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Option: Plants improvement

Theme

Foliar Morphology Study of Species in the *Oxyacanthae* Section (Loudon, 1838) of the Genus *Crataegus* L. : Case of Two Natural Populations in Algeria

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DEDICATION

FROM THE BOTTOM OF MY HEART, I DEDICATE THIS WORK TO ALL THOSE DEAR TO ME:

TO MY DEAR FATHER:

Who has consistently stood beside me, investing all his resources to ensure I receive the finest education

TO MY DEAR MOTHER:

Who has been my rock, tirelessly working and sacrificing for my sake, her love and guidance a beacon of warmth and strength amidst life's storms, showcasing the remarkable spirit of motherhood

TO MY SISTERS AND BROTHER:

Thank you for always being there for me, guiding me through the years, driving me to university, and providing unwavering support and love

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TO MY NEPHEW:

Just i love you so much

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TO MY DEAR FRIEND CHIRO:

Thank you for being there for almost 9 years giving me all the support and help

TO ALL MY FAMILY MEMBERS

TO ALL THOSE WHO CONTRIBUTED TO MY SUCCESS."

SEE YOU NEXT YEAR, OR NOT HAHAHA

« RIHAB »

Abbreviations

A or Ic - Average annual thermal amplitude (T max - T min)

CB - Blade color: 1-Light green 2-Green 3-Dark green

DBS - Depth of basal sinus measured from the midvein

DS - Distance between the two basal lobe sinuses in mm

H -Houara

HAC - Ascending Hierarchical Classification

LB - Length of leaf blade in mm

LBL - Length of basal lobe of the abaxial face in mm

LP - Length of petiole in mm

M - Average value of the coldest month minimums (°C)

M - Average value of the hottest month maximums (°C)

M' - Average value of the hottest month minimums (°C)

NOM - National Meteorological Office

NSV - Number of secondary veins of the blade

NTB - Number of teeth of the basal lobe of the abaxial face

NTT - Number of teeth of the terminal lobe of the abaxial face

NVB - Number of visible secondary veins of the basal lobe

O - Djebel Ouahch

P - Total annual precipitation (mm/year)

PBS - Position of basal sinus right compared to left one: 1-Superior 2-Inferior 3-Similar.

PCA - Principal Component Analysis

Q3 - Modified Emberger pluviothermal quotient by Stewart

SB - Symmetry of the blade: 1-Symmetrical 2-Asymmetrical

SP - Shape of the petiole insertion

T - Annual average value (°C)

T max - Highest value of monthly averages (°C)

T min - Lowest value of monthly averages (°C)

WB - Width of leaf blade in mm

WLB - Width of lobe of the abaxial face in mm

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Introduction

The term "biodiversity," proposed in 1988 by Wilson (Wilson & Peter, 1988), refers to the variety of living organisms regardless of their original environment and takes into account intraspecific, interspecific, and functional diversities.

Biodiversity also aims to analyze the conservation problems of rare or threatened species by proposing solutions.

Among the threatened species in Algeria, we have the genus *Crataegus* L. Species of this genus, belonging to the Rosaceae family, are represented by thorny trees or shrubs in the northern hemisphere (Christensen, 1992). Their leaves are generally lobed and recognizable (Cardenas, 2013). In Algeria, hawthorns are spontaneous in the North and widespread in the Eastern part, especially in mountainous areas (Abdelgherfi, 2003). Numerous studies have been conducted on Crataegus worldwide: on extracts and essential oils (Zhang *et al.*, 2004; Ordonez *et al.*, 2006; Adedapo *et al.*, 2008).

The main objective is to study the morphological diversity of the *Crataegus oxyacantha* species within two natural populations in Algeria (Houara in Guelma and Djebel Ouahch in Constantine) through the morphological characteristics of its leaves. This work is a morphometric contribution to the structuring and systematics of this taxon, defining its morphological and even dynamic status impacted by the evolutionary pressures of the environment.

To accomplish our objective, we structured our study into three distinct chapters, outlined as follows:

- The first chapter delves into the species' bibliography on a global scale and specifically in Algeria.
- In the second chapter, we provide detailed descriptions of the sampling stations, including their physical and climatic contexts, as well as the materials utilized and the methods employed during the study.
- The final chapter is devoted to presenting the results obtained from our research, accompanied by an in-depth discussion of their implications.

In conclusion, this thesis wraps up with a summary highlighting the main findings and offering insights into future perspectives.

CHAPTER I

SPECIES PRESENTATION

1. Overview of the genus *Crataegus* L. worldwide

1.1 Generalities and description

The *Rosaceae* family comprises more than 3000 to 3500 species, classified into 4 subfamilies: *Rosoideae, Spiraeoideae, Amygdaloideae,* and *Maloideae*, found in the temperate regions of the northern hemisphere. It exhibits significant morphological variability and a marked evolutionary trend (Takhtajan, 1893; Botineau, 2010; Spighiger *et al*., 2002). Within this family, we have the genus *Crataegus*, which includes several hundred species worldwide. These species hybridize easily, making it difficult to determine their exact number (Grieve, 1931; Davies, 2000).

Figure 1. Hawthorn tree from Djebel Ouahch in Constantine (Hadidi, 2024).

Hawthorn is the common name for species of this genus in the *Rosaceae* family. There are over 1000 different species and hybrids worldwide; approximately 280 species are identified in the temperate zones of the north, often between latitudes 30° and 50°, in Europe, Eastern Asia, and Eastern North America. Medically, they share many similar characteristics (Phipps, 1983; Zhao & Tian, 1996; Davies, 2000).

1.2 Historical Background

Beliefs about hawthorn have been revered throughout history. In the Middle Ages, it was believed to attract fairies who would dance around the tree (Webster, 2008; Nicole & François, 2013).

- The Romans considered this tree as a protector (babies' cribs were surrounded by hawthorn branches).
- Among the Greeks, church altars were adorned with flowering hawthorn branches during wedding celebrations, symbolizing purity and holiness.
- For Christians, it held a sacred significance, as the crown of Christ was said to be made from hawthorn.

1.3 Etymology

- **In French: (**Poir.). DC, the etymology is derived from the Latin word "crataegus" or "kratos," meaning a hard branch, alluding to the hardness of this shrub (Couplan, 2012). Additionally, according to Coquillat (1962), the term "Aubépine" is derived from the old French deformation of the Latin name "spina alba" and "albispina," which means white thorn.
- **In English:** The English use the term "hawthorn," which originates from the Old English compound word "hagathorn," where "hedge" means hedge and "thorn" means thorn (Patrick & Henry, 1996).
- **In literary Arabic:** This shrub is known as "Zaaror" (Ibn El Baytar, 1602). As for vernacular names in Algeria, the most common ones in Arabic dialect are: Baba adjina, Boumekherri, Ain baquera, and Zaaror (Beloued, 2012), and in Berber or Tuareg they are: Admamai, Allmène, and Idmine.

1.4 Classification and Taxonomic Keys of Species in the Genus

The classification according to APG III (Chase & Reveal, 2009) and APG IV is as follows:

APG III (Chase & Reveal, 2009)	**APG IV**
Clade: Angiosperms	*Clade: Angiosperms*
Clade: Eudicots	*Clade: Eudicots*
Clade: True Dicotyledons	*Clade: Superrosids*
Clade: True Dicotyledons Superiores	*Class: Rosids*
Clade: Rosids	*Order: Rosales*
Clade: Fabids	*Family: Rosaceae*
Order: Rosales	*Subfamily: Spiraeoideae*
Family: Rosaceae	*Genus: Crataegus L. (1753)*
Genus: Crataegus L. *(1753)*	

The taxonomic organization of species within the genus *Crataegus* L. remains unclear and varies among authors and botanists.

According to Maire (1980), this genus is subdivided into four sections:

1.4.1 Section *Crus-galli* Loudon (1838)

1.4.1.1 *C. Carrière* Vauvel ex Carrière (1883)

The *Crataegus* L. species is characterized by small trees, reaching heights of up to 7 meters. Initially very spiny, they become almost unarmed with age, featuring spreading branches and robust spines up to 5 cm long.

Leaves are oval-oblong or elliptical, with acuminate apexes and long petioles. They are unevenly toothed and occasionally slightly lobed, with pubescent undersides and shiny upper surfaces.

The multiflowered corymbs have slender flowering peduncles, while the flowers themselves are approximately 2 cm in diameter, with green sepals and bright purplish anthers.

The ovoid or subglobular fruits are red-orange, with sweet and tart flesh and 2-3 stones, crowned by persistent sepals. Flowering typically occurs in April-May.

Figure 2. ***Crataegus carrierei*** **Vauvel ex Carrière (1883) (Maire, 1980)**

1.4.2 Section *Mexicanae* Loudon (1838)

1.4.2.1 *Crataegus mexicana* Moc. & Sessé ex DC., 1825

This species, presenting as a shrub or small tree, can reach heights of up to 10 meters, initially spiny but often becoming unarmed over time, with spines that may grow up to 4 cm long. Its branches are tomentose in youth.

The leaves feature short, villose petioles (5-15 mm long) and oblong-ovate or obovate-oblong blades, somewhat acute at the apex and briefly tapering at the base. These leaves, measuring 4-8 x 1.7-3.8 cm, are initially pubescent but become glabrous and dark green on the upper surface while remaining villous and paler underneath, particularly along the veins. Stipules, typically deciduous, are linear or lanceolate, often foliaceous, and adorned with short ciliate-glandular hairs. Corymbs are composed of 6-12 flowers arranged loosely, with linear bracts featuring short ciliate-glandular hairs along the margins.

Flowers, approximately 2 cm in diameter, are white, with linear-lanceolate sepals that are spreading, villous, and either entire or slightly denticulate towards the apex.

Figure 3. ***Crataegus mexicana*** **Moc. & Sessé ex DC., 1825 (Manrique, 2007).**

1.4.3 Section *Oxyacanthae* Loudon (1838)

1.4.3.1 *C. Oxyacantha* L. (1753)

This species of spiny shrub or small tree, up to 8 meters tall, bears leaves with variable characteristics, from homomorphic to heteromorphic, featuring short petioles and glabrous or pubescent surfaces. Leaf blades are obovate or oblong, often lobed or dentate, with pinnate venation and prominent primary veins underneath. Its corymbs, terminal on branches, carry numerous flowers, approximately 10-18 mm wide, with reflexed sepals and suborbicular, glabrous petals. Stamens number around 20, and styles vary from 1 to 3. Fruits are ovoid or subglobose, ranging from red-brown to scarlet, crowned by a persistent calyx, and contain 1-3 woody seeds. Flowering typically occurs from February to May.

Highly polymorphic species with three subspecies:

- **Subspecies *oxyacanthoides*** (Thuill.) Maire (syn. C. *oxyacanthoides* Thuill, 1799): Found in Europe and Western Asia.
- **Subspecies *monogyna*** (Jacq.) Rouy et Camus (1901) (Syn. **C. *monogyna*** Jacq. (1775)): Found in Europe, Western Asia, Siberia, and the Himalayas, with six varieties: var. ***typica*** Asch. & Gr.; var. ***miniata*** Maire; var. ***stenoloba*** Maire; var. ***supravillosa*** Maire; var. ***hirsuta*** Boiss.; var. ***ciliata*** Maire, and var. ***fallax*** Maire.
- **Subspecies *maura*** (L. fil.) Maire (1932) (***C. maura*** L. fil. 1781): Found in the Mediterranean region, with four varieties: var. ***Saccardyana*** Maire; var. ***brevispina*** (Kunze) Dippel; var. ***coriacea*** Maire, and var. ***heterophylla*** (Flugge) Wenzig.

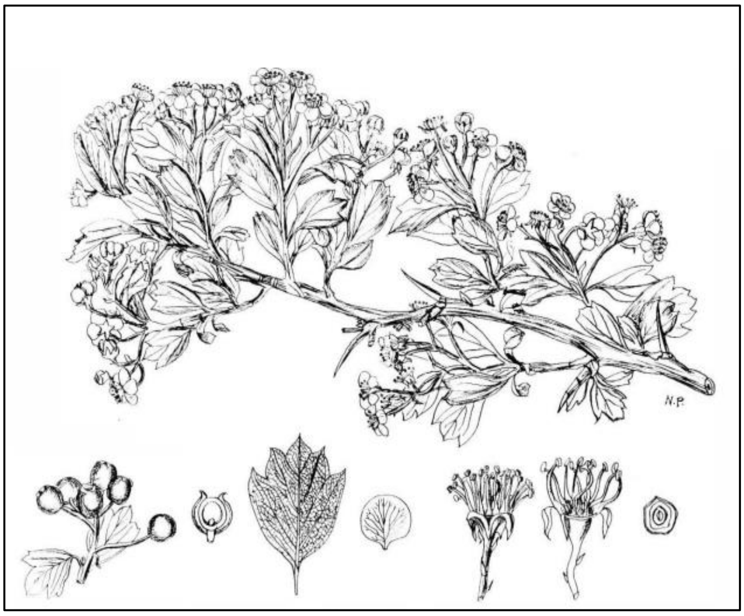

Figure 4. *C. Oxyacantha* L. (1753) (Maire,1980)

1.4.4 Section *Azaroli* Loudon (1838)

1.4.4.1 *C. Laciniata* Ucria (1796)

This species presents as a small tree or shrub (Figure 5), with heights up to 6 meters and spreading branches. Its branches exhibit various textures, with woolly-hairy young shoots and dark brown older branches, some of which may be glabrous. Robust thorns are short and terminal on leafy branches. The leaves are subconform, petiolate, and feature a subcoriaceous lamina, often rhomboidal or obovate-cuneiform, and densely grayish-hairy on both surfaces. Stipules are large on turional leaves, reniform, deeply toothed, and long-persistent. Terminal corymbs on brachyblasts bear 5-15 flowers, with membranous, reddish bracts, and flowering peduncles longer than the flower. Flowers have a campanulate receptacle, woolly-hairy, with sepals spreading and then reflexed, shorter than the petals, while the stamens, numbering 15, have subulate filaments and red, ovoid anthers. Fruits are dull red drupes, sometimes hairy, subglobular or ovoid-subglobular, crowned by a persistent, reflexed calyx, with 2-3 woody stones.

Several subspecies exist: ssp. ***tanacetifolia*** (Poiret), ssp. ***pycnoloba*** (Boiss. & Heldr.), and ssp. ***orientalis*** (Pail.). **Geographical range:** Sicily and southern Spain.

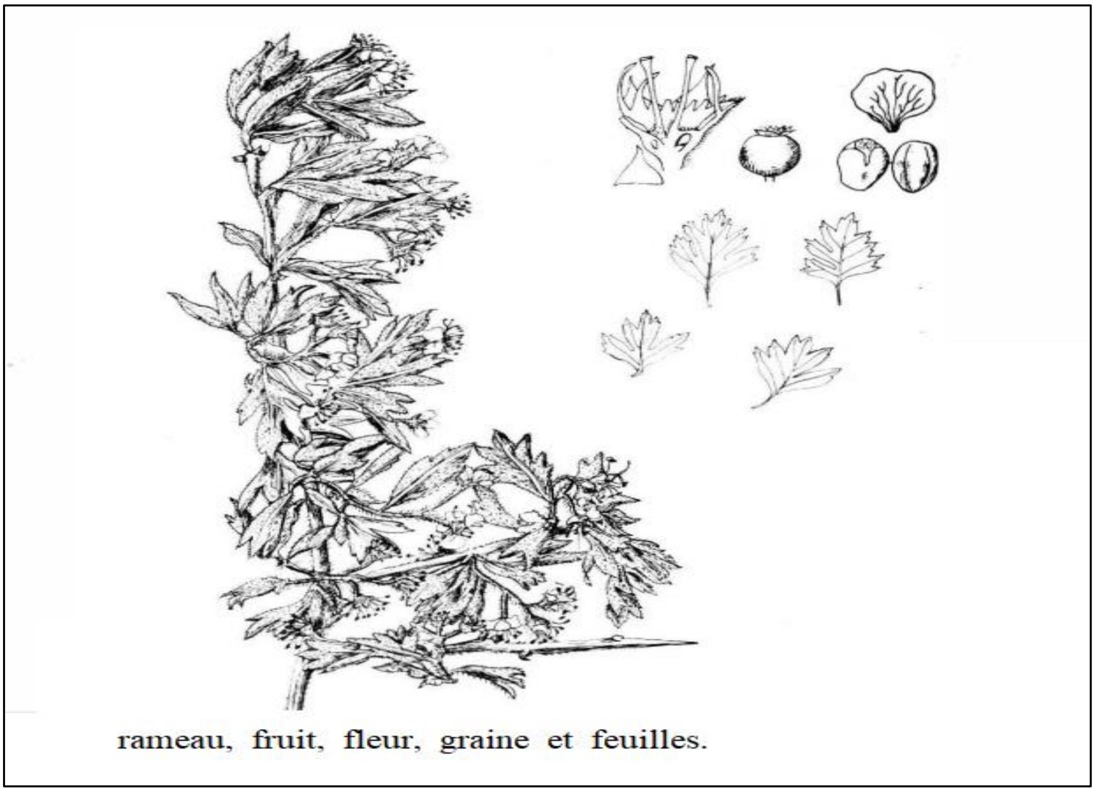

Figure 5. ***C. Laciniata*** **Ucria (1796) (Maire, 1980)**

1.4.4.2 *C. Azarolus* L. (1753)

This species, whether appearing as a small tree or shrub, can reach heights of up to 8 m and features spreading branches with young branches being woolly-hairy, turning glabrous by the second year. Its leaf petioles are short and somewhat hairy, while the leathery leaf blades are typically lobed and hairy in youth, becoming mostly glabrous on the upper surface as they mature. Terminal corymbs on brachyblasts are dense or somewhat loose, with reddish linear bracts and flowering peduncles usually shorter than the flower. Flowers are white, with tomentose sepals and glabrous petals, accompanied by stamens and styles of varying numbers. The fruits are either red or yellow, subglobular or briefly pyriform, with sweet, tart, and fragrant flesh, often containing 2-3 stones, and the species typically blooms from April to May.

Two varieties are recognized: var. ***eu-Azarolus*** Maire and var. ***Aronia*** (Willd.). These are predominantly found in the eastern Mediterranean region.

Figure 6. *C. Azarolus* L. (1753) (Duhamel du Monceau, 1768)

1.4.2.3 / x / *C. ruscinonensis* Grenier et Blanc (1866) (This hybrid is the result of a cross between *C. azarolus* and *C. monogyna.*

The spiny shrub or small tree, characterized by spreading-ascending branches, exhibits oblong-obovate leaves with cuneate bases and short pubescent petioles. Its leaf blades, which are 3-5-lobed, become glabrous in adulthood, with highly visible venation forming a network on the lower surface. Corymbs feature slender, elongated branches that are initially hairy but become glabrous over time, with a hairy receptacle and short, reflexed sepals. White suborbicular petals adorn the flowers, accompanied by stamens with pink filaments and purplish anthers, usually numbering 1-2 styles. The fruits, subglobular and red, are typically glabrous and contain 1-2 seeds, with flowering occurring from April to May.

Figure 7. X *C. ruscinonensis* Grenier and Blanc (1866) in the Maltese Islands (Mifsud, 2020).

1.5 Dendrological Characteristics of the Genus

1.5.1 Trunk and Branches

The mature trunk is characterized by its scaly, grayish bark covering (Figure 8). The gray branches bear thorns of varying color, length, and thickness, differing from one species to another (Christensen, 1992; Aldasoro *et al.*, 2005).

Figure 8. Trunk of a specimen of *C. monogyna* from the Djebal Ouahch site in Constantine (Hadidi, 2024).

1.5.2 Leaves

The leaves (Figure 9) are shiny green or dark, deciduous, alternate, and divided into 1 to 8 pairs of lobes per leaf, with their leaf margin either entire, toothed, or crenate. The broad, stipulate leaves attached to a main branch are different from those found on a floral or sterile secondary branch (Christensen, 1992; Aldasoro et *al.*, 2005).

Figure 9. Foliage of *C. monogyna* from the Djebel Ouahch station in Constantine (Hadidi, 2024).

1.5.3 Flowers

The flowers (Figure 10) range from 9 to 50, typically grouped in corymbs and occasionally in umbels, with 1 to 3 deciduous bracts at their base. They are pentamerous, featuring a calyx that ranges from linear to triangular in shape, with entire or dentate-glandular margins, followed by a concave white or occasionally pink corolla. The androecium comprises 10 to 20 stamens, with filaments of varying lengths bearing yellow, pink, or white anthers (Christensen, 1992; Aldasoro *et al.*, 2005).

Figure 10. Flowers with a single style of *C. monogyna* from the Djebel Ouahch in Constantine (Hadidi, 2024).

1.5.4 Fruits and Fruitfulness

The fruiting of Crataegus begins in late summer and extends into early autumn, giving rise to variously sized globose, pyriform, or elliptical berries. The charming colors of the fruit (yellow, green, orange, or red) and the succulent taste of its flesh attract many birds, which significantly contribute to the dispersal of Crataegus over long distances. The calyx (Figure 11), deciduous in some species, is typically persistent and sessile, forming a crown on the apical part of the berries. Inside these, one to five seeds are found (Christensen, 1992; Aldasoro *et al.*, 2005).

Figure 11. Drupes of *C. monogyna* from the Dj Ouahch station in Constantine (Hadidi, 2024).

1.6 Geographic Distribution

Its distribution range is vast and includes all of Europe, Western Asia to India, and North Africa (Brosse, 2000).

1.7 Edapho-climatic Requirements

Hawthorn is highly resilient, enduring all the harshness of the climate: winds, cold, drought, and torrential rains. Its fruits, however, are not so coveted by propagation methods. The fruits are eagerly consumed by thrushes, blackbirds, pigeons, turkeys, and other winged enthusiasts (Pierre, 2006). It mainly multiplies by seed, which is the safest method to obtain uniformly sized plants with assured growth. Fruits harvested at perfect ripeness are sown in the field, either whole or stratified in a pit to be planted in the second year's spring, awaiting the prolonged seed germination at least one year after sowing (Pierre, 2004).

1.8 Interests, Roles, and Uses

1.8.1 Worldwide

Hawthorn is cultivated for live hedges, offering soil protection against erosion and wind damage, and reducing soil evaporation. Its dense foliage provides effective windbreaks and discourages animal intrusion, while its fruits attract birds (Pierre, 2004). Over 20 hawthorn species are used globally as herbal medicines, listed in pharmacopoeias of various countries like China, Germany, France, and England (Chang & But, 1986). Hawthorn's pharmaceutical activities include cardiotonic, antiarrhythmic, hypolipidemic, antioxidant, and hypotensive effects (Hamdaoui, 2017).

1.8.2 In the Maghreb

In Algeria, the fruit of *C. oxyacantha* L. is used internally in folk medicine as an antidiarrheal and in the treatment of calculous affections. Conversely, the fruit of *C. monogyna* Jacq. is used in the Aurès Mountains as a subsistence food. In Morocco and the Middle Atlas, ripe fruits of *C. monogyna* Jacq. or *C. laciniata* Ucr. are consumed by shepherds. In Tunisia, the fruits of *C. oxyacantha* L. and *C. azarolus* L. were used in food (Mohand, 2006).

2. Presentation of the Genus Cratægus L. in Algeria

In Algeria, this genus is well represented (Maire, 1980; Quézel & Santa, 1962). There are three distinct species along with one hybrid (Figure 12):

2.1 *Crataegus Oxyacantha* L.:

It is distributed throughout Algeria except in the high plateaus and includes two subspecies:

- **ssp. *monogyna*** (Jacq.) Rouy et Camus: Common in the Tell region, Aurès, Saharan Atlas, and the Hodna Mountains.
- **ssp. *maura*** (L. fils) Maire: Common in the Tell region, Aurès, Hodna Mountains, and the Saharan Atlas. It is common throughout the range of ssp. *monogyna*.

2.2 *Crataegus Laciniata* Ucria:

Found in forests and rocky limestone and siliceous areas of mountains above 1300 meters, in well-watered regions. Its distribution includes the Bellezma and Hodna Mountains, the Babors Range, Djurdjura (Zaccars), and Mount Dira (Teniet El-Had).

2.3 *Crataegus Azarolus* L.:

Located in forests in the Algiers-Constantine Tell, Djurdjura region.

2.4 *Crataegus Ruscinonensis* Grenier et Blanc:

This species, a fixed hybrid of *C. azarolus* & C. *monogyna*, as reported by Maire (1980), is found sporadically with its parents in the Constantine region (Mont de Dréat) and Bejaia (El –Kseur).

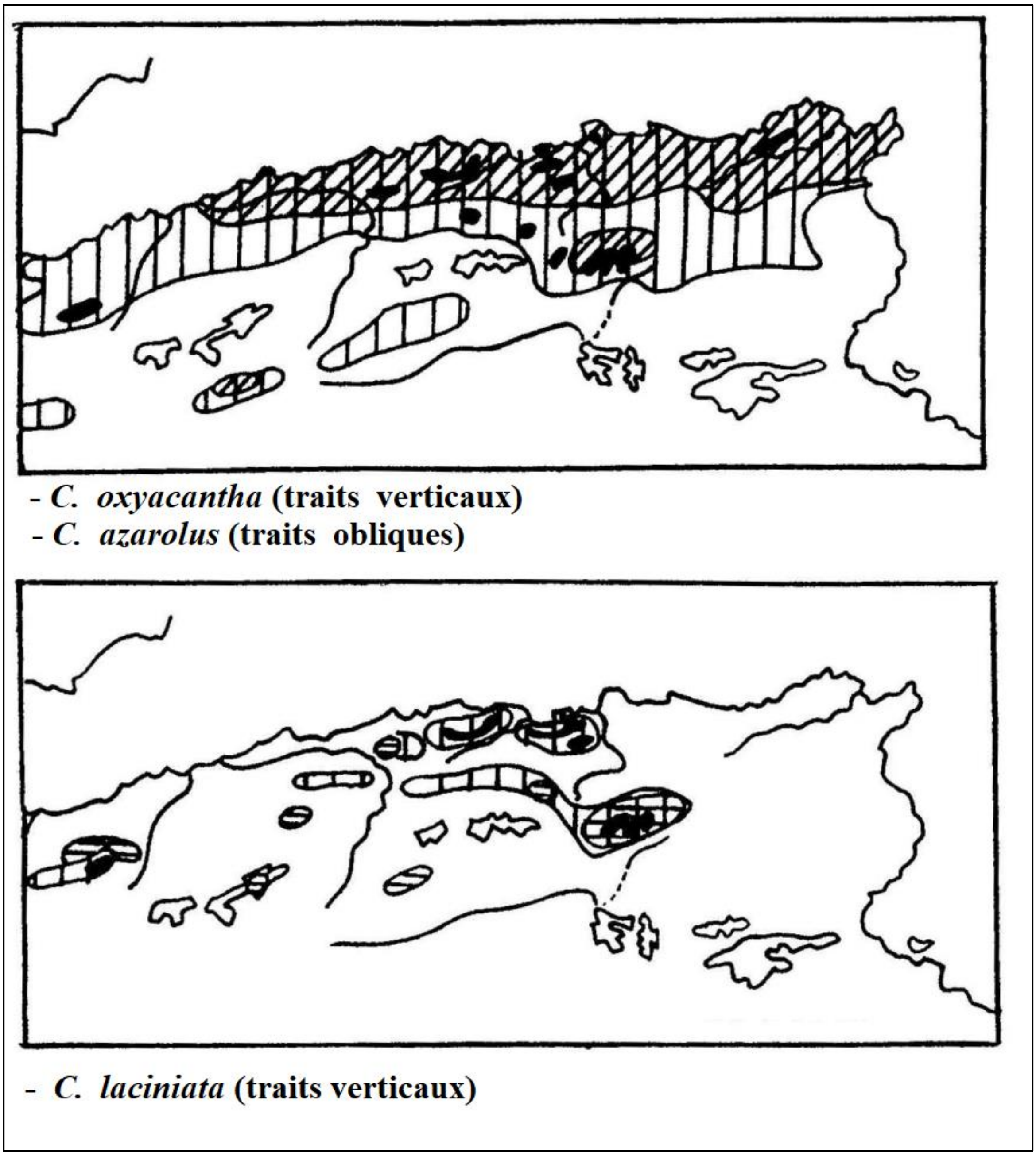

Figure 12. Natural Distribution Area of *Cratægus* L. species in Algeria according to Quézel & Santa (1962)

CHAPTER II

Study of environment, Material & Methods

1. Study of the Environment

1.1 Physical context

1.1.1 Selection and Location

The study was carried out on the leaves of two natural Algerian populations of the species *Crataegus oxyacantha* L. The choice of these populations was guided by a combination of practical and scientific considerations, including: the presence of an adequate number of individuals, accessibility to the field, and the variability of bioclimates. The main geographical characteristics of the sampling sites are detailed in Table 1 and Figure 13.

Table 1. Main geographical characteristics of the studied sites

Site	Altitude (m)	Lambert Coordinates	Location (Wilaya)
Houara (H)	518	36°31’N 7°34’ E	Guelma
Djebel Ouahch (O)	790	36°23 N 06°40 E	Constantine

Figure 13. Localization of the sampling sites of our species. Houara (H) and Djebel Ouahch (O).

1.1.2 Biogeographical Context

1.1.2.1 Houara (Guelma)

Our sampling site is located in the Houara mountain, Djeballah Khemissi commune in the Guelma region, the city nestled in the northeast of Algeria. Guelma is situated at the heart of a large agricultural region at an altitude of 290 meters, surrounded by mountains (Maouna, Dbegh, Houara), earning it the nickname "city nestled". Its region benefits from great fertility, notably due to the Seybouse River and a large dam that ensures extensive irrigation.

It is located 60 km southwest of Annaba, 110 km east of Constantine, 60 km from the Mediterranean Sea, and 150 km from the Tunisian border. It also occupies a strategic geographical position, serving as a crossroad in the northeastern region of Algeria, on which depend five provincial capitals, linking the coast of the provinces of Annaba, El Tarf, and Skikda to the inland regions such as the provinces of Constantine, Oum El Bouagui, and Souk Ahras. The climate is sub-humid, with rainfall averaging around 450 to 600 mm per year (Wikipedia, 2023).

1.1.2.2 Djebel Ouahch (Constantine)

Djebel Ouahch forest, located 5 km northeast of the city of Constantine, is a remarkable site with natural boundaries mainly defined by the watershed. Currently, these boundaries correspond to the former grounds of the zoological and leisure park, now integrated into the amusement park, marked by a metal fence erected after the creation of the latter. From an orographic and ecological perspective, Djebel Ouahch is included in the Constantine Mountains, which are part of the larger Tellian Atlas mountain range with an agro-silvo-pastoral typology.

Administratively, Djebel El Ouahch site is entirely located within the territory of the Constantine municipality, representing approximately 2.37% of its total area. Its boundaries are defined to the north by Didouche Mourad municipality, to the east by the Brahmia and Massali agricultural farms, the municipalities of Ben Badis and El Khroub, to the south by the urban neighborhoods of the Constantine municipality (Ziadia), El Berda, and to the west by Hamma Bouziane municipality and the neighborhoods of Constantine (Djebel El Ouahch, Tafrent subdivisions).

The relief of Djebel Ouahch exhibits variations, with moderate to steep slopes, while the topography to the southeast is characterized by gentler slopes.

The geological study conducted by B.N.E.D.E.R in 2005 reveals that the general stratigraphic series of Djebel Ouahch includes formations from the Lower Cretaceous (Secondary) and Quaternary ages. This region presents a variety of soils, including raw mineral soils (9%), poorly evolved soils (20%), vertisols (1%), calcareous-magnesium soils (20%), and isohumic soils (50%) (C.U.R.E.R, 1977).

1.2 Climatic context

Studying the constituent elements of climate, as selected in ecological studies, involves measuring several climatic parameters to define its components.

1.2.1 Sources and Periods of Meteorological Data

The meteorological data utilized are sourced from the monthly climate bulletins of the National Meteorological Office (N.M.O) in Algiers. They are collected over a thirty-year period for two sampling sites (Table 2).

Table 2. Characteristics of reference climatic stations, periods, and sources of data (N.M.O. Algiers).

Meteorological Station	Period	Lambert Cordonates		Altitude (m)	Sampling Site
		Latitude	Longitude		
Guelma	1993 / 2023	36,47°N	7,47°E	227	Houara (H)
Constantine	1993 / 2023	36°28 N	06°62 E	694	Djebel Ouahch (O)

1.2.2 Studied Climatic Parameters and Indices

The climatic parameters and indices selected for the climate study of each sampling site are presented in Table 3.

Table 3. Climatic parameters and indices applied for the sampling sites.

Parameters and bioclimatic indices		
Thermal Parameters	**T**	Annual mean temperature (°C).
	m	Mean of the minimums of the coldest month (°C).
	M	Mean of the maximums of the hottest month (°C).
	T min	Lowest value of monthly averages (°C).
	T max	Highest value of monthly averages (°C).
Pluviometric Parameters	**P**	Total annual rainfall (mm/year).
Climatic indices	**A or Ic**	Average annual temperature range (T max - T min).
	Q_3	Emberger pluviothermal quotient modified by Stewart.

1.1.2.3 Climate Data and Parameters

Air temperature and precipitation are the two atmospheric parameters most frequently measured in meteorological monitoring networks (Leroy, 2002).

Extrapolations of temperature values are carried out based on a 100-meter altitude gradient, calculated at -0.7°C for maximum (M) and -0.4°C for minimum (m) temperatures (Seltzer, 1946). For precipitation, an increase of 40 mm (20 mm according to Djelaili, 1984 in continental regions) is added to the annual totals for every 100 m of altitude.

Corrected data pertaining to monthly and annual temperatures (averages, minimums, and maximums), as well as monthly averages and annual totals of precipitation for the studied sites, are presented in Table 4.

1.1.2.4 Climatic Synthesis

Several authors have proposed climatic indices that are combinations of the averages of different climatic components, notably temperature and precipitation (Emberger, 1955).

1.2.4.1 Seasonal Regime

The concept of the seasonal regime was first defined by Musset (1935). This method involves calculating the sum of precipitation by season and arranging or ranking seasons by decreasing rainfall, designating each season by its initial. Consequently, this system allows for the definition of a seasonal indicator for each site.

The data presented in Table 8 reveal one type of seasonal regime (Table 5). We observe the same WSpAS type for both sites (Houara and Djebel Ouahch), with the highest recorded precipitation in winter (240.3 mm) at Houara. Additionally, significant precipitation at the Djebel Ouahch site (O) occurs in two seasons: winter (184.9 mm) and spring (155.3 mm).

Table 4. Corrected Thermal (in °C) and Pluviometric (in mm) Data from the Studied Sites

Site / Parameter		J	F	M	A	M	J	J	O	S	O	N	D	Average	Sum
Houara (H)	**m**	2,9	4,5	5,9	7,5	11,1	14,5	17,4	18,5	16,1	12,0	8,9	6,5	10,5	-
	M	12,3	11,7	13,9	16,8	23,2	27,4	30,9	30,1	25,9	21,8	17,6	13,3	20,4	-
	T	7,6	8,1	9,9	12,1	17,1	20,9	24,1	24,3	21,0	16,9	13,2	9,9	15,4	-
	P	92,9	65,9	79,8	56,7	50,9	19,0	4,4	17,8	47,0	51,0	79,8	81,5	-	646,5
Djebel Ouahch (O)	**m**	2,1	2,4	4,4	6,8	10,5	14,9	18,1	18,2	15,3	11,3	6,5	3,6	9,5	-
	M	11,9	12,8	16,0	19,4	24,8	30,8	34,7	34,1	28,6	23,9	16,9	13,0	20,1	-
	T	7,0	7,6	10,2	13,1	17,7	22,9	26,4	26,2	22,0	17,6	11,7	8,3	14,8	-
	p	65,1	50,3	58,3	51,2	45,7	23,1	4,5	22,3	36,7	44,6	62,2	69,4	-	533,6

m: **mean of the minimums of the coldest month in °C*****; M: Mean of the maximums of the hottest month in °C; P: Total annual rainfall in mm/year (Source: N.M.O., National Meteorological Office)***

Table 5. Types of seasonal regimes corresponding to the sampling sites.

Site	W	Sp	S	A	Type of seasonal regime
Houara (H)	240,3	187,3	41,2	177,7	WSpAS
Djebel Ouahch (O)	184,9	155,3	49,9	143,6	WSpAS

1.2.4.2 Evaluation of Continentality

The continentality of a climate results from the combination of interactive thermal and rainfall factors to distinguish types of rainfall (continental, semi-continental, and maritime climates) (Mokhtari *et al.*, 2013). Many authors have used the average annual temperature range "A," which increases with distance from the sea, to assess the degree of thermal continentality. This range is defined as the difference between the extreme monthly mean temperatures (T max - T min) of the year at a meteorological station (Emberger, 1971; Rivas-Martinez, 2005 ; Mokhtari *et al.*, 2013). It has a significant influence on the distribution of vegetation and, consequently, on the boundaries of many bioclimates (Rivas-Martinez, 2005).

Rivas-Martinez (2005) defined three types and eighteen subtypes of thermal continentality (with its index Ic = A) worldwide (Table 6).

Table 6. Types and subtypes of thermal continentality according to Rivas-Martinez (2005)

Types	Subtypes	A or Ic (°C)
Hyperoceanic (0-11 C°)	Ultra-hyperoceanic accentuated	0-2
	Ultra-hyperoceanic attenuated	2-4
	Eu-hyperoceanic accentuated	4-6
	Eu-hyperoceanic attenuated	6-8
	Sub-hyperoceanic accentuated	8-10
	Sub-hyperoceanic attenuated	10-11
Oceanic (11-21 C°)	Semi-hyperoceanic accentuated	11-13
	Semi-hyperoceanic attenuated	13-14
	Eu-oceanic accentuated	14-16
	Eu-oceanic attenuated	16-17
	Semi-continental accentuated	17-19
	Semi-continental attenuated	19-21
Continental (21-66 C°)	Sub-continental accentuated	21-24
	Sub-continental attenuated	24-28
	Eu-continental accentuated	28-37
	Eu-continental attenuated	37-46
	Hyper-continental accentuated	46-56
	Hyper-continental attenuated	56-66

The application of this classification to the sampling sites reveals the following (Table 7):

Houara site (16.7°C) exhibits the Eu-oceanic attenuated bioclimate. Meanwhile, Djebel Ouahch sampling site (O), with a higher value of (Ic = 24.5°C), is characterized by its Sub-continental attenuated bioclimate.

Table 7. Values of the average annual temperature range and corresponding Bioclimates according to Rivas-Martinez's classifications (2005)

Site	Ic = A (°C)	Bioclimate
Houara (H)	16,7	Eu-oceanic attenuated
Djebel Ouahch (O)	24,5	Sub-continental attenuated
***A= (T max-T min)*, amplitude thermique annuelle moyenne en °C.**		

1.2.4.3 Evaluation of Drought

The pluviothermal quotient Q2 established by Emberger (1955) is specific to the Mediterranean climate. It is most commonly used in North Africa to study overall drought. This system, called the "Emberger climagram," allows for determining the bioclimatic stage of a given station. It is determined using the following formula. $\mathbf{Q_2 = \frac{1000P}{\frac{(M+m)(M-m)}{2}}}$

- **P:** Total annual precipitation (mm);
- **M:** Mean of the maximums of the hottest month (°K);
- **m:** Mean of the maximums of the coldest month (°K)
- Temperatures are expressed in Kelvin (K): TK = TC + 273.15.

Stewart (1969) developed a simplified formula for this Emberger pluviothermal quotient for Algeria and Morocco, which is defined as follows: $\mathbf{Q_3 = 3,43\ \frac{P}{M-m}}$

- **3.43:** Constant relative to the region: Algeria-Morocco;
- **P:** Total annual precipitation in mm;
- **M:** Mean of the maximums of the hottest month in °C;
- **m:** Mean of the minimums of the coldest month in °C

The Emberger climagram involves two essential factors: on one hand, drought represented by the pluviothermal quotient Q_3 on the ordinate axis, and on the other hand, the mean of the minimum temperatures of the coldest month on the abscissa axis (Stewart, 1969).

By applying the previous formula from Stewart, we observe the following (Table 8 and Figure 14): Djebel Ouahch site is characterized by its Semi-arid cool bioclimate with a value of (Q_3 = 56,1). Whereas, the site (Houara) stands out with its Sub-humid cool type, registering the highest value (Q_3 = 81,7).

Table 8. Rainfall, temperatures, and aridity quotients of the studied sites

Site	M (°C)	m (°C)	P (mm/an)	Q_3	Bioclimates
Houara (H)	30.1	2.9	646.5	81,7	Sub-humid Cool
Djebel Ouahch (O)	34.7	2.1	533.6	56,1	Semi-arid cool

m: Mean of the minimums of the coldest month in °C; *M:* Mean of the maximums of the hottest month in °C; *P:* Annual rainfall in mm/year; *Q3:* Emberger pluviothermal quotient.

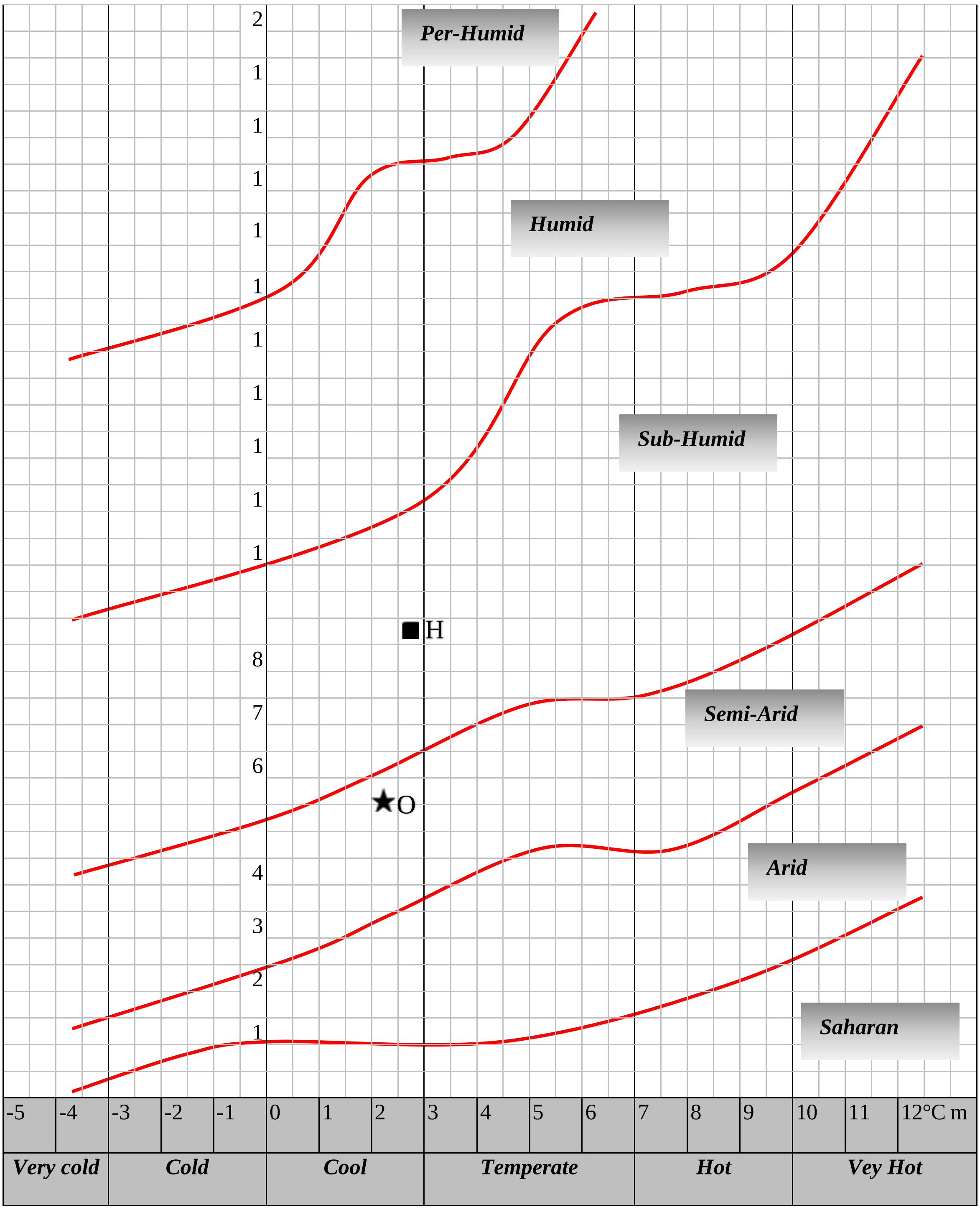

Figure 14. Position of the sampling sites in the Emberger climagram regarding our species. Houara (H) and Djebel Ouahch (O).

2. Material and Methods

2.1 Material

2.1.1 Plant Material

Sampling involved leaves from two natural populations of our species (*Crataegus oxyacantha* L.) existing in Algeria (Table 1). The collection was carried out during the campaign (2023-2024). Thirty trees were randomly chosen per population (a total of 60 trees). Subsequently, thirty mature leaves were collected around the crown of each sampled tree (02 stations with 1800 leaves).

2.1.2 Experimental Setup

The study of the phenotypic variability of our species was conducted at the laboratory (Soil Chemistry), Department of Agronomy, University 20 August 1955 of Skikda. It involved equipment including: Secateurs, Stapler, Paper bags, Saw, Protective gloves, Digital camera, Vernier caliper, Zoom binocular loupe (Bentley vision No. 310828), Conservation boxes (plastic and paper).

2.2 Methods

2.2.1 Morphometric Study

2.2.1.1 Observation and Selection of Characteristics

To study the morphological diversity of our species (Figure 14), an evaluation of quantitative and qualitative morphological characteristics (Tables 9 and 10), inspired by several studies, was conducted on species of the genus *Crataegus* and even for other similar species.

2.2.1.2 Measurements

Measurements for the leaves (Figure 15) concerning our species were made using: Digital Vernier caliper (150 mm); Optika Stereoscope (magnification 40x).

Figure 15. Materials used

Table 9. Quantitative morphological characteristics measured.

Organ	Characteristic	Coding
Blade	Length of the blade in mm	LB
	Width of the blade in mm	WB
	Number of secondary veins of the blade	NSV
Petiole	Length of the petiole in mm	LP
Lobe	Length of the basal lobe of the abaxial surface in mm	LBL
	Width of the basal lobe of the abaxial surface in mm	WBL
	Distance between the two sinuses of the basal lobes in mm	DS
	Number of teeth of the basal lobe of the abaxial surface	NTB
	Number of visible secondary veins of the basal lobe	NVB
	Depth of the basal sinus measured from the midrib in mm	DBS
	Number of teeth of the terminal lobe of the abaxial surface	NTT

Table 10. Qualitative morphological characteristics studied.

Organ	Character	Codification	Variants
Limbe	Symmetry of the blade	SB	1- Symmetrical 2- Asymmetrical
	Color of the blade	CB	1- Light green 2- Green 3- Dark green
Petiole	Shape of the petiole insertion	SP	1- Rounded 2- Rounded flattened on one side 3- Flat
Lobe	Position of the basal sinus right relative to the left	PBS	1- Upper 2- Lower 3- Similar

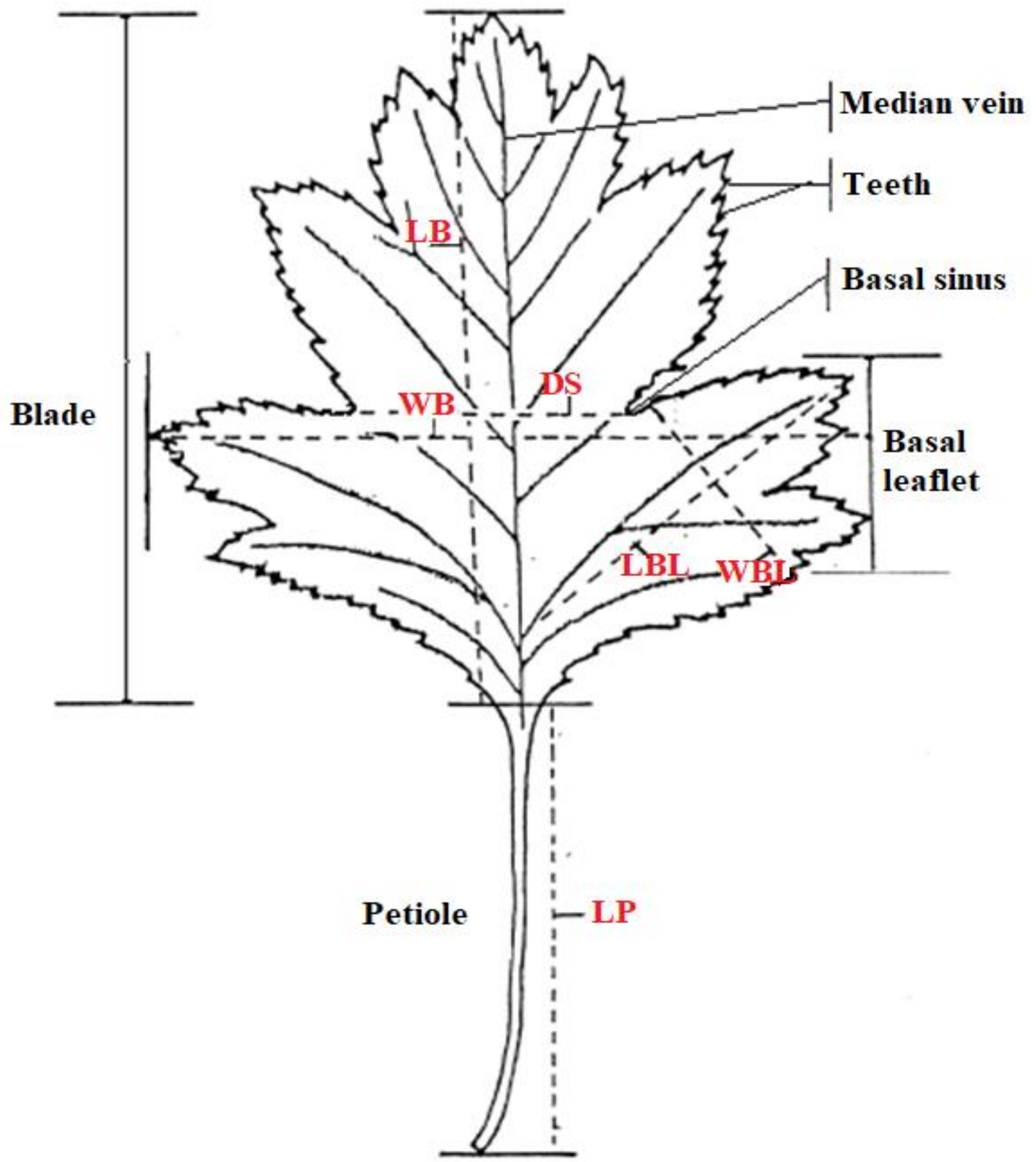

Figure 16. Parts studied of the leaf (blade, petiole, and leaflet): Length of the blade (LB); Width of the blade (WB); Length of the basal lobe of the abaxial surface (LBL); Width of the basal lobe of the abaxial surface (WBL); Distance between the two sinuses of the basal lobes (DS); Length of the petiole (LP).

2.2 Statistical Analysis Methods

2.2.1 Types of Characteristics: To better describe the variability of the populations of our species, the morphological characteristics considered in our study are qualitative (a discontinuous, observable expression) and quantitative (measurable).

2.2.2 Normality Tests: The normality of the data was checked using the Kolmogorov-Smirnov test. The distribution of the sample tends to follow the normal distribution (sufficiently large sample sizes).

2.2.3 Descriptive statistics: Basic statistics were calculated at the intra and inter-population levels for our species for the variables: Quantitative (mean, minimum, maximum, standard deviation, and coefficient of variation) and Qualitative.

2.2.4 Significance Tests: For our species, we performed an analysis of variance with one factor for each population, focusing on quantitative variables. Consequently, to compare our populations effectively, the utilization of a Student's t-test becomes necessary.

2.2.5 Correlation Tests: The correlation coefficient "r" with its value ranging from -1 to 1, was applied to visualize the relationship between quantitative variables.

2.2.6 Factorial Analyses: To visualize the structuring of the morphological diversity of our populations, multivariate analyses were applied to the drupes.

- **Principal Component Analysis (PCA):** Principal Component Analysis (PCA) was applied to the quantitative variables related to the drupes. In this analysis: The correlation circles visualize the linear relationships among all the considered variables. While the study of individuals allows us to see the resemblance or differentiation of groups of individuals.
- **Hierarchical Ascendant Classification (HAC):** In our study, hierarchical methods aim to group the trees of each species studied into homogeneous classes (high similarity). Therefore, a hierarchical ascendant classification (HAC) after factorial analysis was applied to the two studied populations.

2.2.7 Software used: All these tests were performed using the following programs: **STATISTICA 12** and **R 4.0.1**

CHAPTER III

Results and Discussion

1. Results

1.1 Morphometry

1.1.1 Quantitative traits

1.1.1.1 Length of the blade in mm (LB)

The average leaf length is 27.70 mm with a range of 10.49-48.92 mm in Houara. In contrast, Djebel Ouahch records an average of 37.76 mm with a range of 16.20-89.09 mm. The standard deviation and the coefficient of variation are 6.08 mm-21.96% and 8.87 mm-23.49%, respectively, for Houara and Djebel Ouahch. The average recorded for the species is 23.49 mm. The leaves are longer at Djebel Ouahch compared to the other station (Table 11).

1.1.1.2 Width of the blade in mm (WB)

The leaf width records an average of 20.68 mm with a range of 6.98-45.61 mm in Houara, whereas in Djebel Ouahch, the average is higher (27.32 mm) with a range of 5.67-66.55 mm. For the species, the indicated average is 24.00 mm. The standard deviation and the coefficient of variation are 5.84 mm-28.22% and 8.21 mm-30.04%, respectively, for Houara and Djebel Ouahch (Table 11).

1.1.1.3 Number of secondary veins of the blade (NSV)

The number of secondary veins in the leaf blade has given the following averages: 9.72 veins and 8.89 veins with their minimum and maximum values of 2.00-18.00 veins and 4.00-14.00 veins for the Djebel Ouahch and Houara stations, respectively. Regarding the standard deviation and the coefficient of variation, the recorded values are 2.49 veins and 25.59% at Djebel Ouahch and 1.91 veins and 21.43% at Houara. The average recorded for the species is 9.31 veins (Table 11).

1.1.1.4 Length of the petiole in mm (LP)

For the species, the petiole length has an average of 11.77 mm. At Djebel Ouahch, this variable recorded an average of 11.61 mm with a range of 2.98-39.57 mm. It is smaller compared to Houara, which has an average of 11.93 mm and a range of 2.01-40.66 mm. The standard deviation and the coefficient of variation are 4.46 mm-38.45% at Djebel Ouahch and 5.51 mm-46.23% at Houara (Table 11).

1.1.1.5 Length of the basal lobe of the abaxial surface (LBL)

At Djebel Ouahch, this variable indicated an average of 20.24 mm with a range of 7.56-39.90 mm. However, at Houara, the average is 15.51 mm with a range of 2.53-28.53 mm.

The standard deviation and the coefficient of variation are 5.41 mm-26.75% at Djebel Ouahch and 4.19 mm-27% at Houara. By station, the longest basal lobe is recorded at Djebel Ouahch with an average of 17.87 mm for the species within a min-max interval of 2.53-39.90 mm (Table 11).

1.1.1.6 Width of the basal lobe of the abaxial surface in mm (WBL)

The width of the basal lobe gave the following averages: 6.65 mm and 6.33 mm with ranges of 2.15-14.58 mm and 2.06-28.73 mm for the Djebel Ouahch and Houara stations, respectively. Regarding the standard deviation and the coefficient of variation, the values are 1.77 mm and 26.65% at Djebel Ouahch and 2.32 mm and 36.71% at Houara. The average recorded for the species is 6.49 mm, indicating that the basal lobe is wider at Djebel Ouahch (Table 11).

1.1.1.7 Distance between the two sinuses of the basal lobes in mm (DS)

For this variable, the species average is 7.89 mm with a range of 1.93-21.25 mm. The longest distance was recorded for Houara (8.99 mm) compared to the other station, which is 6.79 mm. The standard deviation and the coefficient of variation are 2.71 mm and 40% at Djebel Ouahch and 3.12 mm and 34.74% at Houara (Table 11).

1.1.1.8 Number of teeth of the basal lobe of the abaxial surface (NTB)

The average number of lobes for the basal teeth is 2.74 lobes for Djebel Ouahch and 4.45 lobes for Houara. The min-max interval provided values of (1.00-8.00 lobes and 1.00-23.00 lobes), respectively, for the two stations. The standard deviation and coefficient of variation are 1.11 lobes and 40.70%, respectively, for Djebel Ouahch, and 3.40 lobes and 75.48% for Houara. The species' mean is 3.59 lobes, with the significant value being recorded at Houara (Table 11).

1.1.1.9 Number of visible secondary veins of the basal lobe (NVB)

The number of teeth on the basal lobe averages 2.74 lobes for Djebel Ouahch and 4.45 lobes for Houara. The min-max interval values are (1.00-8.00 lobes and 1.00-23.00 lobes), respectively, for the two stations. The standard deviation and the coefficient of variation are 1.11 lobes-40.70% and 3.40 lobes-75.48%, respectively, for Djebel Ouahch and Houara. The species average is 3.59 lobes, with the higher value recorded at Houara (Table 11).

1.1.1.10 Depth of the basal sinus measured from the midrib in mm (DBS)

The average recorded for the species for the depth of the basal sinus is 3.65 mm. By station, this variable has the following averages: 9.92 mm and 0.45 mm, with minimum and maximum values of 0.45-9.81 mm and 1.01-9.92 mm for the Djebel Ouahch and Houara stations, respectively. Regarding the standard deviation and the coefficient of variation, the recorded values are 1.60 mm and 50.54% at Djebel Ouahch and 1.61 mm and 39.07% at Houara (Table 11).

1.1.1.11 Number of teeth of the terminal lobe of the abaxial (NTT)

By station, this characteristic has the following averages: 1.92 and 2.56, with minimum and maximum values of 1.00-12.00 and 1.00-10.00 for the Djebel Ouahch and Houara stations, respectively. Regarding the standard deviation and the coefficient of variation, the recorded values are 1.20 and 62.56% at Djebel Ouahch and 1.76 and 68.98% at Houara. The average for the species is 1.54 with a range of 1.00-12.00 (Table 11).

1.1.2 Qualitative traits

1.1.2.1 Symmetry of the blade (SB)

At both intra- and inter-population levels, symmetrical form predominates, with a value of 99.89% for the species. The highest proportion was recorded at the Djebel Ouahch station, with a value of 100% (Table 12).

1.1.2.2 Color of the blade (CB)

There is a dominance of dark green leaf color (51.72%) for the species, with Djebel Ouahch showing the highest percentage (86.56%). Simultaneously, the Houara station has a dominance of green color at 44.78% (Table 12).

1.1.2.3 Shape of the petiole insertion (SP)

The rounded flattened on one side shape is the most significant at the inter-population level (99.50%). The others have an almost negligible percentage (Table 12).

1.1.2.4 Position of the basal sinus right relative to the left (PBS)

In the species, the position of the right basal sinus relative to the left one is nearly similar, with a percentage of 51.33%. Similarly, in both populations, the values are close (Table 12).

Table 11. Characteristics of the quantitative variables by station.

Variable / Station	Houara (H)	Djebel Ouahch (O)	Average (Species)
Length of the blade in mm (LB)	27,70±***6,08 (10,49-48,92) 21,96	37,76±***8,87 (16,20-89,09) 23,49	32,74±***9,11 (13,24-89,09) 27,82
Width of the blade in mm (WB)	20,68±***5,84 (6,98-45,61) 28,22	27,32±***8,21 (5,67-66,55) 30,04	24,00±***7,85 (5,67-66,55) 32,73
Number of secondary veins of the blade (NSV)	8,89±***1,91 (4,00-14,00) 21,43	9,72±***2,49 (2,00-18,00) 25,59	9,31±**2,25 (2,00-18,00) 24,21
Length of the petiole in mm (LP)	11,93±***5,51 (2,01-40,66) 46,23	11,61±***4,46 (2,98-39,57) 38,45	11,77±***5,02 (2,01-40,66) 42,64
Length of the basal lobe of the abaxial surface in mm (LBL)	15,51±***4,19 (2,53-28,53) 27,00	20,24±***5,41 (7,56-39,90) 26,75	17,87±***5,39 (2,53-39,90) 30,14
Width of the basal lobe of the abaxial surface in mm (WBL)	6,33±***2,32 (2,06-28,73) 36,71	6,65±***1,77 (2,15-14,58) 26,65	6,49±**2,07 (2,06-28,73) 31,92
Distance between the two sinuses of the basal lobes in mm (DS)	8,99±***3,12 (2,68-21,25) 34,74	6,79±***2,71 (1,93-19,49) 40,00	7,89±***3,13 (1,93-21,25) 39,63
Number of teeth of the basal lobe of the abaxial surface (NTB)	4,45±***3,40 (1,00-23,00) 75,48	2,74±***1,11 (1,00-8,00) 40,70	3,59±NS2,64 (1,00-23,00) 73,57
Number of visible secondary veins of the basal lobe (NVB)	2,35±***1,24 (1,00-10,00) 52,74	5,79±***2,55 (1,00-14,00) 43,97	4,07±***2,64 (1,00-14,00) 64,83
Depth of the basal sinus measured from the midrib in mm (DBS)	4,12±***1,61 (1,01-9,92) 39,07	3,17±***1,60 (0,45-9,81) 50,54	3,65±***1,67 (0,45-9,92) 45,93
Number of teeth of the terminal lobe of the abaxial surface (NTT)	2,56±***1,76 (1,00-10,00) 68,98	1,92±***1,20 (1,00-12,00) 62,56	2,24±***1,54 (1,00-12,00) 68,85

Mean, Mean; SD, standard deviation; Min, minimum; Max, maximum; Statistical significance threshold *, p < 0.05; **, p < 0.01; ***, p < 0.001

Table 12. Frequencies (%) for qualitative variables by station.

Variable / Station		Houara (H) %	Djebel Ouahch (O) %	Average (Species)
Symmetry of the blade (SB)	1- Symmetrical	0,22	0	0,11
	2- Asymmetrical	99,78	100	99,89
Color of the blade (CB)	1- Light green	16,89	86,56	51,72
	2- Green	44,78	13,33	29,06
	3- Dark green	38,33	0,11	19,23
Shape of the petiole insertion (SP)	1- Rounded	0,67	0,33	0,50
	2- Rounded flattened on one side	99,33	99,67	99,50
	3- Flat	0	0	0
Position of the basal sinus right relative to the left (PBS)	1- Upper	49,67	53	51,33
	2- Lower	50,22	47	48,61
	3- Similar	0,11	0	0,06

1.2 Analysis of morphological diversity

1.2.1 Significance tests

At the intra-population level, analysis of variance with one way (Table 10) for all quantitative variables revealed significant differences among trees within each population. At the inter-population level, significant differences were recorded by the student's t-test for all variables, except for the variable 'Number of teeth of the basal lobe of the abaxial surface (NTB)' which was found to be non-significant.

1.2.2 Correlation tests

The correlations between the different quantitative variables related to the leaves are illustrated in Table 13. Strong positive correlations ($r > 0.5$) and highly significant ($p < 0.001$) are recorded between:

- Length and width of the blade (LB) with $r = 0.77$. These two variables are also related to the length of the basal lobe of the abaxial surface (LBL) with r (0.69; 0.67), respectively.
- Distance between the two sinuses of the basal lobes (DS) and depth of the basal sinus measured from the midrib in mm (DBS) with $r = 0.82$.

The other variables showed sometimes significant but weak correlations ($r < 0.5$).

Tableau 13. Correlations between quantitative variables measured for leaves.

Variables quantitatives	LB	WB	NSV	LP	LBL	WBL	DS	NTB	NVB	DBS	NTT
Length of the blade in mm (LB)	1,00	0,77 ***	0,43 ***	0,37 ***	0,69 ***	0,35 ***	0,07 **	-0,07 **	0,44 ***	0,08 **	-0,02
Width of the blade in mm (WB)		1,00	0,43 ***	0,32 ***	0,67 ***	0,40 ***	0,13 ***	0,03	0,37 ***	0,08 ***	0,01
Number of secondary veins of the blade (NSV)			1,00	0,19 ***	0,36 ***	0,23 ***	0,17 ***	0,09 ***	0,23 ***	0,11 ***	0,03
Length of the petiole in mm (LP)				1,00	0,24 ***	0,17 ***	0,17 ***	0,21 ***	0,05	0,15 ***	0,17 ***
Length of the basal lobe of the abaxial surface in mm (LBL)					1,00	0,46 ***	0,12 ***	-0,04	0,34 ***	0,10 ***	-0,02
Width of the basal lobe of the abaxial surface in mm (WBL)						1,00	0,35 ***	0,21 ***	0,13 ***	0,27 ***	0,14 ***
Distance between the two sinuses of the basal lobes in mm (DS)							1,00	0,26 ***	-0,19 ***	0,82 ***	0,19 ***
Number of teeth of the basal lobe of the abaxial surface (NTB)								1,00	-0,15 ***	0,24 ***	0,40 ***
Number of visible secondary veins of the basal lobe (NVB)									1,00	-0,13 ***	-0,06 *
Depth of the basal sinus measured from the midrib in mm (DBS)										1,00	0,18 ***
Number of teeth of the terminal lobe of the abaxial surface (NTT)											1,00

1.2.3 Multivariate tests

The factorial plan of principal component analysis explains a total inertia of 64.88 %, meaning that the first and the third dimensions (1x3) allowed for a better interpretation of individuals and variables (see Figure 17 and Table 14). The first axis accounts for 58,39 %, while the other summarizes 6,49 %.

The correlation circle reveals that all quantitative leaf-related variables (see Figure 15A) are more or less correlated with the two axes, as shown in Table 15. The variables " Length of the blade in mm (LB), Width of the blade in mm (WB), Length of the basal lobe of the abaxial surface in mm (LBL) and Number of visible secondary veins of the basal lobe (NVB)" are strongly correlated at axis 1, with correlation coefficients (r) of (-0,77; -0,69; -0,66; -0,85), respectively. These variables are related as follows (see Table 15):

- Negatively overall dryness or aridity, as indicated by the Emberger coefficient Q_3 and explained by the positive effects of precipitation "P", cold intensity "m", and longitude "Long" and latitude "Lat".
- Positively to thermal continentality explained by its thermal gradient Ic under the moderating effect of altitude "Alt" and maximum temperature "M".

The projection of individuals (60 trees) obtained through the interaction of morphological and environmental variables (Figure 17B) shows two distinct groups, O (Group 1) and H (Group 2), which are also evident on the dendrogram of the hierarchical clustering analysis (CHA) obtained using Ward's method via Euclidean distance (Figure 17C).

According to the factorial map (Figure 17B), the grouping of the two populations (Djebel Ouahch, O and Houara, H) is determined by a decrease in continentality and an increase in aridity, influenced by geographical factors, especially altitude. This means that the values of the "Ic" index decrease from the sub-continental attenuated station Djebel Ouahch (Ic = 24.5) to the eu-oceanic attenuated station Houara (Ic = 16.7). Simultaneously, the values of Q_3 increase.

Tableau 14. Eigenvalues from PCA.

Number of values	Eigenvalues	% Total variance	Cumulative Eigenvalues	Cumulative %
1	11,09	58,39	11,09	58,4
2	3,87	20,39	14,97	78,8
3	1,23	6,49	16,20	85,3

Tableau 15. Correlations between variables on the factorial plane.

Variables	Factor 1	Factor 2	Factor 3
LB	-0,77	-0,51	-0,10
WB	-0,69	-0,62	-0,12
NSV	-0,45	-0,63	-0,19
LP	0,01	-0,53	0,37
LBL	-0,66	-0,58	-0,25
WBL	-0,19	-0,83	-0,16
DS	0,48	-0,73	-0,22
NTB	0,51	-0,49	0,54
NVB	-0,85	-0,05	0,19
DBS	0,45	-0,69	-0,13
NTT	0,40	-0,48	0,70
Alt	-0,99	0,07	0,08
Lat	0,99	-0,07	-0,08
Long	0,99	-0,07	-0,08
M	-0,99	0,07	0,08
m	0,99	-0,07	-0,08
P	0,99	-0,07	-0,08
Ic	-0,99	0,07	0,08
Q3	0,99	-0,07	-0,08

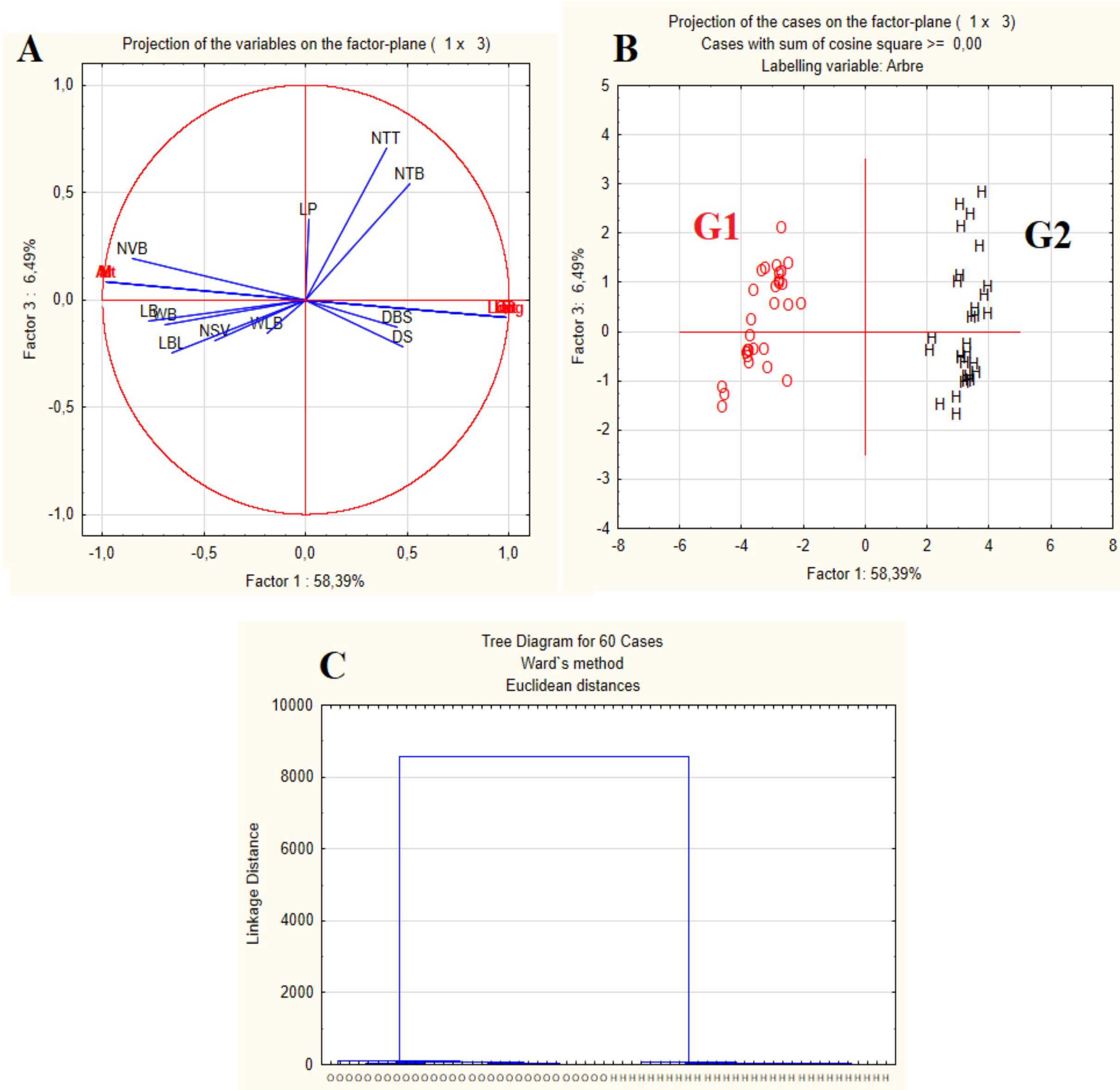

Figure 17. Principal Component Analysis (PCA) of quantitative morphological and environmental variables: Correlation circle of variables (A), projection of individuals (B), and Hierarchical Clustering Analysis (HCA).

2. Discussion

This section primarily explains the effect of geographical factors (altitude, latitude, and longitude) and climatic variables (thermal and ombric) on the studied phenotypic traits, including a comparative study of some results obtained in the literature of our species

2.1 Abiotic pressures

The variability expressed for all leaf morphological variables concerning the two populations is explained by the combination of thermo and ombro-climatic factors of the sampling stations and geographical components. According to Rivas-Martinez (2005), the delimitation of bioclimatic zones is based on thermo and ombro-climatic factors, allowing for a simpler expression of the vegetation-climate concept.

Our findings (Figure 17) from the multivariate analysis (PCA and CHA) of tree populations indicate gradients associated with aridity or drought (overall) and continental influences (thermal). As aridity and continentality increase, the Houara population forms a distinct group, characterized by a Sub-humid Cool temperate stage (Q_3 = 81.7) and an eu-oceanic attenuated nature (Ic = 16.7°C), in contrast to the Djebel Ouahch population, with a Semi-arid cool bioclimate (Q_3 = 56.1) of sub-continental attenuated type (Ic = 24.5°C). Additionally, winter thermal stress (m) and precipitation "P" influenced by altitude (Alt), latitude "Lat.", and even longitude "Long." seem to impact the polymorphism of this species.

Species diversity, as defined by Bidault (1971) and Metro (1975), stems from taxonomic traits, individual characteristics, or properties of a plant, which can vary among individuals of the same species due to environmental conditions. The maintenance of aerial parts, particularly leaves, during adverse conditions is supported by a range of morphological and anatomical adaptations (Ozenda, 2000). Furthermore, interactions between environmental factors and the phenotypic plasticity of many plant species have been noted by various authors (Aussenac, 1973; Hsiao, 1973; Alyafi, 1978; Ehleringer, 1980).

Numerous studies (Alyafi, 1979; Belhadj *et al.*, 2007; Doughbage, 2009) indicate that intraspecific variation in leaf traits among Anacardiaceae species is predominantly influenced by climatic rather than genetic factors. Alyafi (1979) and Barboni *et al.* (2004) propose that plants prioritize different functional traits to mitigate the effects of drought. Consequently, in arid environments, xeromorphic plants tend to have smaller leaves, correlated with transpiration rates (Fahn, 1967), with smaller leaves being more prevalent in high-altitude and cold locations (Barboni *et al.*, 2004).

2.2 Comparison of the data collected in the literature

The phenotypic variability of the leaves of our species is well documented. According to Quézel & Santa (1962) and Maire (1980), there are two distinct species (*C. Oxyacantha* L.; *C. laciniata* Ucria) with a hybrid (x *C. ruscinonensis* Grenier and Blanc), except for *C. Azarolus* L., which is known for its yellow fruit. *C. Oxyacantha* L. is distributed throughout Algeria except in the high plateaus, consisting of two subspecies (ssp. *monogyna* (Jacq.) Rouy & Camus and ssp. *maura* (L. fils) Maire), which agrees with our sampling in Constantine and Guelma.

The blade length falls within the range reported by Maire (1980) with its value of 3-7 mm for *C. Oxyacantha*, so that of the subspecies *monogyna* (Jacq.) Rouy and Camus is deeply lobed or pennatifid like ours (Depth of basal sinus measured from the midrib (PSN) is equal to 3.65 mm in our species). Regarding the petiole length, the data recorded by the same author are close to his values (8-20 mm for *C. Oxyacantha*).

Finally, it appears that the values reported for many phenotypic characters collected in the literature for hawthorn are consistent with ours; however, they differ for others. This diversity is probably due to:

- Abiotic pressures as our two populations are differentiated based on specific ecological factors (aridity, continentality, altitude, etc.).

- Biotic pressures which could play a limiting role; that is, introgressions between species (*C. oxyacantha* and *C. azarolus*) could very well occur in these contact zones and could be explained by the influence of selective pressures from dispersing vertebrates (especially birds), as is the case with the yew (Hafsi, 2018). These hybridization phenomena between the two different taxa could be responsible for taxonomic problems in certain populations. Furthermore, according to Grieve (1931) and Davies (2000), different species of the genus Crataegus hybridize easily, making it difficult to accurately count their number.

As a result, it seems preferable to consider the polymorphism of Algerian hawthorn as a specific complex whose interspecific organization is not clear and remains debatable.

Conclusion

This present study provides an overview of the specific complex *Crataegus oxyacantha* L., hawthorn in Algeria, whereby the phenotypic variability of its leaves was studied at both intra- and inter-population levels using quantitative and qualitative morphological characters.

It appears that the Algerian formations of this species seem to be rapidly sliding towards intense and progressive degradation due to strong anthropogenic and environmental pressures. Subsequently, following the statistical analysis of the data, the analysis of variance for the quantitative variables studied concerning the leaves revealed significant differences at both intra- and inter-population levels.

This variability is primarily justified by abiotic pressures, i.e., limiting geographical and climatic factors or gradients that exert a significant influence (grouping of the two sampled populations via factorial analysis). These factors are linked to continentality and even aridity under the influence of environmental components. At the same time, other biotic factors have also been reported, including the presence of hybridization phenomena produced by ornithochory.

Consequently, the data obtained during this study confirm that:

- The studied Algerian populations seem to exhibit morphological variation (studied phenotypic characters) that is not clear and remains to be discussed.
- Phenotypic variation among different populations helps understand the resistance and adaptation of this species to environmental constraints.

In perspective, it emerges that the variability of Algerian populations of the specific complex *C. oxyacantha* is still largely to be discussed, which should encourage us to address other taxonomic traits (flowers, pollen, roots, etc.) and why not in other forest stations, particularly those in the Algerian coastal or continental environment.

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Miss **HADIDI Rihab**

Title : Foliar Morphology Study of Species in the *Oxyacanthae* Section (Loudon, 1838) of the Genus *Crataegus* L. (Case of Two Natural Populations in Algeria)

Abstract

In order to better characterize hawthorn and understand its adaptive behavior in response to the environment, we assessed phenotypic variability at both intra- and inter-population scales in two stations located in Algeria (Houaraet and Djebel Ouahch), conducting a descriptive and comparative analysis of its leaves.

A random sampling of thirty (30) trees was carried out in each of the two stations. Subsequently, thirty (30) leaves were collected from each tree and preserved in the laboratory. Morphological characteristics were then evaluated for these leaves.

The obtained data underwent statistical analysis. Single-factor analysis of variance revealed significant differences for the variables studied at both intra- and inter-population levels, while factor analysis clearly distinguished two distinct groups.

These results highlight a high phenotypic diversity for our species across all studied variables, which may be explained by the influence of ecological pressures.

Keywords: hawthorn, leaves, variability, population, morphology, Algeria.

Titre : Étude de la Morphologie Foliaire des Espèces de la Section *Oxyacanthae* (Loudon, 1838) du Genre *Crataegus* L. (Cas de Deux Populations Naturelles en Algérie)

Résumé

Afin de mieux caractériser l'aubépine et de comprendre son comportement adaptatif face à l'environnement, nous avons évalué la variabilité phénotypique à l'échelle intra et inter-population dans deux stations répertoriées en Algérie (Houaraet et Djebel Ouahch), en réalisant une analyse descriptive et comparative de ses feuilles

Un échantillonnage aléatoire de trente (30) arbres a été effectué dans chacune des deux stations. Par la suite, trente (30) feuilles ont été prélevées sur chaque arbre et conservées en laboratoire. Des caractères morphologiques ont ensuite été évalués pour ces feuilles.

Les données obtenues ont été soumis à une analyse statistique. L'analyse de variance a un seul facteur a révélé des différences significatives pour les variables étudiées au niveau intra et inter-population, tandis que l'analyse factorielle a permis de distinguer clairement deux groupes distincts.

Ces résultats mettent en évidence une grande diversité phénotypique pour notre espèce à travers toutes les variables étudiées, ce qui peut s'expliquer par l'influence des pressions écologiques.

Mots-clés : aubépine, feuilles, variabilité, population, morphologie, Algérie.

العنوان: دراسة التشكل الورقي لأنواع من قسم *Oxyacanthae* (Loudon, 1838) من جنس *Crataegus* L. (حالة مجموعتين طبيعيتين في الجزائر).

ملخص:

لتوضيح خصائص الزعرور البري وفهم سلوكه التكيفي تجاه البيئة، قمنا بتقييم التباين الظاهري داخل وبين المجموعات النباتية المأخوذة من منطقتين في الجزائر (هوارة وجبل واحش)، من خلال إجراء تحليل وصفي ومقارن لأوراقه.

تم القيام بعينة عشوائية من ثلاثين (30) شجرة في كل من المنطقتين. ثم تم جمع ثلاثين (30) ورقة من كل شجرة والاحتفاظ بها في المختبر. تم تقييم الخصائص المورفولوجية لهذه الأوراق بعد ذلك.

خضعت البيانات المحصلة لتحليل إحصائي. أظهر تحليل التباين الواحد لعامل واحد وجود فروق ذات دلالة إحصائية عالية داخل وبين المجموعات ، بينما سمح التحليل العاملي بتمييز مجموعتين متميزتين بوضوح.

تبرز هذه النتائج تنوعًا ظاهريًا كبيرًا للنبات عبر جميع المتغيرات المدروسة، والذي يمكن تفسيره بتأثير الضغوط البيئية.

الكلمات المفتاحية: الزعرور البري، اورق، تنوع، مجموعة، مورفولوجيا، الجزائر.

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