17″ N, 103°36′43″ W; 1352 m.a.s.l.). In the cultivated system, blackberry plants were managed under conventional practices, including routine phytosanitary applications. The wild blackberry site was a natural system with no agronomic intervention or agrochemical application during the study period.

2.2. Mite Sampling and Collection

Sampling was conducted monthly from November 2023 to May 2024. The samples were taken randomly between 10:00 a.m. and 12:00 p.m. along a 500 m transect. Samples were taken directly [25]. Thirty plants were randomly selected per site, from which the basal, middle, and upper layers were sampled, cutting 15 leaves from each layer using pruning shears (secateurs) (Fiskars PowerGear2® Pruner, Model 392792-1003, Fiskars®, Espoo, Finland), this to ensure random representation throughout the plot. In addition, flower buds, young and senescent vegetative shoots, and fruits (if present) were collected. Samples were placed in 250 mL plastic containers (Rubbermaid®, Atlanta, GA, USA) and preserved in 70% ethanol (prepared from absolute ethanol, J.T. Baker®, Phillipsburg, NJ, USA, diluted with distilled water to the final concentration). The containers were then taken to the viral insect and mite vector laboratory at the Colegio de Postgraduados-Montecillo Campus in Texcoco (State of Mexico).

2.3. Mite Extraction, Mounting, and Identification

The mite extraction was carried out using the washing technique described by Castiglioni and Navia [26]. The foliage was immersed in a water and soap solution (1 L of water and 0.5 mL of liquid soap) then filtered through a stainless steel test sieve (Model 5217, No. 400 mesh, 38 µm opening; Hogentogler & Co., Inc., Columbia, MD, USA), and the residue was rinsed with 70% ethanol. The filtrate was placed in a Steriplan® Petri dish (90 × 15 mm, Art. No. PY88.1; DWK Life Sciences [Carl Roth GmbH + Co. KG], Karlsruhe, Germany), and individuals were counted by family under a Stemi DV4R® stereomicroscope (Carl Zeiss®, Oberkochen, Germany) using a four-digit manual counter (model HS6594; Heathrow Scientific, Vernon Hills, IL, USA).

Mites were mounted on slides with Hoyer's solution, except for the superfamily Eriophyoidea, which was mounted with modified Berlese medium. The slides were placed on a hot plate at 60 °C for 15 days to allow the fixative to evaporate. The slides were sealed with black vinyl spray paint (Rust-Oleum Specialty Black Vinyl Spray Paint, Model

1909830; Rust-Oleum Corporation, Vernon Hills, IL, USA). [11,27]. Families were identified using the taxonomic keys of Lindquist et al. [28] and Krantz [29]. The validation of the families was conducted by Dr. Jesús Alberto Acuña-Soto, a specialist in phytophagous mites. Relative abundance (RA) was calculated using the formula $RA = n/N \times 100$, as proposed by Ayala-Ortega et al. [10], where “*n*” is the number of individuals of a given family and “*N*” is the total number of mites recorded. Feeding habits were observed in the laboratory before deployment and confirmed by bibliographic references. The field data were entered into an Excel spreadsheet using Microsoft® Excel, version 16.0 (Microsoft Corporation, Redmond, WA, USA) to produce graphs of the results.

2.4. Fruit Quality Evaluation

A total of 72 healthy fruits and 72 mite-damaged fruits were evaluated from each treatment, each fruit being considered an experimental unit. The physical (weight, firmness, length, diameter, and color) and physicochemical (°Brix, titratable acidity, and vitamin C) properties were analyzed. The plant samples used to evaluate physicochemical characteristics were collected from the same representative site where the mite sampling was conducted: wild fruits from Telcruz, Cuautitlán de García Barragán, and cultivated fruits from Rancho Tecamo, Sayula. Fruits were collected monthly, from November 2023 to May 2024, from multiple randomly selected shrubs within each orchard. Each location was considered an experimental unit throughout the study period.

2.4.1. Physical Variables

The fruit weight (g) was determined with a portable electronic scale (Scout Pro SP202, Ohaus®, Parsippany, NJ, USA) with an accuracy of 0.01 g. The firmness (N) was measured at the equatorial zone of the fruit using a digital texturometer (Compact Gage, Mecmesin CE®, Slinfold, UK) mounted on a bench with a conical probe (9 mm diameter and height).

Fruit length and equatorial diameter (mm) were measured with a digital caliper (Model 122200, Surtek®, Mexico City, Mexico). The color was quantified on the epidermis in the equatorial region using a portable sphere spectrophotometer (X-Rite SP-62®, Grand Rapids, MI, USA), which provided CIE 1976 (Lab*) coordinates [30]. Chroma [$C^* = (a^2 + b^2)^{1/2}$] and the hue angle [$\arctan^{-1}(b/a)$] were then calculated.

2.4.2. Physicochemical Variables

Titratable acidity (% citric acid) was determined according to the AOAC Official Method 942.15 as described in the Official Methods of Analysis of the Association of Official Analytical Chemists [31], with minor modifications. Briefly, ten grams of fruit were homogenized in 50 mL of distilled water. Then, a 10 mL aliquot of this solution was titrated with 0.1 N NaOH (BDH Chemicals, Poole, Dorset, UK; prepared from pellets) using 1% (*w/v*) phenolphthalein (Merck KGaA, Darmstadt, Germany) as an indicator. The total soluble solids (°Brix) were measured using a digital handheld refractometer (PAL-1®, Atago Co., Ltd., Tokyo, Japan), with a scale from 0 to 53°. Vitamin C (ascorbic acid) was estimated following the AOAC Official Method 967.21, also known as the Tillmans method or DFI-2 [31], using 2,6-dichlorophenol-indophenol sodium salt dihydrate (Sigma-Aldrich, St. Louis, MO, USA) as the titrant. Afterward, a 10 mL aliquot was taken from a mixture of 5 g of finely chopped fruit homogenized in 50 mL of oxalic acid (analytical grade; R&M Chemicals, Selangor, Malaysia).

2.5. Statistical Analysis

Statistical analyses were performed to assess population fluctuations of phytophagous mites and quality differences in blackberry fruit. The statistical analysis checked for the normality and homogeneity of the data; however, the assumptions required for parametric

tests were not met. Therefore, nonparametric tests were applied. The number of mites recorded in the lower, middle, and upper layers of cultivated and wild plants was analyzed using the nonparametric Kruskal–Wallis test, followed by a post hoc comparison of means with a significance level of $p < 0.05$. The nonparametric Wilcoxon independent samples test ($p < 0.05$) was used to assess fruit quality (healthy and damaged samples). Lower and upper limits were also calculated for each variable. All analyses were performed using SAS[®] software, version 9.3 (SAS Institute Inc., Cary, NC, USA).

3. Results

During the study 6438 mites were collected, of which 4984 were obtained from cultivated blackberry plants and 1454 from wild blackberry plants. Six families of phytophagous mites from the order Trombidiformes were detected in both cultivated and wild fruit: Diptilomiopidae, Eriophyidae, Tydeidae, Tarsonemidae, Tenuipalpidae, and Tetranychidae.

3.1. Relative Abundance and Population Fluctuation of Phytophagous Mite Families in Cultivated Blackberry (*Rubus* spp. L.)

According to the results, the most representative family was Eriophyidae, with 1707 mites representing 34.2% of the relative abundance (RA), followed by Tetranychidae with 27.6%, Diptilomiopidae with 26.2%, Tarsonemidae with 5%, Tenuipalpidae with 4.3%, and Tydeidae with 2.7% (Figure 1). The RA indicates that the Eriophyidae, Tetranychidae, and Diptilomipidae families in the cropping system could contribute to fruit damage in conventional production systems.

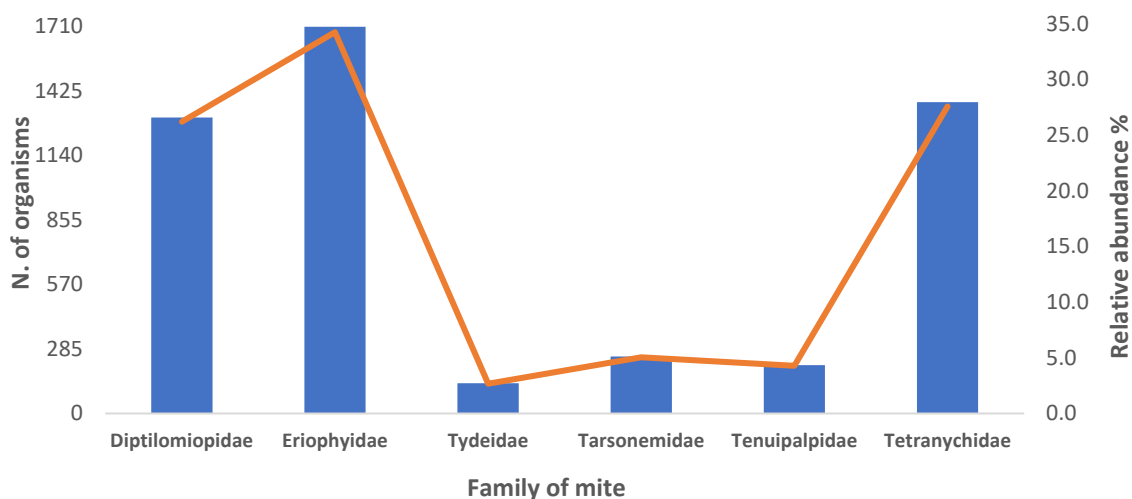


Figure 1. Number of organisms and relative abundance (%) of mite families associated with cultivated blackberry plants.

The population fluctuation of phytophagous mites in blackberry crops showed higher numbers/abundance from February to May 2024 ($p = 0.0001$) compared to November to January 2023. A higher number of mites was observed in March ($n = 95.39$), April ($n = 53.61$), February ($n = 51.67$), and May ($n = 31.67$) of 2024 than in January ($n = 10.83$), November ($n = 6.28$), and December ($n = 2.94$) of 2023 (Figure 2).

The Diptilomiopidae family showed the highest population density in the months of 2023, with the highest density of 108 mites occurring in December. On the other hand, an increase in population was observed in the Eriophyidae and Tetranychidae families in the months of 2024, with the highest values of 567 and 632 mites occurring in February and January, respectively (Figure 3).

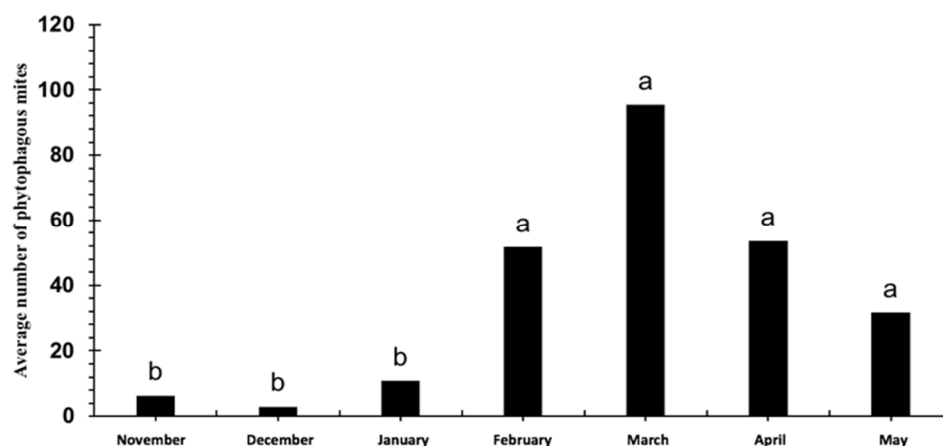


Figure 2. Statistical analysis of the average number of phytophagous mites recorded from November to May in cultivated blackberry plants. Different letters indicate significant differences ($p < 0.05$).

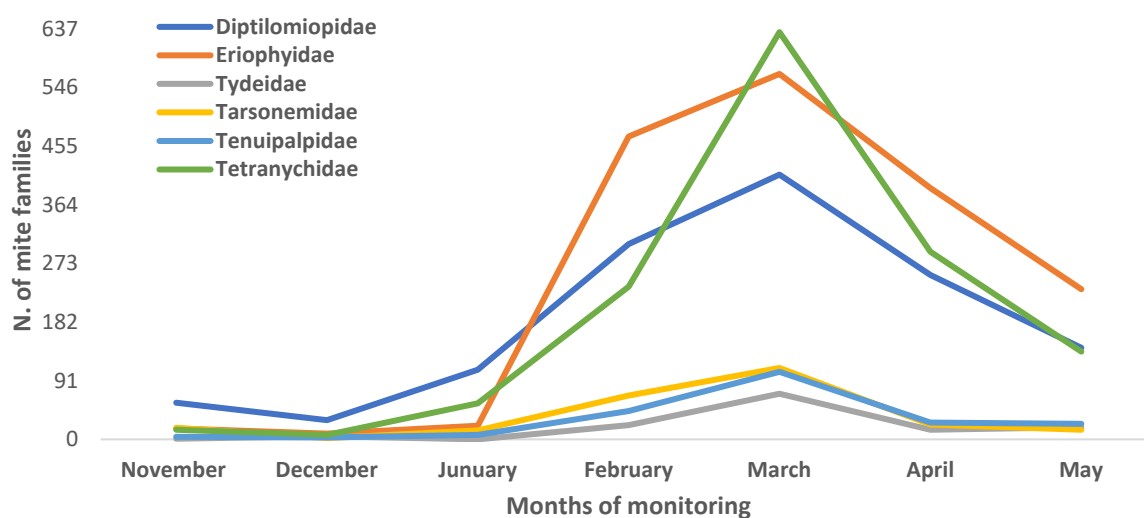


Figure 3. Population fluctuation of phytophagous mite families in cultivated blackberry plants.

3.2. Spatial Distribution of Phytophagous Mite Families on Cultivated Blackberry Plants

The phytophagous mite families present in the different plant layers (low, medium, and high) were Diptilomiopidae, Eriophyidae, Tydeidae, Tarsonemidae, Tenuipalpidae, and Tetranychidae. Significant differences were found between the different plant strata during the sampling period ($p = 0.0001$). A higher number of mites was detected in the upper ($n = 54.4$) and middle ($n = 48.26$) layers of the plant than in the lower layer ($n = 5.5$) (Figure 4).

Interestingly, it was observed that all mite families were found on leaves, while only the family Eriophyidae was found on the shoots and fruits in all plant layers (Table 1). In the lower layer of the plant, no differences in the number of mites per family were observed ($p = 0.1905$). In contrast, statistically significant differences in the number of mites recorded per family were found in the middle and upper layers of the plant ($p = 0.0187$ and $p = 0.0013$, respectively).

The highest number of mites from the families Tetranychidae ($n = 104.71$), Eriophyidae ($n = 79$), and Diptilomiopidae ($n = 73.14$) were recorded in the middle layer of the plant. The number of mites from these families was statistically higher ($p < 0.05$) than those from the families Tenuipalpidae ($n = 14.71$), Tarsonemidae ($n = 11.29$), and Tydeidae ($n = 6.71$) (Figure 5).

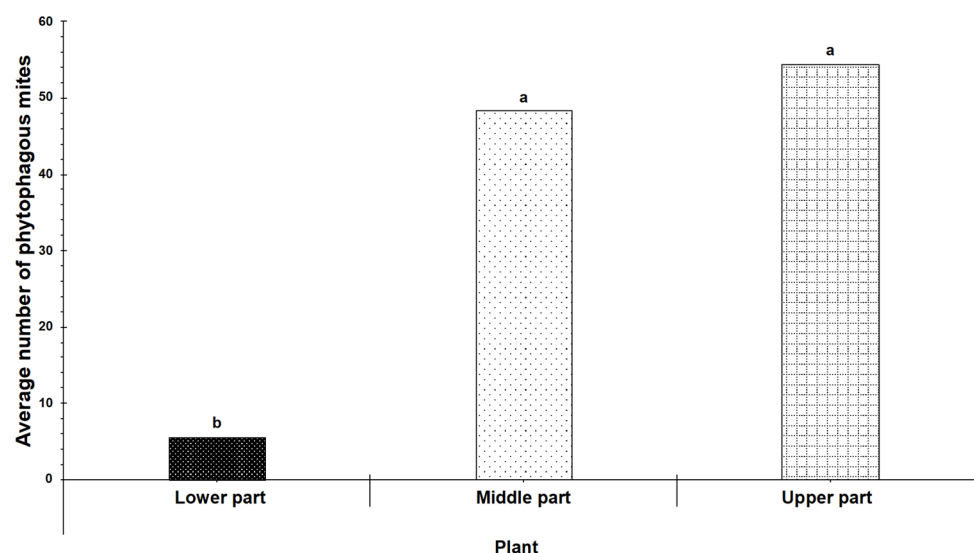


Figure 4. Statistical analysis of the average number of phytophagous mites recorded in the lower, middle, and upper layers of cultivated blackberry plants. Different letters indicate a significant difference ($p < 0.05$).

Table 1. Distribution of phytophagous mite families in the different strata of cultivated blackberry plants.

Mite Family	Lower Layer	Middle Layer	Upper Layer
Eriophyidae	214	553	940
Tetranychidae	177	733	464
Diptilomiopidae	81	512	713
Tarsonemidae	138	79	34
Tenuipalpidae	45	103	65
Tydeidae	17	47	69

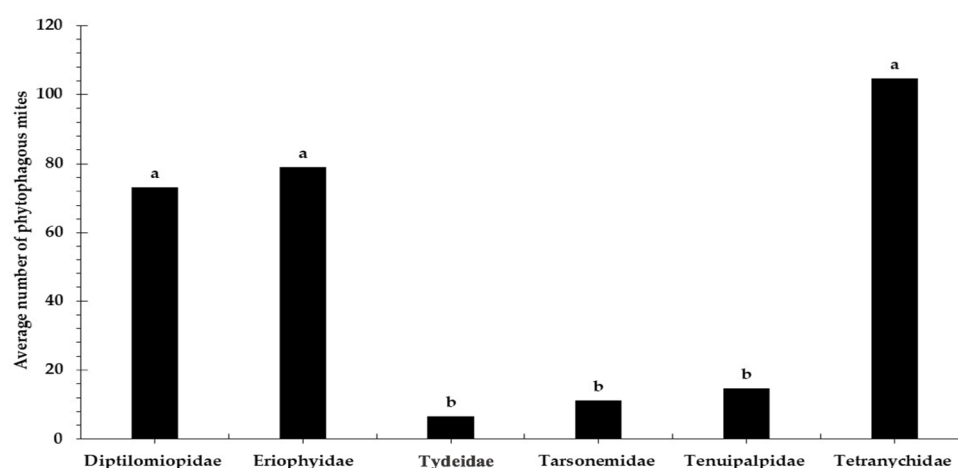


Figure 5. Statistical analysis of the average number of phytophagous mite families recorded in the midsection of cultivated blackberry plants. Different letters indicate a significant difference ($p < 0.05$).

In the upper layer of the plant, the highest number of mites was found in the families Eriophyidae ($n = 134.29$), Diptilomiopidae ($n = 101.86$), and Tetranychidae ($n = 66.29$). The number of mites in these families was similar and statistically higher ($p < 0.05$) than that of the families Tydeidae ($n = 9.86$), Tenuipalpidae ($n = 9.29$), and Tarsonemidae ($n = 4.86$) (Figure 6).

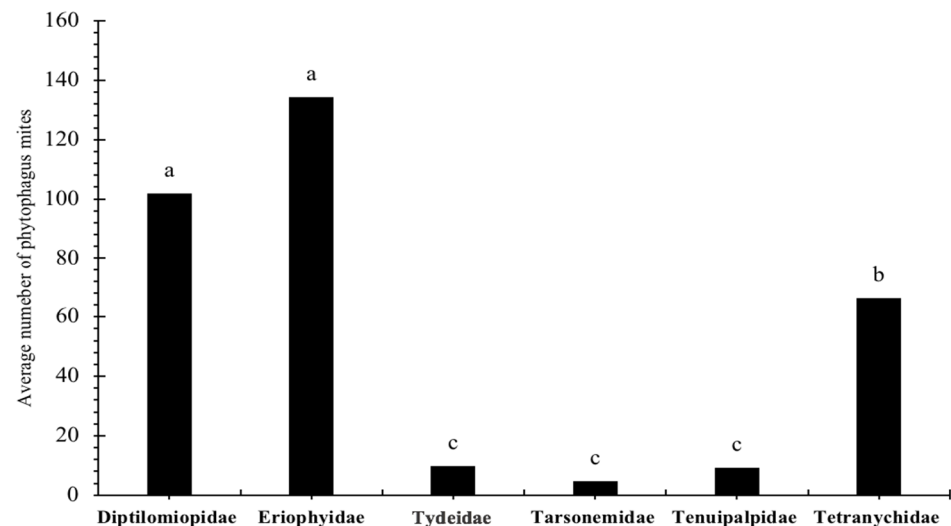


Figure 6. Statistical analysis of the average number of phytophagous mite families recorded in the upper part of cultivated blackberry plants. Different letters indicate a significant difference ($p < 0.05$).

The average number of mites from the families Tetranychidae ($p = 0.0223$) and Eriophyidae ($p = 0.1743$) showed no statistically significant differences between the different plant layers. In contrast, a statistically significant difference was found in the average number of mites from the family Diptilomiopidae between the lower, middle, and upper plant layers ($p = 0.0062$). Mites from this family were found in greater numbers in the upper ($n = 101.86$) and middle ($n = 73.14$) plant layers. The number of mites in these plant layers was similar and significantly higher than in the lower layer ($n = 11.57$). In the other three families (Tydeidae, Tarsonemidae, and Tenuipalpidae), no statistically significant differences were observed ($p > 0.05$).

3.3. Relative Abundance and Population Fluctuation of Phytophagous Mite Families on Wild Blackberry (*Rubus* spp. L.)

On wild blackberry plants, the most representative family was Tetranychidae with 461 specimens, accounting for 31.71% of the RA, followed by Diptilomiopidae with 27.24% of the RA. The family Eriophyidae accounted for 23.11% of the RA, while the family Tarsonemidae accounted for 6.67% of the RA. Finally, the families Tydeidae and Tenuipalpidae accounted for 5.64% of the RA (Figure 7).

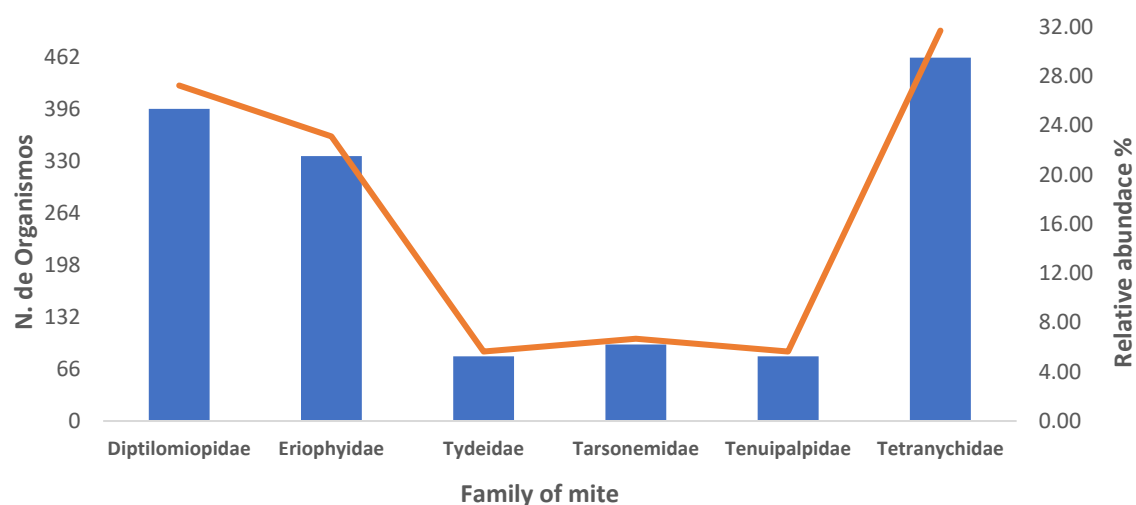


Figure 7. Numbers of organisms and relative abundance of mite families associated with wild blackberry plants.

A higher number of mites was detected in 2024 than 2023. A higher number of mites was detected in the months April ($n = 28.44$), May ($n = 19.94$), March ($n = 18.83$), and February ($n = 9$), with significant differences ($p = 0.0001$) compared to the other months (Figure 8).

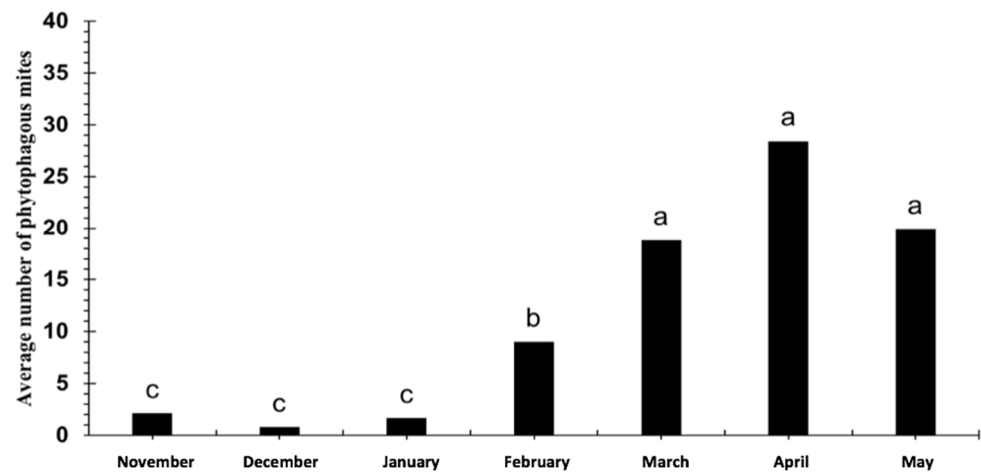


Figure 8. Statistical analysis of the average number of phytophagous mites recorded from November to May on wild blackberry plants. Different letters indicate a significant difference ($p < 0.05$).

The family with the highest population density was Tetranychidae in November with 27 mites; Eriophyidae in December with 4 mites; Diptilomiopidae and Tetranychidae in January with 12 mites each; Eriophyidae in February with 54 mites; Tetranychidae in March with 120 mites; and Diptilomiopidae in April and May with 145 and 116 mites, respectively (Figure 9).

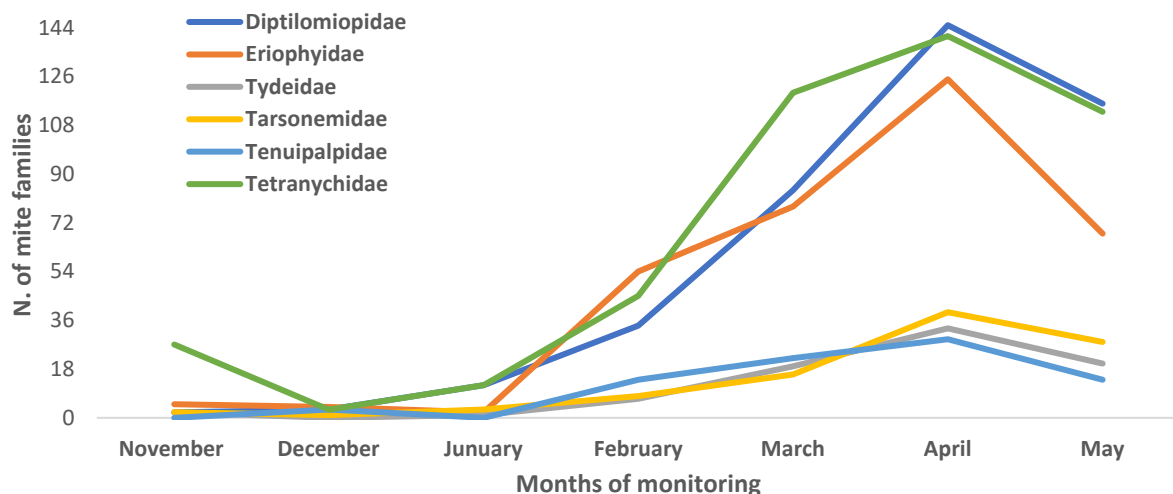


Figure 9. Population fluctuation of phytophagous mite families on wild blackberry plants.

3.4. Spatial Distribution of Phytophagous Mite Families on Wild Blackberry Plants

The six families of phytophagous mites were recorded in different plant strata (low, medium, and high). Differences were only found between the low and medium strata ($p < 0.05$). The lowest stratum had the lowest number of mites, while the upper stratum had intermediate values. At the field level, an average of 5.5, 8.79, and 20.33 mites were detected in the low, medium, and high strata, respectively (Figure 10).

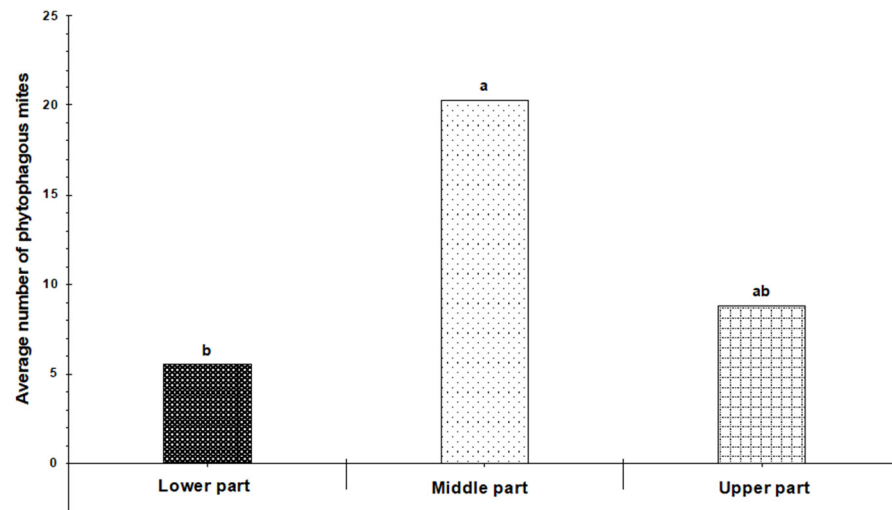


Figure 10. Statistical analysis of the average number of phytophagous mites recorded in the lower, middle, and upper layers of wild blackberry plants. Different letters indicate significant differences ($p < 0.05$).

The mite families Diptilomiopidae, Eriophyidae, Tydeidae, Tarsonemidae, Tenuipalpidae, and Tetranychidae were observed on leaves; however, the Eriophyidae family was also observed on shoots and fruits in different layers of the plant (Table 2).

Table 2. Distribution of phytophagous mite families in the different strata of wild blackberry plants.

Mite Family	Lower Layer	Middle Layer	Upper Layer
Eriophyidae	7	9	320
Tetranychidae	98	138	225
Diptilomiopidae	51	107	238
Tarsonemidae	59	38	0
Tenuipalpidae	13	36	33
Tydeidae	3	41	38

Statistically significant differences in the number of mites recorded per family were observed in the lower, middle, and upper layers of the plant ($p = 0.0080$, $p = 0.0122$, and $p = 0.0021$, respectively). In the lower layer of the plant, the highest number of mites was observed in the families Tetranychidae ($n = 14$), Tarsonemidae ($n = 8.43$), and Diptilomiopidae ($n = 7.29$). The number of mites in these families was similar and significantly higher than in the families Tenuipalpidae ($n = 1.86$), Eriophyidae ($n = 1$), and Tydeidae ($n = 0.43$) (Figure 11).

In the middle layer of the plant, the highest number of mites was found in the families Tetranychidae ($n = 19.71$) and Diptilomiopidae ($n = 15.29$). The number of mites in these families was similar and significantly higher than that of the families Tydeidae ($n = 5.86$), Tarsonemidae ($n = 5.43$), Tenuipalpidae ($n = 5.14$), and Eriophyidae ($n = 1.29$) (Figure 12).

In the upper layer of the plant, the highest number of mites was found in Eriophyidae ($n = 45.71$), Diptilomiopidae ($n = 34$), and Tetranychidae ($n = 32.14$). The number of mites in these families was similar and significantly higher than that in the families Tydeidae ($n = 5.43$), Tenuipalpidae ($n = 4.71$), and Tarsonemidae ($n = 0$) (Figure 13).

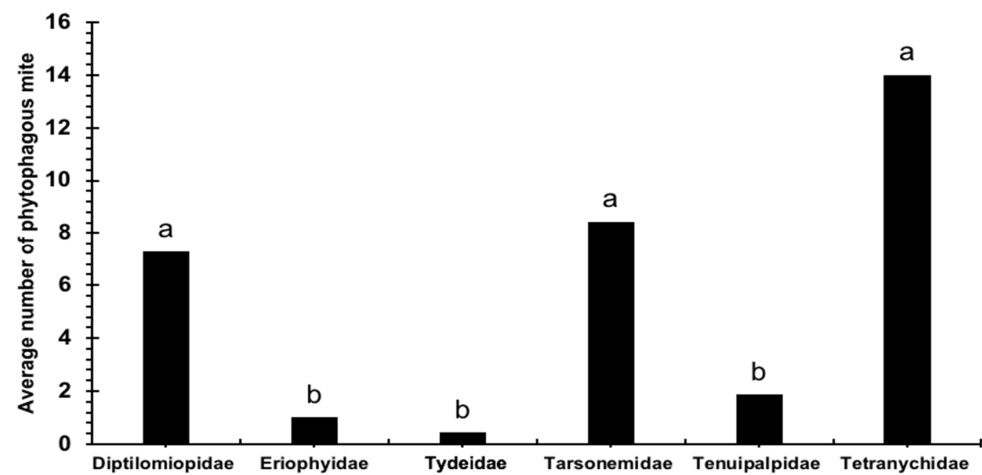


Figure 11. Statistical analysis of the average number of phytophagous mites from each family recorded in the lower layer of wild blackberry plants. Different letters indicate a significant difference ($p < 0.05$).

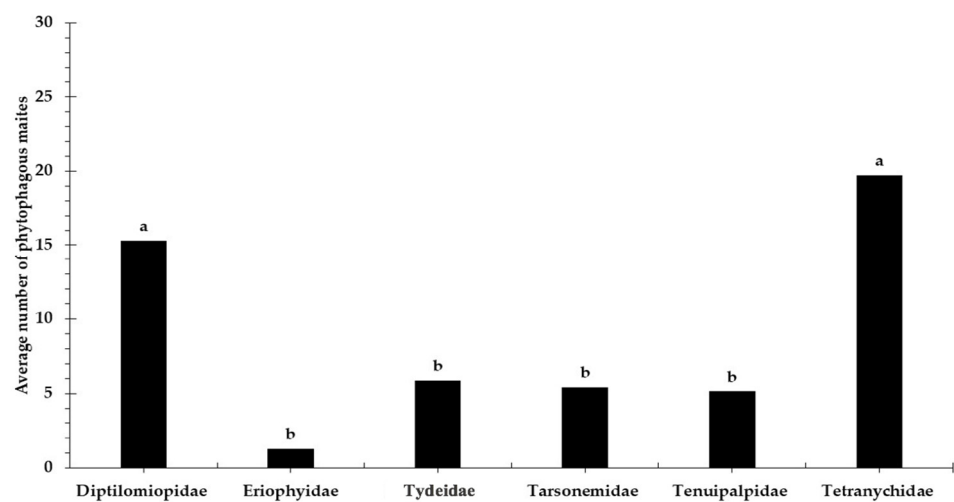


Figure 12. Statistical analysis of the average number of phytophagous mites from each family recorded in the middle layer of wild blackberry plants. Different letters indicate a significant difference ($p < 0.05$).

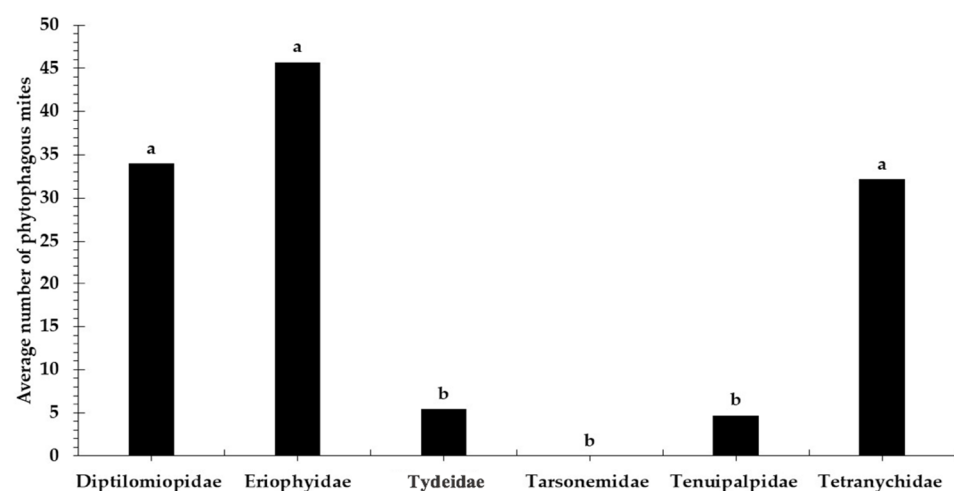


Figure 13. Statistical analysis of the average number of phytophagous mites from each family is recorded in the upper stratum of wild blackberry plants. Different letters indicate a significant difference ($p < 0.05$).

The family Eriophyidae showed a significantly different distribution between the lower, middle, and upper plant layers ($p = 0.0018$), while the families Tetranychidae and Diptilomiopidae showed no significant differences between the different plant layers ($p = 0.6501$ and $p = 0.0901$, respectively). Mites of the family Eriophyidae were found in higher numbers in the upper layer ($n = 45.71$) than in the middle ($n = 1.0$) and lower ($n = 1.29$) layers of the wild blackberry plants. As for the three remaining families (Tydeidae, Tarsonemidae, and Tenuipalpidae), no statistically significant differences were observed between strata.

3.5. Determination of Quality Parameters of Cultivated Blackberry (*Rubus* spp. L.) Fruits

3.5.1. Physical Properties of Cultivated Blackberry Fruits

The results of the physical characteristics of the cultivated blackberry fruits showed a significant difference ($p < 0.05$) between healthy and damaged fruits in relation to the different variables of this study (weight, firmness, length, diameter, L, Hue (a), and chroma (b)). The results showed that healthy fruits were better quality compared to damaged fruits (Table 3).

Table 3. Statistical analysis of quality parameters of cultivated blackberry fruits.

Variable	Damaged Fruit	Healthy Fruit	<i>p</i>	Damaged Fruit		Healthy Fruit	
				LI	LS	LI	LS
Physical Variables							
Weight (g)	4.49 ± 1.44 ^b	6.1 ± 1.22 ^a	0.0001	4.15	4.83	5.81	6.38
Firmness (N)	40.84 ± 19.25 ^a	29.81 ± 19.70 ^b	0.0002	36.31	45.36	25.18	34.44
Length (mm)	22.28 ± 3.72 ^b	26.78 ± 2.48 ^a	0.0001	21.41	23.16	26.19	27.36
Diameter (mm)	18.11 ± 2.00 ^b	21.19 ± 1.98 ^a	0.0001	17.64	18.58	20.73	21.65
L (mm)	31.23 ± 9.23 ^a	26.8 ± 6.03 ^b	0.0031	29.06	33.4	25.38	28.22
Hue (a)	1.06 ± 1.60 ^a	0.82 ± 0.24 ^b	0.0187	0.69	1.44	0.77	0.68
Chroma (b)	4.97 ± 1.46 ^a	3.97 ± 2.00 ^b	0.0014	4.63	5.31	3.5	4.44
Physicochemical Variables							
°Brix (%)	0.76 ± 0.22 ^a	0.83 ± 0.16 ^a	0.1914	0.7100	0.8200	0.8000	0.8700
Titrateable Acidity (%)	80.07 ± 19.10 ^a	71.54 ± 15.98 ^b	0.0177	75.580	84.560	67.790	75.300
Vitamin C (mg/100 g)	4.76 ± 1.53 ^b	5.31 ± 0.83 ^a	0.0008	4.4000	5.1200	5.1300	5.5300

LI = lower limit; LS = upper limit. Different superscript letters indicate statistically significant differences between groups ($p < 0.05$).

3.5.2. Physicochemical Properties

The results showed differences ($p < 0.05$) in the titrateable acidity and vitamin C variables between healthy and damaged fruit. Damaged fruit had a higher titrateable acidity, while healthy fruit had a higher vitamin C content. No significant differences were found between the two fruits for the °Brix variable (Table 3). The differences found confirm that mites cause damage that compromises the physicochemical properties of fruits, which can lead to commercial losses.

3.6. Determination of Quality Parameters of the Fruits of Wild Blackberry (*Rubus* spp. L.)

3.6.1. Physical Properties of Wild Blackberry Fruits

The results showed significant differences ($p < 0.05$) between healthy and damaged fruits in terms of weight, length, diameter, and chroma (b). No significant differences were found for the variables firmness, L, or hue (a) (Table 4).

Table 4. Statistical analysis of quality parameters of wild blackberry fruits.

Variable	Damaged Fruit	Healthy Fruit	<i>p</i>	Damaged Fruit		Healthy Fruit	
				LI	LS	LI	LS
Physical Variables							
Weight (g)	1.41 ± 0.89 ^b	2.44 ± 1.03 ^a	0.0001	1.2	1.62	2.2	2.69
Firmness (N)	28.98 ± 17.81 ^a	26.78 ± 16.24 ^a	0.6632	24.78	33.18	22.97	30.6
Length (mm)	13.33 ± 4.01 ^b	17.06 ± 3.26 ^a	0.0001	12.39	14.28	16.3	17.83
Diameter (mm)	13.31 ± 2.44 ^b	15.31 ± 2.10 ^a	0.0001	12.73	13.88	14.82	15.8
L (mm)	22.79 ± 4.49 ^a	21.85 ± 1.81 ^a	0.6034	21.74	23.85	21.42	22.27
Hue (a)	3.75 ± 19.62 ^a	0.088 ± 0.41 ^a	0.0944	−0.86	8.36	0.78	0.97
Chroma (b)	2.64 ± 1.11 ^a	2.05 ± 0.73 ^b	0.0001	2.38	2.9	1.88	2.22
Physicochemical Variables							
°Brix (%)	0.68 ± 0.17 ^a	0.68 ± 0.22 ^a	0.8672	0.6400	0.7200	0.6200	0.7300
Titrateable Acidity (%)	71.82 ± 24.76 ^a	64.56 ± 19.68 ^b	0.0125	66.000	77.640	59.930	69.180
Vitamin C (mg/100 g)	6.42 ± 2.22 ^a	6.54 ± 2.48 ^a	0.6361	5.9000	6.9400	5.9500	7.1200

LI = lower limit; LS = upper limit. Different letters indicate a significant difference ($p < 0.05$).

3.6.2. Physicochemical Properties of Wild Blackberry Fruits

In the physicochemical analysis, only the variable titrateable acidity showed a significant difference ($p < 0.05$) between the fruits, with the values of the healthy fruits being higher than those of the damaged ones. In addition, no significant differences were found between the °Brix value and the vitamin C content of the two fruit varieties (Table 4).

4. Discussion

The phytophagous mite families associated with both cultivated and wild blackberry plants in this study were Diptilomiopidae, Eriophyidae, Tydeidae, Tarsonemidae, Tenuipalpidae, and Tetranychidae. These findings are consistent with previous studies [3,4,23], which indicate that these mite families are strictly phytophagous and associated with a wide range of hosts ranging from perennial and annual plants to pines and weeds. It is important to clarify that in the present study only some representative species of each family were detected and evaluated, not all the species existing within these groups. These species can cause morphological damage to plants and act as vectors of plant pathogens.

Regarding the relative abundance (RA) of families in both cultivated and wild species, the Eriophyidae family had the highest RA of 34.2% in cultivated blackberry plants. In wild blackberries, in contrast, the *Tetranychidae* family had the highest RA at 31.71%. Both families are known for their phytophagous feeding habits and are of great economic importance for blackberry cultivation [10,16]. The significant RA of Tetranychidae can be attributed to the conventional management programs in the orchards. The inappropriate use of agrochemicals and fertilizers could promote an increase in tetranychid populations [32,33]. Additionally, mites from the family Eriophyidae, which live in the fruits and shoots of blackberry, enjoy protection from unfavorable environmental factors, predators, and acaricide applications [34], which would explain their high prevalence in the plant. Although Diptilomiopidae showed a higher RA than some other families, it is not considered economically important in agriculture as it feeds without causing appreciable damage to plants [35]. Furthermore, several biological aspects of this family are unknown [10,16,36]. However, their abundance suggests that further studies are needed to clarify their role in blackberry ecosystems. These studies highlight the feeding habits of these organisms that favor their protection from biotic and abiotic factors in their environment, which could explain their abundance.

Considering population fluctuation in cultivated and wild blackberry plants, an increase in mite populations has been observed since February, with the highest population peak in cultivated blackberry plants in March and in wild blackberry plants in April.

Marchetti and [16] and Ayala-Ortega [10] reported a similar population trend, observing an increase in mite densities from February onward and recording the highest population peak of mite families on blackberries in April. These studies, like this one, were conducted in Mexico, where seasonal conditions can influence the dynamics of phytophagous mite populations. Mite population peaks during March through May have also been documented in other studies [9,37]. These results are also related to the availability of fruit in terms of food quality, which favors an increase in mite populations, a pattern previously noted in the literature [23]. The families with the highest population density in both wild and cultivated blackberries were Diptilomiopidae, Eriophyidae, and Tetranychidae. This pattern of abundance has likewise been observed in Mexico and Brazil [9,10,16,37]. The greater abundance of these species is related to the plant's ability to utilize the available resources [23,27]. Regarding the spatial distribution of mite families, they were most frequently distributed in the middle and upper layers of cultivated plants, which is consistent with previous studies [36,37]. In wild blackberries, significant differences were observed between the different strata, with a higher number of phytophagous mites in the middle stratum compared to the lower stratum. These results coincide with those of Ayala-Ortega et al. [10], who collected similar numbers of mites in the shoots of the lower, middle, and upper parts of blackberry plants.

Mites from the families Diptilomiopidae, Eriophyidae, Tydeidae, Tarsonemidae, Tenuipalpidae, and Tetranychidae were collected from leaves of cultivated and wild blackberry plants. Only the family Eriophyidae was found on shoots, leaves, and fruits in all plant layers. The results on the distribution of the Eriophyidae family are consistent with previous reports [23], which indicate that it is common on blackberry shoots and fruits. Fathipour and Maleknia [38] point out that the distribution of mites is related to the characteristic feeding habits of each species. Within each family, some species utilize specific or multiple resources on the same plant, allowing them to avoid competition. However, the structure of the plant probably influenced the distribution of these families on the blackberry plants [39].

Regarding the results of the weight variable, healthy cultivated fruits had a higher weight compared to healthy wild fruits, yet there were differences between the weights of healthy and damaged fruits. These results differ from those of Ibáñez [40], who reported higher weights in wild blackberry fruits. It is worth mentioning that some authors have pointed out that the weight values vary depending on the plants and their management [41,42].

On the other hand, the firmness of damaged cultivated fruits showed higher values compared to healthy cultivated fruits, while wild fruits showed no significant differences. In contrast, Moreno and Deaquiz [43] and González-Jiménez et al. [44] reported lower firmness values compared to those observed in this study. These results could be related to possible structural changes in the plant, mainly related to the components of the cell wall of the fruit (polysaccharides) and to its stage of ripening [45].

The variables length and diameter were higher in healthy fruits than in damaged fruits of cultivated and wild blackberries. It has been documented that fruit shape can vary depending on the number of drupe seeds in each cultivar in the sense that the greater the number of drupe seeds, the more elongated the fruit [40]. González-Jiménez et al. [44] reported similar patterns regarding fruit size and drupelet distribution, consistent with our findings; however, these results differ from those documented by other authors [42,43,46].

Damaged fruits of cultivated and wild blackberries showed higher luminosity (L), hue (a), and chroma (b). The results for the variables luminosity (L) and chroma (b) may be due to changes in the liquid content of the fruit in addition to the degree of ripeness [47,48]. For the variable hue (a), the difference observed in this study could be

related to temperature as the development of hues ranging from deep red to dark purple requires warm days and cool nights [47,48]. No significant differences were found for °Brix, although the values obtained in this study were lower than those previously documented in other studies [40,44,46]. In the study by Pinzón et al. [49], it was found that sugar accumulation depends on the variety studied and the relationship between the source and demand of the plant.

Damaged fruits showed a higher titratable acidity compared to healthy fruits, both in cultivated and wild blackberries. The values reported in the present study differ from those previously reported for other species and cultivars [42,44]; this may be due to differences in metabolic activity or the ripening stage [36]. In contrast, healthy fruits presented higher amounts of vitamin C although lower than those reported by González-Jiménez et al. [44].

In Mexico, the flowering and harvesting stage of blackberry begins in December and ends in June, presenting slight differences in precocity according to the different varieties that exist [50,51]; therefore, a qualitative analysis of the seasonal pattern indicates that the periods of great abundance of the Eriophyidae family, especially in March and April, correspond with the blackberry fruiting season since it was the only family found in shoots and fruits. These results coincide with what observed in the significant decrease in fruit quality parameters, such as weight, size, vitamin C content, and titratable acidity, in both wild and cultivated blackberries. This trend was consistent across the evaluated fruits, thus corroborating the potential effect of eriophyids on fruit integrity. However, the cause has not been confirmed in the study, and these correlations suggest that large populations of this mite family could be contributing to the physical and nutritional damage to the fruit.

The above is related to the reports of several authors, such as Amrine and Stasny [52], Baker et al. [53], Trinidad and colleagues [54], Davies and his team [15], and Pye and Lillo [34]. These authors indicate that certain species of Eriophyidae on blackberry plants cause blisters on the buds and galls on plant petioles, which can limit the development of the branches. They also produce blisters on the underside of drupes and cause discoloration. Eriophyids are directly involved in fruit damage, and, in severe infestations, they can cause the fruit to dry out, decreasing its quality and resulting in sales losses.

In Mexico, three species of eriophyid mites associated with the fruits and buds of blackberries have been reported [55,56]; however, studies on their biology and behavior are scarce as they related the damage to the species found without conducting population dynamics and diversity studies [57]. For this reason, the management of eriophyids in blackberries is complex. It is thought that the control of these mites depends on the species found on the plant; in most cases, chemical products such as abamectin are used but with unfavorable results [58].

Szendrey et al. [59] indicated that the application of Calcium Polysulfide (Sulfur in Lime), Flufenzin, Fenpyroximate, and Piridaben showed better results. It was found that the application of chemical acaricides (Acequinocyl and Hexythiazox) followed by sequential applications of sulfur in lime has satisfactory results in terms of population density reduction. It has been shown that lime sulfur is effective in controlling eriophyid mites on blackberry [60]; however, this compound has also been considered disruptive for integrated mite control due to its effect on phytoseiids [61,62]. Additionally, programs based on soybean oil yielded satisfactory results, representing good alternatives for its application either in alternation or in blocks with lime sulfur to reduce the negative impacts of this compound on natural enemies of eriophyid mites [58].

5. Conclusions

Phytophagous mite families associated with both cultivated and wild blackberry plants included Diptilomiopidae, Eriophyidae, Tydeidae, Tarsonemidae, Tenuipalpidae, and

Tetranychidae. In cultivated blackberries, the family with the highest relative abundance of 34.2% was Eriophyidae, and in wild blackberries, the family with the highest relative abundance of 31.71% was Tetranychidae. Regarding population fluctuations, an increase in mite populations was observed starting in February, with the highest population peak occurring in cultivated blackberry plants in March, while in wild blackberry plants, the highest population peak was recorded in April, both coinciding with the fruiting period of the crop. The six families of phytophagous mites were distributed throughout all plant strata, primarily on the leaves. Only mites from the Eriophyidae family, in addition to being present on the leaves, were also found on the shoots and fruits. The results showed differences in the quality of healthy and damaged fruits (weight, firmness, length, and diameter) and in their physicochemical properties (titratable acidity and vitamin C content) between cultivated and wild blackberry plants. The negative impact of mites on blackberry plants and their fruits, as well as their commercial consequences, is also shown. The results obtained in this study allowed for the identification and monitoring of different families of mites associated with blackberry plants, as well as an understanding of their population dynamics and the impact they have on fruit quality. Although this study is descriptive in nature, its findings can contribute to future research and aid in the implementation of integrated pest management strategies.

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