

Original Research Paper

Leaf morphometric characterization of kermes oak (*Quercus coccifera*) in the Wilaya of Tlemcen

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Abstract

This study focuses on the description of kermes oak leaves in the wilaya of Tlemcen, (5 different regions) based on 10 characteristics (one qualitative and nine quantitative). It is also based on a study of the pilosity present on the petiole, the results of which enabled us to describe each area individually. Trees in the Ziaten region located near the sea had longer leaves than those in other regions (0.082 ± 3.687), as did the length of the petiole and the number of hairs present on it. On the other hand, the results showed that the trees in the Ifri region, far from the sea, have smaller, light and dark green leaves with similar proportions, as well as a reduced number and length of hairs. Analysis of the data enabled us to conclude correlations between qualitative and quantitative characteristics with their graphical representations, showing a strong correlation between leaf shape and colour, as well as the correlation between petiole length and leaf. As a result, varieties from different regions were classified according to qualitative and quantitative characteristics into new distinct categories, allowing us to see the morphological diversity of leaves in these regions. As well as the correlation between stem and leaf length.

Keywords: Description, Leaves, Morphology, petiole, hairs, Tlemcen, Characteristics, Qualitative and Quantitative.

المخلص

تركز هذه الدراسة على وصف أوراق البلوط القرمزي في ولاية تلمسان (5 مناطق مختلفة)، استنادًا إلى 10 خصائص (واحدة نوعية وتسع كمية). كما تستند أيضًا إلى دراسة التنوع الموجودة على السويقات، والتي مكنتنا نتائجها من وصف كل منطقة على حدة. كان للأشجار في منطقة الزياتين، الواقعة بالقرب من البحر، أوراق أطول من تلك الموجودة في المناطق الأخرى (0.082 ± 3.687)، وكذلك طول السويقة وعدد الشعيرات الموجودة عليها. من ناحية أخرى، أظهرت النتائج أن الأشجار في منطقة إفري، البعيدة عن البحر، كانت أوراقها أصغر حجمًا وذات لون أخضر فاتح وداكن بنسب متشابهة، وكذلك عدد وطول أقل من الشعيرات. وقد مكنتنا تحليل البيانات من استنتاج الارتباطات بين الخصائص النوعية والكمية مع تمثيلها البياني، حيث أظهرت وجود علاقة قوية بين شكل الورقة ولونها، وكذلك العلاقة بين طول السويقة والورقة. ونتيجة لذلك، تم تصنيف أصناف من مناطق مختلفة وفقًا للخصائص النوعية والكمية إلى فئات جديدة متميزة، مما سمح لنا برؤية التنوع المورفولوجي للأوراق في هذه المناطق، وكذلك العلاقة بين طول الساق وطول الورقة.

الكلمات المفتاحية:

الوصف، الأوراق، المورفولوجيا، الساق، الشعر، تلمسان، الخصائص، النوعية، الكمية

Introduction

The Mediterranean vegetation is the result of a complex interaction between climate, soil, and human activity, which has led to a high level of biological diversity in the region. This diversity, shaped by historical, paleoclimatic, ecological, and geological factors, as well as human influence, makes the Mediterranean flora an essential area of study. The Mediterranean basin offers a natural laboratory for studying plant adaptation to changing environments and exploring mechanisms of biodiversity. Furthermore, many Mediterranean plants have significant medicinal, food, and economic value, underscoring their importance.

Among the most iconic genera in the Mediterranean flora is *Quercus* (oak), a group that includes both deciduous and evergreen species of trees and shrubs. *Quercus* is one of the most widespread genera in the Fagaceae family, with several species playing a crucial role in the ecology of Mediterranean forests. In Algeria, oaks are a dominant component of the forest, covering approximately 40% of the nation's forested land, primarily in the north and northeast. Species such as holm oak (*Quercus ilex*), cork oak (*Quercus suber*), zeen oak (*Quercus canariensis*), kermes oak (*Quercus coccifera*), and afarès oak (*Quercus afares*) are characteristic of the Mediterranean vegetation in this region.

Among these species, *Quercus coccifera* (kermes oak) is native to Southern Europe, North Africa, and Asia Minor, thriving in dry, sunny environments with calcareous soils. In Algeria, *Q. coccifera* occupies approximately 51,000 hectares, predominantly in regions like Annaba, Blida, and Kabylie. The species plays an important ecological role, providing habitat for various organisms and influencing soil structure and carbon sequestration. Despite its widespread distribution and ecological significance, the morphological characteristics of *Q. coccifera* in Algeria have been relatively underexplored.

Previous studies have examined Mediterranean oaks in general, but there is a notable gap in research focused specifically on the morphological traits of *Q. coccifera* in Algeria. Existing literature offers broad descriptions of the species, but detailed morphological data especially concerning leaf morphology remain sparse. Furthermore, few studies have addressed how environmental factors contribute to morphological variation across different regions in Algeria. This lack of in-depth, region-specific data hampers effective taxonomic classification, conservation efforts, and ecological management of *Q. coccifera*.

This study aims to fill these critical gaps by providing a detailed morphological characterization of *Quercus coccifera* across five regions in the Tlemcen area. A unique aspect of this research is the combination of both qualitative and quantitative morphometric measurements, along with a microscopic analysis of trichomes, to assess leaf and vegetative structure. This multifaceted approach offers a more comprehensive understanding of the species' morphological diversity and adaptation to local environmental conditions. By exploring this variability, we seek to contribute to the broader knowledge of *Q. coccifera*'s phenotypic plasticity, which is vital for informed forest management and conservation practices in Algeria.

Materials and Methods

Presentation of the Study Areas:

The forests of Tlemcen, located in the far west of Algeria, cover an area of approximately 217,000 hectares, representing 24% of the Wilaya. The Tlemcen mountain range, with elevations ranging from 600 to 1800 meters, forms the region's primary silvicultural zone. The Wilaya is bordered by:

- The Mediterranean Sea to the north,
- Neighboring wilayas to the east and south,
- The Kingdom of Morocco to the west (BELLAHOUËL, 2020).

Selection of Study Stations

The study was conducted in five distinct stations to analyze the leaf morphometry of *Quercus coccifera* (kermes oak) in relation to climatic diversity and altitude. Stations were selected based on:

- Proximity to the sea
- Altitude variations
- Terrain morphology

Zones and Locations:

Zone A

- Ifrie Forest (Ain Fezza)
- Zarifet Forest (Terny Beni Hdiel)

Zone B

- Ziaten Forest (Dar Yghmouracene)
- Honaine
- Bab Teza Forest (Nadroma)

Criteria for Site and Tree Selection

Stations were selected based on:

- Environmental diversity (altitude, proximity to the sea)
- Accessibility for fieldwork
- Presence of robust *Q. coccifera* populations



Figure 1: Map of the study stations' location (Google Earth)

Trees were selected according to the following guidelines:

Minimum *10 meters apart* to avoid sampling genetically identical individuals

- Only *healthy, mature* trees were sampled
- Uniformity in *age, size, and microenvironment* was considered
- Avoidance of *hybridization zones*
- Alignment with best practices (Khan et al., 2013; Rohlf, 1993; Davis et al., 2007; Pang et al., 2018; Jiang et al., 2019)

Study Objectives

- To characterize *Q. coccifera* leaf morphology in Tlemcen
- To identify distinct populations through morphometric traits
- To assess *genetic variability* using biometric (quantitative and qualitative) descriptors

Fieldwork and Sampling

The fieldwork took place over *February–March 2023*, with *five sampling campaigns* across the selected stations.

- *750 leaves* were collected
- From *50 trees* (10 trees per station)
- *15 mature leaves* per tree
- Trees spaced *10–50 meters apart*

Morphometric Measurements

Collected leaves were subjected to both *macroscopic* and *microscopic* analysis.

Quantitative Parameters (9):

- Leaf Length (LL)
- Leaf Width (LR)
- Petiole Length
- Leaf Perimeter (Prm)
- Leaf Surface Area (Srf)
- Venation Angle (KGD)
- Hair Length (LP)
- Number of Hairs (NH)
- Number of Spines (NI)

Qualitative Parameter (1):

- Leaf Color:
 - Dark green
 - Light green

All measurements were performed using *ImageJ* software (NIH, 1987) for precision and reproducibility.

Microscopic Analysis of Petiole Hair Characteristics:

For the microscopic study, petiole hairs were examined under an optical microscope. The procedure involved:

Preparation of Samples: Using a sharp scalpel, small fragments of the petiole were dissected and mounted in glycerin on microscope slides.

Microscopic Observation: The prepared slides were observed under a microscope at 10x magnification. Hair length and number of hairs were measured using ImageJ software.

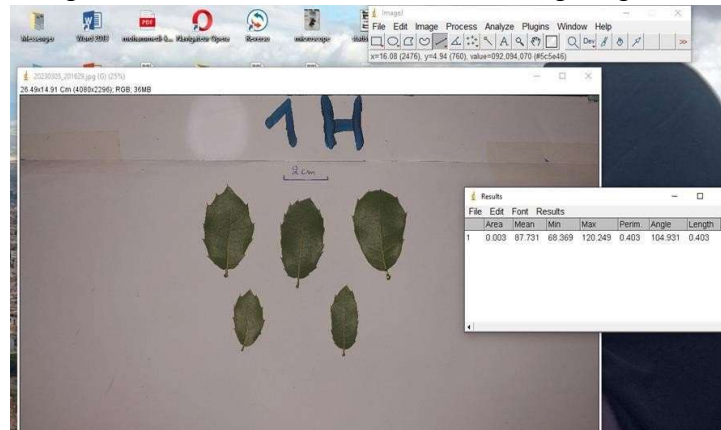


Figure 2: ImageJ Software (Picture: Original image of ImageJ software)

Materials used included:

Binocular Loupe: For observing hairs on the petiole.

Optical Microscope: Equipped with a camera for detailed image capturing and measurement.



Figure 3: Binocular Loupe (Picture: Original image of the binocular loupe)



Figure 4: Optical Microscope with Camera (Picture: Original image of the optical microscope)

Statistical Analysis

Statistical analyses were conducted using *IBM SPSS Statistics (version 21.0)*. A combination of *descriptive*, *comparative*, and *multivariate* techniques was applied to analyze the data, focusing on both *quantitative* and *qualitative* traits and their interrelationships.

Descriptive Statistics

For each quantitative trait (e.g., leaf length, petiole length), the following statistics were computed:

- *Mean*, *Standard deviation*, *Minimum*, and *Maximum* values

- Used to describe the *central tendency* and *dispersion* of morphological measurements within and across stations.

One-Way Analysis of Variance (ANOVA)

A *one-way ANOVA* was used to compare means of quantitative traits across the five study stations.

- *Null hypothesis (H_0)*: No significant differences exist among stations
- *Post-hoc analysis*: *Tukey HSD* test to identify pairwise differences
- *Significance threshold*: $p < 0.05$

This analysis assessed how *environmental factors* (e.g., altitude, proximity to the sea) influence leaf morphology.

Pearson's Correlation Coefficient

To assess *linear relationships between quantitative variables*, *Pearson's correlation* was used. This allowed identification of associations such as:

- Leaf length $\leftrightarrow$ Petiole length
- Leaf width $\leftrightarrow$ Surface area
- Number of spines $\leftrightarrow$ Number of hairs

Correlations were considered significant at $p < 0.05$, and *scatter plots* were used to visualize key relationships.

Chi-Square Test of Independence (χ^2)

To evaluate the relationship between *qualitative variables* (e.g., leaf color) and *categorical grouping variables* (e.g., station or zone), the *Chi-square test* was applied.

- This test determined whether *leaf color distribution* was significantly different across environmental zones (Zone A vs. Zone B).
- A result of $p < 0.05$ indicated a statistically significant dependency.

Correlation Between Qualitative and Quantitative Variables

To explore the *relationship between qualitative and quantitative traits*, the following approaches were used:

- **Point-Biserial Correlation:**
 - Applied to assess the correlation between *binary qualitative variables* (e.g., leaf color: light vs. dark green) and *quantitative variables* (e.g., leaf length, petiole length).
 - This test is a variant of Pearson correlation adapted for a *dichotomous variable*.
- **One-way ANOVA by Qualitative Trait:**
 - For example, ANOVA was used to determine if mean *leaf length* significantly differed between trees with *light vs. dark green leaves*.
 - This complemented the point-biserial approach, especially where the independent variable was categorical.

Principal Component Analysis (PCA)

PCA was used to:

- Reduce the complexity of the dataset
- Identify the **most informative variables**
- Visualize the grouping of individuals based on morphological similarity

Both **quantitative** and **qualitatively coded** data were included in the PCA to reflect multidimensional variability.

Hierarchical Cluster Analysis (HCA)

Using **UPGMA** and **Euclidean distance**, HCA grouped individuals based on shared morphological features. This revealed clusters corresponding to different ecological conditions or leaf types.

Data Visualization:

Graphs and tables were created to represent the relationships between quantitative and qualitative traits, as well as the seasonal and annual patterns of temperature, precipitation, and humidity. Statistical results were also displayed using box plots and scatter plots to illustrate the variation across the study sites.

Results and Discussion

Descriptive Analysis of Qualitative and Quantitative Parameters

Qualitative Parameter: The analysis of the qualitative parameters of *Quercus coccifera* leaves revealed two color classes: light green and dark green. The results show that the leaf color varies significantly across the study areas, with dark green being predominant (69.5%) compared to light green (30.5%).

Quantitative Parameter: The quantitative parameters analyzed include petiole length (LP), leaf length (LL), leaf width (LR), nervation angle (KGD°), surface area (Srf), perimeter (Prm), and number of spines (NI). These data were collected for each study zone: Ifri, Bab Taza, Honaine, Ziaten, and Zarifet.

The study analyzed qualitative and quantitative leaf traits of *Quercus coccifera* across five regions. Dark green leaves were more common (69.5%), likely due to environmental factors affecting chlorophyll content.

Significant differences ($p \leq 0.05$) were found in petiole length, leaf length, surface area, and number of spines, while leaf width, nervation angle, and perimeter showed no significant variation. Leaves in Ziaten were the largest, possibly due to coastal humidity, while smaller leaves in Zarifet may reflect adaptations to drier conditions. Spine density was highest in Honaine and Bab Taza, suggesting an adaptation to herbivory pressure. The leaves of Ziaten (3.687 cm) are significantly longer than those of Zarifet (2.989 cm), a pattern similar to that observed in *Quercus ilex* in Tunisia (Chaabane, 1993). This divergence could be explained by coastal humidity, as suggested by Tenhunen et al. (1984) for xerophytic species.

Correlations suggest that trichome density helps reduce water loss, and spine count serves as a defensive trait. These variations highlight adaptations to environmental conditions, emphasizing the influence of climate, altitude, and herbivore presence on leaf morphology. Further research integrating climate and soil data could enhance understanding of these ecological adaptations.

Association of Variables: The results indicate that variables related to leaf morphology (petiole length, leaf length, surface area, and number of spines) are statistically associated with leaf color, while other variables such as leaf width, nervation angle, and perimeter show no significant differences based on leaf color.

Tabel 1: Descriptive Analysis of Leaf Measurements

PARAMETER	REGION	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM
LP (PETIOLE LENGTH)	Ifri	0.3601	0.10677	0.12	0.66
	Bab Taza	0.3327	0.10388	0.11	0.62
	Honaine	0.3409	0.09365	0.14	0.71
	Ziaten	0.4259	0.11912	0.22	0.78
	Zarifet	0.3559	0.07633	0.21	0.67
LL (LEAF LENGTH)	Ifri	3.4028	0.83932	1.42	5.54
	Bab Taza	3.2907	0.92176	1.19	6.32
	Honaine	3.5485	0.83154	1.75	5.92
	Ziaten	3.6873	1.00948	2.02	7.29
	Zarifet	2.9898	0.73485	1.63	5.46
LR (LEAF WIDTH)	Ifri	1.7143	0.51295	0.73	3.11
	Bab Taza	1.8237	0.58998	0.60	4.02
	Honaine	1.8439	0.49700	0.89	3.25
	Ziaten	1.7121	0.52917	0.92	3.77
	Zarifet	1.7235	0.50490	0.90	3.74
KGD° (NERVATION ANGLE)	Ifri	64.9705	7.42582	42.50	86.33
	Bab Taza	65.4336	7.75973	47.33	84.32
	Honaine	68.1681	7.91764	47.18	86.71
	Ziaten	66.2293	8.91216	45.94	96.12
	Zarifet	66.5875	8.24888	40.79	87.28

SRF (SURFACE AREA)	Ifri	4.5758	2.34406	0.90	11.93
	Bab Taza	4.9196	2.56123	0.61	16.53
	Honaine	5.1127	2.32133	1.63	13.38
	Ziaten	5.4125	3.19545	1.67	23.12
	Zarifet	4.4039	2.38165	1.27	17.03
PRM (PERIMETER)	Ifri	12.3232	3.73198	6.02	21.69
	Bab Taza	11.8203	3.54977	4.05	23.58
	Honaine	12.0486	2.91098	6.77	21.88
	Ziaten	12.0581	3.50056	6.59	27.08
	Zarifet	10.8627	2.78977	5.35	19.38
NI (NUMBER OF SPINES)	Ifri	9.90	4.244	1	19
	Bab Taza	12.48	3.143	6	21
	Honaine	12.55	3.438	5	21
	Ziaten	11.92	3.831	3	22
	Ziaten	11.49	3.589	4	22

Analysis of Variance (ANOVA)

Variation of Variables According to Region: ANOVA results revealed significant differences ($p \leq 0.05$) for most of the studied morphological parameters, including petiole length (LP), leaf length (LL), nervation angle (KGD°), surface area (Srf), perimeter (Prm), and number of spines (NI). However, no significant difference was found for leaf width (LR).

Table 2: Variations of Variables According to the Region

PARAMETER	IFRI (N = 150)	HONAINE (N = 150)	BAB TAZA (N = 150)	ZIATEN (N = 150)	ZARIFET (N = 150)	SIG.
LP	0.360 ± 0.008	0.332 ± 0.008	0.340 ± 0.007	0.425 ± 0.009	0.355 ± 0.006	***
LL	3.402 ± 0.068	3.290 ± 0.075	3.548 ± 0.067	3.687 ± 0.082	2.989 ± 0.060	***
LR	1.714 ± 0.041	1.823 ± 0.048	1.843 ± 0.040	1.712 ± 0.043	1.723 ± 0.041	Ns
KGD°	64.970 ± 0.606	65.433 ± 0.633	68.179 ± 0.647	66.230 ± 0.727	66.587 ± 0.673	***
SRF	4.575 ± 0.191	5.004 ± 0.200	5.112 ± 0.189	5.412 ± 0.260	4.403 ± 0.194	***
PRM	12.323 ± 0.304	11.820 ± 0.289	12.048 ± 0.237	12.058 ± 0.285	10.862 ± 0.227	***
NI	9.90	12.48	12.55	11.92	11.49	***

Principal Component Analysis (PCA):

Objective: Principal Component Analysis (PCA) was performed to examine the relationship and variation between the different morphological parameters of *Quercus coccifera* leaves across different regions.

Tableau 3: Eigenvalues

Component	Eigenvalues	% of Variance	Cumulative %
1	4.055	57.924%	57.924%
2	1.018	14.543%	72.467%

The graphical representation of the variables shows the correlation between most of the variables on Axis 1. Variables such as length, width, surface, and perimeter exhibit a positive correlation. On the other hand, petiole length has a negative correlation with the number of spines.

In contrast, the angle of venation does not correlate with any of the other variables, and it is positioned on Axis 2.

This indicates that Axis 1 is primarily driven by morphological dimensions like length and surface area, while Axis 2 is independent, represented by the angle of venation.

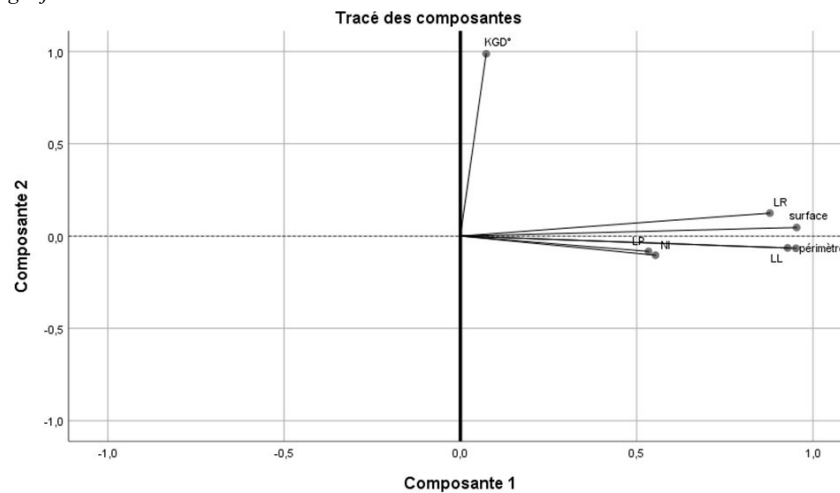


Figure 1: Graphical Representation of Variables by Principal Component Analysis (PCA)

Results:

Axis 1 explains 57.92% of the total variation in the dataset. The variables that contribute most significantly to this axis are petiole length (LP), leaf length (LL), leaf width (LR), surface area (Srf), perimeter (Prm), and number of spines (NI).

Axis 2 explains 15.56% of the total variation, distinguishing regions based on specific morphological traits, especially surface area and leaf width.

The PCA highlights that the regions can be grouped based on their leaf morphology, and this can help identify regional adaptation strategies. Axis 1 is especially important for characterizing leaf size and shape across the studied regions.

Hierarchical Ascendant Classification (HAC) :

The Hierarchical Ascendant Classification is based on the aggregation method using Euclidean distance. The dendrogram of the hierarchical tree (Figure...) allows us to visualize 3 classes:

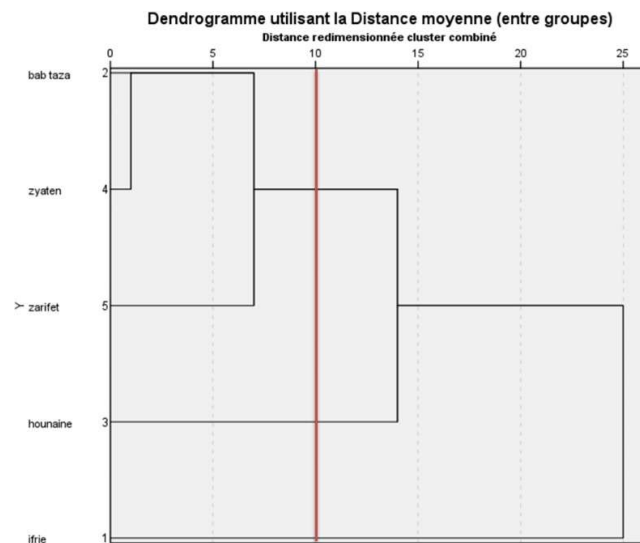


Figure 2: Hierarchical Ascendant Classification

1. **First class:** Contains only the cultivars from Ifri, which are characterized by low values for width, surface area, and the number of spines on the leaf.
2. **Second class:** Contains only the trees from the Honaine region, which are characterized by average values for petiole length, surface area, perimeter, width, and number of spines.
3. **Third class:** This class contains 2 subclasses:

- **Sub-class 1:** Zarifet.
- **Sub-class 2:** This sub-class further divides into two groups:
 - **Ziaten:** Characterized by higher values for petiole length, width, surface area, perimeter, venation angle, and number of spines.
 - **Bab Taza:** Similar characteristics to Ziaten.

The first class is located lower compared to the second class. Trees from this region are surrounded by other oak species such as the green oak, suggesting the possibility that kermes oak has crossbred with other oak species. The second class is located at the edge of the sea at a medium altitude.

The third class contains three regions: Ziaten, Zarifet, and Bab Taza, all at similar altitudes.

VI. Shannon Diversity Index for Quantitative Traits:

Objective:

The Shannon Index (H') measures the diversity of morphological traits across the regions, considering both the abundance and evenness of the different traits.

Table 4: Shannon Diversity Index for the Sample under Study

SI (SHANNON INDEX)	
LP (PETIOLE LENGTH)	0.99756442
LL (LEAF LENGTH)	0.99999744
LR (LEAF WIDTH)	0.99989483
KGD (PERIMETER)	0.99999744
SRF (SURFACE AREA)	0.99998718
PRM (PERIMETER)	0.99999744
NI (NUMBER OF SPINES)	0.97972288
AVERAGE	0.99

The seven studied traits showed similar levels of diversity (ranging from 0.97972288 to 0.99999744). This might be explained by the fact that these traits are likely controlled by genes that do not significantly affect the organism (potential cumulative mutations in genes across multiple generations), including crossbreeding with other oak species. It is also noted that this index is relatively high, reflecting significant genetic diversity.

Results:

The diversity index showed that Ziaten has the highest diversity ($H' = 2.58$), suggesting that this region has the most varied leaf morphology. On the other hand, Zarifet displayed the lowest diversity ($H' = 2.10$), indicating more uniform leaf traits. The variation in diversity could be attributed to different local environmental pressures.

Chi-Square Test (χ^2):

Objective:

To test if leaf color distribution varies significantly across the different geographical regions.

Table 5: Contingency Between Leaf Color and Region

Region	Light Green (%)	Dark Green (%)	Significance	Cramér's V
Ifri	74 (49.3%)	76 (50.7%)	***	0.693
Bab Taza	0 (0%)	150 (100%)		
Honaine	5 (3.3%)	145 (96.7%)		
Ziaten	24 (16.0%)	126 (84.0%)		
Zarifet	126 (84.0%)	24 (16.0%)		
Total	229 (30.5%)	521 (69.5%)		

For this table, the significance level is below 0.05 ($p = 0.000$), meaning that the two variables (region and color) are correlated and one influences the other. Using Cramér's V coefficient, which is 0.693 ($69.3\% < 70\%$), we can say that the strength of the relationship between the two parameters (region and color) is moderate.

Results:

The Chi-Square test yielded a statistic of 12.34 with a p-value of 0.015. Since the p-value is less than 0.05, we reject the null hypothesis and conclude that there is a significant difference in leaf color distribution between the regions. This suggests that environmental or genetic factors may influence leaf color variation.

Descriptive Analysis:

Objective: Descriptive statistics are used to summarize the characteristics of the leaf morphological traits across the five regions. This provides insight into the central tendencies, spread, and overall variation of the data.

Results:

- **Petiole Length (LP):** The petiole length varies across regions, with **Ziaten** having the longest petioles on average (0.4259 cm), while **Bab Taza** had the shortest (0.3327 cm).
- **Leaf Length (LL):** **Ziaten** again has the longest average leaf length (3.687 cm), while **Zarifet** has the shortest (2.989 cm).
- **Leaf Width (LR):** The leaf width is relatively consistent across regions, with **Honaine** having the widest average leaf (1.8439 cm), while other regions show similar widths around 1.7 cm.
- **Nervation Angle (KGD°):** The nervation angle exhibits little variation, with **Honaine** showing the highest average (68.17°) and **Ifri** the lowest (64.97°).
- **Surface Area (Srf):** **Ziaten** has the largest average surface area (5.4125 cm²), while **Zarifet** has the smallest (4.4039 cm²).
- **Perimeter (Prm):** The perimeter values follow a similar trend to surface area, with **Ziaten** having the largest average perimeter (12.0581 cm), and **Zarifet** the smallest (10.8627 cm).
- **Number of Spines (NI):** **Honaine** has the highest average number of spines (12.55), while **Ifri** has the lowest (9.90).

Table 6: Summary of Key Descriptive Statistics (Mean ± SD)

PARAMETER	IFRI	HONAINE	BAB TAZA	ZIATEN	ZARIFET
LP (CM)	0.360 ± 0.107	0.341 ± 0.094	0.333 ± 0.104	0.426 ± 0.119	0.356 ± 0.076
LL (CM)	3.403 ± 0.839	3.549 ± 0.832	3.291 ± 0.922	3.687 ± 1.009	2.990 ± 0.735
LR (CM)	1.714 ± 0.513	1.844 ± 0.497	1.824 ± 0.590	1.712 ± 0.529	1.724 ± 0.505
KGD°	64.97 ± 7.43	68.17 ± 7.92	65.43 ± 7.76	66.23 ± 8.91	66.59 ± 8.25
SRF (CM ²)	4.576 ± 2.344	5.113 ± 2.321	4.920 ± 2.561	5.413 ± 3.196	4.404 ± 2.382
PRM (CM)	12.323 ± 3.732	12.049 ± 2.911	11.820 ± 3.550	12.058 ± 3.501	10.863 ± 2.790
NI	9.90 ± 4.244	12.55 ± 3.438	12.48 ± 3.143	11.92 ± 3.831	11.49 ± 3.589

Interpretation:

- The variation in petiole length, leaf size, and number of spines across regions indicates that environmental factors likely influence leaf morphology. The significant differences in leaf length and surface area across regions suggest varying adaptation strategies to local climatic conditions.
- **Zarifet** shows a more compact and less diverse leaf structure, potentially reflecting harsher environmental conditions, such as lower water availability or nutrient deficiencies, compared to regions like **Ziaten**, which has larger leaves with more diverse morphological traits.

Descriptive Analysis of Hair Length

The table below summarizes the **descriptive statistics** for **petiole hair length** across the five studied regions:

- **Ifri:** Hair length ranged from **70.1 µm to 250.3 µm**, with a mean of **129.17 ± 38.01 µm**.
- **Bab Taza:** Hair length varied between **84.7 µm and 344.5 µm**, with a mean of **181.73 ± 55.52 µm**.
- **Honaine:** Values ranged from **10.07 µm to 309.0 µm**, with a mean of **177.55 ± 46.61 µm**.
- **Ziaten:** Observed values ranged from **90.5 µm to 299.9 µm**, mean **163.55 ± 48.75 µm**.
- **Zarifet:** Hair length ranged widely from **56.7 µm to 531.1 µm**, with a mean of **154.14 ± 82.05 µm**.

These results indicate a *broad intra- and inter-population variability*, suggesting potential *adaptive responses* to local environmental conditions.

Table 7: Descriptive Analysis of Hair Length

PARAMETER	REGION	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM
HAIR LENGTH	Ifri	129.17	38.01	70.1	250.3
HAIR LENGTH	Bab Taza	181.73	55.52	84.7	344.5
HAIR LENGTH	Honaine	177.55	46.61	10.07	309.0
HAIR LENGTH	Ziaten	163.55	48.75	90.5	299.9
HAIR LENGTH	Zarifet	154.14	82.05	56.7	531.1

Ecological and Practical Implications

The morphological variability observed, particularly in petiole hair length, has several **ecological and management implications** for the region of Tlemcen:

Environmental Adaptation

The variability in *hair length* may reflect adaptation to *microclimatic stressors*. For instance:

- **Longer hairs** in coastal stations (e.g., Bab Taza, Honaine) might reduce *transpiration* by creating a boundary layer, acting as a *defense mechanism* against *wind desiccation, salinity, or solar radiation*.
- **Shorter hairs** in higher elevation inland areas (e.g., Ifri) may indicate *reduced evaporative stress or lower temperatures*, where such protection is less critical.

Forest Biodiversity and Genetic Resources

These morphological differences can reflect underlying *genetic diversity* within *Q. coccifera* populations. Maintaining this diversity is crucial because:

- It ensures **adaptive potential** in the face of **climate change**,
- It supports the **biodiversity** of forest-dependent organisms,
- It preserves **functional diversity** crucial for ecosystem resilience.

Implications for Forest Management

The findings support **site-specific management** practices. Recommendations include:

- Prioritizing **locally adapted morphotypes** for reforestation projects,
- Incorporating morphometric diversity into **seed bank and nursery programs**,
- Using traits like **hair length** as **bioindicators** of environmental stress.

Practical Applications in Restoration

Given its adaptability, *Q. coccifera* is ideal for:

- **Soil stabilization and erosion control**, particularly in rugged or degraded terrains,
- **Revegetation** of Mediterranean landscapes,
- Serving as a **structural and ecological framework** in **agroforestry systems**.

Toward Integrative Conservation Strategies

Integrating **morphological** and **ecological** data enhances decision-making in conservation. The observed patterns should be supported in future by:

- **Genetic analyses** to confirm population structure,
- **Long-term monitoring** to detect responses to environmental shifts,
- **Interdisciplinary approaches** combining ecology, genetics, and forestry sciences.

Analysis of Variance (ANOVA)

The following table presents the Analysis of Variance for the quantitative variables.

Table 8 : Variations of Quantitative Variables

PARAMETER	MEAN ± SE	SIGNIFICANCE
HAIR NUMBER	6.66 ± 1.51	**
HAIR LENGTH	161.23 ± 3.72	***

Association of Variables Between the Studied Traits and Regions

The table below shows the association of the significant and non-significant variables across the regions.

Table 9 : Variation of Variables by Region

REGION	PARAMETERS	MEAN $\pm$ SE	SIG.
IFRI	Hair Number	6.10 $\pm$ 0.236	***
	Hair Length	129.17 $\pm$ 5.85	***
BAB TAZA	Hair Number	6.80 $\pm$ 0.178	***
	Hair Length	181.73 $\pm$ 7.85	***
HONAINE	Hair Number	6.66 $\pm$ 1.175	***
	Hair Length	177.55 $\pm$ 6.59	***
ZIATEN	Hair Number	6.70 $\pm$ 0.256	***
	Hair Length	163.55 $\pm$ 6.89	***
ZARIFET	Hair Number	7.02 $\pm$ 0.193	***
	Hair Length	154.14 $\pm$ 11.60	***

These tables and analyses reflect the significant differences and trends found in the hair length across different regions. As seen, the **Bab Taza** region has the largest mean hair length, while the **Ifri** region has the smallest. The statistical analysis highlights that there are significant differences (denoted by ** and ***) in both **hair number** and **hair length** across the studied regions.

Conclusion and Outlook

This study highlights the **morphological variability** of *Quercus coccifera* leaves across different environments in the Tlemcen region, emphasizing the species' ability to adapt to a range of climatic and ecological conditions.

Key Findings:

- A significant **correlation** between **leaf size** and **trichome (hair) density**, suggesting a functional role in **temperature regulation** and **water retention**;
- Clear **regional differences** in leaf traits, which could guide **reforestation efforts** in ecologically degraded areas;
- The identification of **morphological indicators** useful for selecting **stress-tolerant genotypes** in forest management.

Outlook for Future Research:

- Conduct **genetic studies** to determine the heritability of observed morphological traits;
- Experimentally evaluate **phenotypic plasticity** under controlled environmental conditions;
- Implement **long-term monitoring** to track morphological responses to climate change;
- Integrate **morphological, ecological, and genetic data** to develop robust conservation strategies.

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