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Morphological Behavior of the Leaves, the Fruits and the Trees of 03 Natural Atlas Pistachio Populations (*Pistacia Atlantica* Desf.) Collected in the Algerian Arid Region

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ABSTRACT:

Introduction: The Atlas pistachio (*Pistacia atlantica*) is a robust tree endemic to North Africa with a well-defined trunk and deciduous leaves. It contributes to soil conservation and plays a vital role in reforestation programs in arid and semi-arid areas.

Methods: This study focused on three populations of the Atlas pistachio tree located in different stations in the arid region of Algeria, namely: Sidi M'Hamed (M'sila), Messaad (Djelfa), and Ras El Miaad (Biskra). It was conducted to determine the morphological behavior of the species in arid bioclimatic regions, taking into consideration the effect of the soil physicochemical characteristics. In this regard, eleven traits of the trees, the leaves and the fruits were measured.

Results: The statistical analysis of the soil physicochemical parameters concluded that the soils of the studied areas have a medium texture and moderately a basic pH, and are low to moderately limestone, slightly saline, and relatively rich with the organic matter. Regarding the morphological variability, groups of stations were discriminated based on the different variables studied. The principal component analysis (PCA) revealed a correlation between the dimensions of the trees and the leaves with the soil properties and the climatic factors. It allowed dividing the three stations into three groups. The variables of total tree height, tree circumference, crown height, organic matter, soil moisture content, pH, electrical conductivity, total limestone content, and altitude discriminate the station SM (group 1). The variables fruit length, leaf area, leaf width, and leaf length discriminate the station MS (group 2). The station RM represents group 3 and is characterized with the variables of trunk height and fruit width.

Keywords: Algeria, Pistacia atlantica, biometry, morphology, trees, leaves, fruits, soil.

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1. Introduction

Atlas pistachio (*Pistacia atlantica* Desf., Anacardiaceae) is a tree that may reach a height of 20 meters with individualized leaves and deciduous leaves (Benhssaini & Belkhodja, 2004; Belhadj, 2007). Its ecology cannot be easily identified because of its high plasticity. It adapts to all the soils, except the sandy ones, and has a slow growth. According to Monjauze (1980) and Ozenda (1983), *P. atlantica* is an endemic species from North Africa.
The degradation of the vegetal patrimony is the outcome of many ecophysiological, anthropic, and climatic factors (Benhassaini & Belkhodja, 2004). Besides, the Algerian Atlas pistachio is in an alarming situation due to its high degradation (Belhadj et al., 2007; Belhadj et al., 2008a; 2008b). Other factors such as the pests, the diseases, and the drought contribute to this phenomenon (Louzabi et al., 2016; 2020). In this regard, the lack of the scientists and managers around this species will lead to its extinction. Its regeneration is natural and at random, which limits its potential use. Very little information on the ecophysiological and adaptive behavior of the species is known (Belhadj et al., 2011). Therefore, this study aims at analyzing the soil underneath the pistachio tree in order to understand the morphological diversity and variability of the species. Therefore, a morphological description of the species in the arid and semi-arid regions (Msila, Djelfa, and Biskra) was undertaken. Moreover, the analysis of the morphological diversity of three spontaneous local populations of this species is studied using the morphological characteristics of the trees as well as the leaves and the fruits. Finally, the morphological variability is recorded according to different climatic conditions and physico-chemical soil variations in the study region.

2. Material and Methods

1. Description of the Sampling Sites

The sampling includes 03 sites (stations) in 03 different disctricts in the Algerian arid zone, namely: Sidi M'hamed (SM) in M'sila district, Messaad (MS) in Djelfa district, and Ras El Miaad (RM) in Biskra district (figure 1). The synthesis of the general characteristics is shown in table 1 and figure 2. In order to characterize the climate of the studied sites during the experimentation period (1996-2019), the pluviometric quotient (Q_2) introduced by Emberger (1955) is calculated, according to the formula: Q_2 = 3,43P/Mm. Where M is the average maxima of the temperatures of the hottest month; m is the average minima of the temperatures of the coolest month and P is the average annual amount of the precipitations.
The climatic data, according to the N.O.M. (National office of meteorology), with corrections following the altitudinal gradient, are used.

2. Sampling:

For each study site, the leaves and the fruits were collected at random from 30 trees. The leaves were collected late June-early July 2017, 2018 and 2019, and the ripe fruits in September 2017, 2018 and 2019. In total, 90 trees, 900 leaves, and 900 fruits were sampled. Then, the leaves and the fruits were dried and conserved in Kraft paper bags in the laboratory conditions until use.

3. Measures of the Quantitative Morphological Characters:

Eleven (11) quantitative characters were measured: (1) Total height of the tree (TH) in meter, (2) Drums height of the tree (DH) in meter, (3) Circumference of the tree (CR) in meter, (4) Crown height of the tree (CH) in meter, (5) Foliar surface (FS) in square millimeter, (6) Leaf width (LW) in millimeter, (7) Leave length (LL) in millimeter, (8) Number of leaflets NL, (9)

Fruit width (FW) in millimeter, (10) Fruit length (FL) in millimeter and (11) Fruit thickness (FT) millimeter.
For the biometric measures (quantitative characters), we relied on the method described in the I.P.G.R.I repository (1980). In addition, the measures of the total height of the tree were recorded by a Dendrometer Blume Leiss- BL 7, and the measures of FT, CR, and HP were measured using a meter tape. Besides, the measures of FS, LW, and LL were measured using a planimeter (Area meter. AM 30). The AM 350 is a mobile measurement instrument to find out the area of the leaves. In this context, the measures were optically measured using a simple numeration process. The fruits size (width, length, and thickness) was calculated with a chart paper placed under binoculars.

4. The Physico-Chemical Analysis of the Soil
Form each study site, 03 samples were collected and conditioned according to the most possible hermetic way in plastic bags, which were labeled with the necessary information (date, name of the sampling site**).** The samples were allowed to dry in the lab conditions for 48 hours. After the grinding and sieving at 2 mm, a fine soil is obtained and conditioned in hermetic boxes. The methods used are those described by Aubert (1978) in his manual on the soil analysis. The studied physico-chemical parameters of the soil are as follows: (1) The humidity % (H), (2) Water pH (pH), (3) The electric conductivity (Ec), (4) The total limestone level (Li), (5) The organic substance level (OS) and (6) The granulometry (Gr).

- The humidity is the water quantity (in %) $H_2O\ (\%) = (W_1 - W_2 / W_1) \times 100$
  W1: the weight of 10g of the thin land before drying.
  W2: the weight of 10g of thin land after drying in an oven of 105°C, during 48 hours.
  W1-W2: corresponds to the loss of water by the 10g.
- The water pH measures the electromotive force of a soil aqueous solution (soil/water= 1/ 2.5) using a pH-meter.
- The measure of EC is a method that gained ground slowly for measuring the soil salinity (De Jonc et al., 1979: Williams & Hoey, 1982). We determine the conductivity on a solution of aqueous extraction (soil/water equals 1/5) expressed in millisiemens per centimeters (ms/cm) using a conductivimeter.
- The total limestone level is based on the characterized reaction of the calcium carbon ($CaCO_3$) using hydrochloride acid (Hcl). The level is characterized using a Bernard Calcimeter.
- The OS level: OS was dozed using Anne Jackson method (1965) (qtd. in Aubert, 1978) $OS\ (\%) = C\ (\%) * 1,72$
- The granulometry is measured according to the international method using the Robinson pipett.

5. Statistical Analysis:
The results were statistically analyzed using STATISTICA (version 13, 2005). For each studied character, we used the descriptive analysis, the analysis of variance, and the means comparison (Newman-Keuls) to detect the homogenous groups. Then, the principal components analysis (PCA) was carried out to find out the spatial distribution of the individuals (typology) according to the morphological characteristics and identify the markers that contribute to their discrimination.

3. Results and Discussion

1. Morphological Variability of *Pistacia Atlantica*:
1.1. Effect of the Provenance on the Tree:

Total height of the tree (TH) shows an average of 9.7m. The trees are smaller in Ras El Miaad (RM) and reach 8.2m. The bigger ones are in Sidi M'hamed (SM) with 11.5 m. The Drums height of the tree (DH) is in average 2.2 m; the highest value is 2.4m in RM while the lowest is 1.9m in SM. Regarding the Circumference of the tree (CR), the average is 3.9m; the highest value 4.6 m in SM while the lowest is in Messaad (MS) with 3.2 m. For the Crown height of the tree (CH), the values are between 14m in RM and 18.9 m in SM; with an average of 15.8 m (table 2; figure 3). The analysis of variance shows high significant differences between the three populations of the species regarding the dimensions of the tree, with $P < 0,001$ at $\alpha = 0,05$. The results obtained using the multiple comparison with Newman-Keuls Test showed (table 02):

- 03 groups for TH: group A in RM, group B in SM, and an intermediary group AB in MS;
- 03 groups for FH: group A in SM, group B in RM, and an intermediary group AB in MS;
- 03 groups for CR: group A in SM, group B in MS, and an intermediary group AB in RM;
- 03 groups for the CH: group A in RM, group B in SM, and an intermediary group AB in MS.

1.2. Effect of the provenance on the leaf:

FS is 3570.9 mm^2 in average. The biggest leaves are found in MS (4090.9 mm^2) and the smallest are in RM (3264.3 mm^2). The leaves dimensions vary between 105.2 and 11.76 mm for the length (an average of 110.4mm), and between 64.9 and 72.8 mm for the width (an average of 67.9 mm). The leaves are longer (117.6 mm) and wider (72.8 mm) in MS, and shorter (105.2 mm) and less wide (64.9 mm) in SM. They have between 3 and 6 pairs of leaflets for the 3 provenances, with an average of 9.3 pairs (table 02, figure 04).

The analysis of the variance shows highly significant differences among the populations regarding the FS, LL, and LW with $P< 0.001$, and significant differences for the NL with $p= 0.021$ at $\alpha = 0.05$. The results obtained using the multiple comparison with Newman-Keuls Test (table 02) showed the presence of :

- 02 groups for FS and LW: group A in SM and RM, and group B in MS;
- 03 groups for LL: group A in SM, group B in MS, and an intermediary group AB in RM.

1.3. Effect of the provenance on the fruit:

The dimensions of the fruits vary between 5.7 and 7.3 mm in length (an average of 6.3 mm), 4.7 and 5.1 mm in width (an average of 5 mm), and 3.6 mm in thickness. The fruits are wider (5.1 mm) in SM and RM, and only 4.7 mm in MS. They are longer in MS (7.3 mm) and shorter (5.74 mm) in SM (table 02; figure 05). The analysis of the variance showed highly significant differences between the three populations regarding the FL and FW, with $P< 0.001$, at $\alpha = 0.05$. The Newman-Keuls Test (table 02) showed the presence of:

- 02 different groups for FW: group A in MS and group B in SM and RM;
- 03 other different groups for FL: group A in SM, group B in MS, and an intermediary group AB in RM.

1.4. Correlation between the morphological variables:

The test of correlation allowed measuring the relation between two or more variables. In our work, the correlations cover 11 quantitative variables taken in twos. They represent the variability for each study sites. The most significant correlations were related to the variables of leaves and fruits dimensions, and NL. In all the stations, we notice a positive correlation between the variables of the dimensions of the trees, the leaves, the fruits, and the NL. Nevertheless, the inverse relations (negative correlations) were registered in the dimensions of the fruits and of the leaves (table 3).

Besides, positive correlations were recorded between the tree TH, CR, the CH, and NF, as follows: r = 0.62, r = 0.95, r = 0.92, between FH and LW (r= 0.50), FH and LL (r= 0.58), and FH and FT (r= 0.61). In addition, positive correlations were recorded between CR and the CH (r= 0.82), CR and LW (r= 0.83), and CH and NF (r= 0.77). The test of correlation confirms that FS and LL, LW, and FL are positively linked to a stronger intensity (r=0.97, r=0.94, r=0.97). This explains the different shapes of the leaves noticed for the species (table 03; figure 06).

We notice that the correlation matrix shows a significant relationship between FL and LL (r= 0.99), and FL (r)= 0.99) for the populations of the species (table 03; figure 06). We must point that there is a strong negative correlation between LL and FL (r= 0.99), and a significant strong correlation between FL and FT (r= 0.55) (table 03; figure 06). In addition, Atlas pistachio shows a morphological variability regarding all the measured variables. Similar observations were found for populations of different origins in the studies of Zohary (1952, 1996), Monjauze (1968), Kafkas & Perl-Treves (2001), Kafkas et al. (2002), Belhadj (2001, 2008a), Doghbage (2011, 2023) and Fakrouni (2018). The values of TH, CR, and CH agree with the findings of several authors (Meikle, 1977; Zohary, 1987; Boulos, 2000; Belhadj, 2001; Benhassaini et al. 2007; Benabdallah, 2011). However, they disagree with those of Yaltirik (1967), Jafri & ElGadi (1978) and Tutin et al. (1981) who found values lower than ours. The dimensions of the leaf, in average, agree with those found by several authors (Boulos, 2000; Yaltirik, 1967; Kafkas et al., 2002; Belhadj, 2007; Doghbage, 2011). Besides, the fruits dimensions go with those found by Zohary (1952), Yaltirik (1967), Tutin et al. (1968), Anwar & Rabbani (2001), and disagree with those of Kafkas et al. (2002), Belhadj (2007). Concerning the weight values of 100 fruits, our findings are lower to the values found by Kafkas et al. (2002), Atli et al.(1999), Elhani & Benmelouka (2003), Belhadj et al. (2008a) and Fakrouni (2018).

2. Study of the soil physico-chemical properties:

2.1 The hygroscopic humidity:

The lowest value is 0.80% in the soil under the Atlas pistachio of RM while the highest is 2.41% in MS. Besides, an average value of 1.33 was recorded in SM (table 04). Our findings are close to those of Chebieb (2008) regarding the lowest limit. However, they are superior to those of other studies regarding the superior limit (Limane, 2009). In general, our findings are included in the interval of the values mentioned by Tahrour (2005). The humidity is more important in MS (Alt: 747 m) and SM (Alt: 863). However, it is low in RM (Alt: 86m). The increase of the humidity in the two first sites may be due to the high location. These findings go with those of Tahrour (2005), Bournine (2007), Kebci (2008), and Limane (2009) regarding the same species.

2.2 Water pH:

Table 04 shows that the samples have an averagely basic pH (between 7.95 and 8.20), and slightly basic pH (7.73). The lowest pH (7.73) is recorded in RM while the highest was in SM (8.20). We deduce that the nature of the soil under the pistachio is more or less basic. In this context, our values are close to those of Limane (2009), inferior to those of Bournine (2007) and Deguiche (2008), and superior to those of Tahour (2005) (table 13). According to (Callot et al., 1982), in the limestone soil, the pH is controlled by the system $CaCO_3$, CO_2, H_2O. The organic acids shown by the roots are neutralized by the Ca^{2+} ions released by $CaCO_3$. Regarding the carbonates (CO_3^{2-}), they fix the protons H^+, decrease the concentration of the free protons, and lead to the increase of pH in these soil.

The increase of limestone in the soil increases the pH. In contrast, Limane (2009) stated that the low pH is the outcome of the high limestone level. The survey on arid soil samples in

Algeria show no correlation between the level of limestone and pH (Halitim, 1988) as reported by Limane (2009). This is confirmed by the findings of Pouget (1980) on 93 samples, where he compared their limestone and pH evolution, and found no correlation. According to Dambrine (2001), the soil pH is the result of a very slow evolution dominated by the biological activity that produces the acidity, the dissolution of the rocks and soils that produce alkalinity, and drainage that affects alkalinity and acidity. Thus, the neutral or alkaline soils under dry climates, are characterized with a low rainfall and a strong evapotranspiration.

2.3 The conductivity:

Table 04 shows that our samples have an Ec inferior to 04. The values of Ec in SM, MS, and RM are, respectively, 0,13 , 0,14 , 0,15. Hence, we conclude that Atlas pistachio occurs in the slightly saline soils. This confirms its big physiological adaptation. In this context, the soil salinity has an influence on the development of the vegetation; the presence of important quantities of salt in the soil decreases the hydric potential and strongly reduces the water availability for the plants. Thus, we face a physiologically dry environment (Tremblin, 2000).

2.4. The total level of the limestone:

Our samples vary between "weakly limestone" (6.14%) and "moderately limestone" with levels varying between 15.2% and 22.29% (table 04). RM has a low quantity of $CaCO_3$ (6,14%). The soils of the two other sites have an average quantity of $CaCO_3$ (about 18.24%). Our findings are close to those of Bournine (2009) and Limane (2009), lower than those of Deguiche (2008), and higher than those of Bournine (2007). The Atlas pistachio is also found in the "very weakly limestone" soils, such as Oued Besbes, and the "very strongly limestone" soils such as in EL-Mergueb. This proves its big adaptation to the chemical component of the soil and makes it a calcicole species, as described by Abdelkrim (1986; 1992).

2.5. The level of OS:

The majority of the samples do not exceed 5% of OS. The higher one is 4.35% in MS while the lowest is 2.43% in RM (table 04). These finding are close to those of Limane (2009) in the national reserve of El-Mergiueb. Besides, they can be explained by the presence of many animals (desert rat, rabbit, and gazelle) and plants, which may modify and enrich the soil with OS thanks to their biological activities. Besides, we can speak about the presence of anthropic actions which take place in the different works of the dayas. In this regard, MS shows a high level of OS thanks to its location in a grazing region. According to Pouget (1980), OS coming from the decomposition of a dead radical system, in the dry periods, represents 50% of the total phytomass. In addition, it constitutes stable humus that represents the arid regions of the North Sahara.

2.6. Granulometric analysis:

The quasi-totality (75%) of our sample has a dominant limestone texture, while the rest have a sandy texture. In this regard, the soil texture in MS and SM is loamy-sand while it is sandy in RM (table 04). The increase of the rate of the sand in RM may be due to its location on an acute slope, where the runoff impoverishes the soil of the fine elements. Therefore, we conclude that the soils under the Atlas pistachio in the study sites have a fine texture. Besides, most of the previous studies regarding the soils granulometric analysis of the Atlas pistachio show a variability in the texture (loam to loamy-sand) (Tahrour, 2005; Bournine, 2007; Kebci, 2008; Limane, 2009). Hence, we can state that the Atlas pistachio grows in the soils with fine texture.

Based on these results, we can conclude that the studied soils under the tree of Atlas pistachio are characterized with the following properties:

- Soil with an average texture ;
- Weakly to moderate limestone soils;
- Soils with basic pH;
- Slight saline soils;
- Soils very rich in OS.

The specie has no strict requirements regarding the pedological side. According to Zohary (1996) and Benhssaini & Belkhodja (2004), this forest species may be found and adapt to all kind of soils. In addition, Alyafi (1979) found out that the nature of the substrate does not exert a big influence on its distribution.

3. The interaction between the morphological variables, the physico-chemical properties of the soil, and the climate conditions:

3.1. The principal components analysis:

To investigate the existing relationships among the different study variables, we performed the principal components analysis. Only the relationship between the morphological characters, the minima temperatures, the altitude, and the physico-chemical parameters of the soil were considered (figure 07). The interpretation of the results of PCA revolved around the 02 first principal components (axes 1 and 2). The values of PCA showed that the 1st principal component (axis 1) explains 27.16% of the total inertia while the 2nd (axis 2) explains 19.43% of the total inertia. Figure 07 showed that the majority of the variables approach the correlation circle. The TH, CH, H, pH, EC, Li, OS, and the altitude are strongly and positively correlated in the axis 1, while the minimal temperature is negatively correlated. The FS, LL, LW, FL, OS, and the altitude are strongly and positively correlated in the axis 02.

Besides, correlations were recorded between the different variables. In this context, it is difficult to interpret them because of the diverse interactions between the different variables. Nevertheless, the correlations are evident, mainly between TH and CH, CR, H, EC, and altitude; between CR and CH and H; between CH and H, EC, and the altitude; between FS and LL and LW; between H and EC and Li; between pH and EC and Li; between EC and Li and altitude; between altitude and Li and the minimal temperature.

The nature and the distribution of the soils are tightly linked to the geomorphological units. The soils of the Algerian arid zones and steppe are described by many authors (Pouget, 1980; Kadi-Hanifi, 1982, 1983, 1998 and Halitim, 1988). Generally, they are poor in humus, fragile, and less profound. These soils have a weak thickness and little organic matter and trophic elements; they are more profound and sometimes used by farmers in the beds of the wadi (river) and in the non-saline depressions (dayas). Besides, they are characterized with a strong sensitivity to the erosion and degradation (Boughani, 2014).

The pedological profile of these regions is calcimagnesic xeric soil, with a limestone crust. This means that the quasi-totality of the soils is limestone in surface; yielding basic pHs that are sometimes close to the neutrality, and saturated absorbing complexes. This is the main common characteristic with the nature of the mother rock, which are practically limestone, and with the climate and the precipitations that are insufficient to produce a complete decarbonization for the surface horizons. These characteristics (presence of limestone, pH, and saturation of the complex) have a limited role in the pedological differentiation; however, they are ecological factors responsible for some ecological determinisms (edaphic ecological group: psamophytes, halophytes, and gypsophytes; species indicating edaphic factors: sand, salt, gypsum, etc) (Pouget, 1980).

We find out that our soils are rich in OS, and that the high retention of water allows better growth of the tree. In parallel, the tree prefers the vegetative growth (number of fruits produced in 100g is low). The trees also have wider crown with leaves. Most of the trees prefer the clay soil that retains water, despite the limestone soil, that is permeable, and that easily dries and heats. The Pistachio has deep roots that can pump water to more than 10m and, thus, resists the salinity and drought even in the poor, limestone, alkaline, or acid soils. Nevertheless, it prefers the sunny and the deep loamy-sandy soils that are well drained. Thus, it is used to valorize the marginal regions, or those threatened by the erosion, to fix the soil of the dunes as windshields, and to fight the desertification. Moreover, it can valorize large zones of the arid and semi-arid regions, where the salinity is an acute issue (Plassard, 1995).
The soils, whose pH is higher than 07, are generally limestone and/or salty. The acidity or presence of limestone in the soil influences the mineral nutrition of the trees and their good growth. In a very acid soil, the biological activity is weak and the decomposition of OS is slow; the litter accumulates on the soil surface. Some elements are, then, recycled and absorbed by the roots, making the trees grow with difficulty. In the presence of the calcium, the litter degrades rapidly and many insects transform the vegetal debris. The mineral elements are rapidly recycled in the soil and are absorbed in huge amounts by the roots, making the trees' development good. Besides, the limestone is a good component of the soil, as it participates to the good physico-chemical structure (Plassard, 1995).
Unfortunately, there are not many works on the tolerance of the forest species and especially on pistachios, of the arid and semi-arid regions, to the limestone soils. However, it is clear that the mycorrhization plays a big role in the improvement of the growth of some forest species (Plassard, 1995). Hence, in natural conditions, this species was considered tolerant to the limestone soils because it showed no sign of chlorosis by the cationic accumulation excess (calcium in particular) in the foliar tissues. In this context, the presence of the mycorrhizae on its radical system may explain the rusticity and adaptation. Unfortunately, we do not have similar data that may illustrate this relation. It is known that some species cannot prosper in the limestone soils. Besides, the nutrition of the species is disturbed because the environment generally lacks the metal and manganese. On the other hand, in the sandy soils, we notice a decrease of OS in the surface due to the accelerated mineralization. As for the limestone soils, the surface OS evolves rapidly more than in the soil because of the mechanic brewing by the worms (Mathieu & Pieltain, 2003).
In the steppic zone, the soils are poor; they are probably arid with a very low organic substance. The soils are limestone and not salty. In a survey by Lahoual (2014) in the region of Messaad (Djelfa), the morphological description of the profile and the analytical study classified these soils as aridosoils. These results were confirmed by physical analysis of the soil, showing high levels of fine sand and coarse sand; thus, a sandy texture.
According to Bouabdelli (2018), the aridosoils have a moderate alkalinity and are not salty. The organic substance showed a low level (1.5%). Besides, they are weakly to moderately limestone. The granulometric analysis showed the dominance of the limestone or sandy fraction. The soil texture is sandy-loamy.
If we consider our findings, the majority of our soils are averagely basic and limestone. Besides, the tree dimensions are correlated with the level of the hygroscopic humidity in the soil, EC, and altitude. According to many authors, the substrate nature does not have a big influence on the distribution and development of the species (Alyafi, 1979; Zohary, 1996; Limane, 2009, Guerine et al., 2021). The species is described as calcicole and may grow on limestone rocks (Abdelkrim, 1986; Khaldi & Khodja, 1995; Merbah et al., 2020; Ifticen et al., 2022). It also can adapt to all the soils (Zohary, 1996; Benhssaini & Belkhodja, 2004
How the soil influences the morphological variability is not known because many factors, in addition to the genetic factor, interact. Similar studies on the same species proved the

influence of the ecological factors related to the diversity of the bioclimates of the sampling zones (Alyafi 1978; Zohary 1952; 1996; Kafkas & Perl-Treves 2001; Kafkas et al. 2002; Belhadj et al., 2008, Doghbage, 2011 ; Benabdallah, 2011, Ifticene, 2016; Ifticen et al., 2022). The NL is a characteristic that can be affected by the ecological factors. It varies according to age of the leaf, the longitudinal gradient (Zohary 1952; Alyafi 1979; Belhadj et al., 2008, Doghbage, 2011; Doghbage, 2023), and the leaf dimensions.
Plants can adopt various strategies to minimize the impact of drought. For instance, small leaves tend to be more abundant in high plateaus and cold regions (Barboni et al., 2004, cited in Belhadj et al., 2008). According to Fahn (1967) (cited in Belhadj et al., 2008), in arid environments, xeromorphic plants generally show small leaves and the reduction in leaf size is correlated with a decrease in transpiration. Hence, consequently, increased aridity leads to a reduction in leaf size. In our study, the sampling sites were grouped accordingly to their bioclimate and altitudinal gradient. The largest leaves were observed at the highest sites (SM at 863 m and MS at 747 m), while the smallest were found at the RM station, at an altitude of 86 m. (table 02).
These findings disagree with those of Belhadj et al. (2008) regarding the same species from different provenances. The bigger individuals TH were found in the higher sites (SM: 863m, MS; 747m), while the smallest were in RM at 86m of altitude. The trees with a wide circumference and crown were found in the higher stations (SM: 863m, MS; 747m), while RM (86m) has trees with short circumference and crown. In conclusion, SM is characterized with the most important values regarding TH, CR, CH, OS, H, pH, Ec, Li, and altitude. Besides, MS is characterized with FL, FS, LW, and LL. Finally, RM is characterized by DH and FW. In an anterior work (Smaili, 2011) in the region of Msila, we realized a pedological profile. The analytical study classified these soils as aridosols. These results were confirmed by physico-chemical analysis of the soil, showing that the soils under Atlas pistachio trees have a medium texture and moderately basic pH, and are low to moderately limestone, slightly saline, and relatively rich with the organic matter.

4. Conclusion

The main aim of this study was the evaluation of the structural dynamics (diametric and vertical structures, descriptive parameters of the crown, and the diametric structure of the leaves and the fruits) of Atlas pistachio tree in the arid bioclimates. The study is based on the morphological variation of three populations of Atlas pistachio grown in wild in the central arid region of Algeria, under the effect of the physico-chemical parameters of the soil and the various climatic parameters.
The physico-chemical parameters of the soil under the species were studied and helped us to find out that the species grows in soils with an average texture, rich with the organic substance (OS), slightly saline, lowly to moderately limestone, and with an averagely basic pH.

Regarding the morphological variability, we used the characters related to the tree, the fruits, and the leaves. PCA allowed discriminating the sites into three groups. The variables of Total height of the tree (TH), Circumference of the tree (CR), Crown height of the tree (CH) , the organic substance level (OS), the humidity (H%), water pH (pH), the electric conductivity (Ec), the total limestone level (Li), and altitude (Al) discriminate Sidi M'hamed (SM) (group 1). In addition, the variables of Fruit length (FL), Foliar surface (FS), Leaf width (LW), and Fruit length (FL) allow discriminating Messaad (MS) (group 2). Finally, the 3rd station Ras El Miaad (RM) marks group 3 and is characterized by drums height of the tree (DH) and fruit width (FW). To understand the relationship and the interaction between the morphological

characters and the soil physicochemical parameters, we studied the correlations. The tree dimensions (Total height (TH), Drums height (DH), Circumference (CR), and Crown height (CH)) were correlated and influenced by the water amount in the soil, while the dimensions of the leaf correlate with the total limestone level (Li) and the humidity (H%) in the soil.
The interaction among the various morphological characters and the climatic factors shows that the altitude plays a basic role. Besides, the trees with bigger leaves are found in the higher sites, and the smaller ones were found in Ras El Miaad (RM) at an altitude of 86 m. Atlas pistachio is an important forest patrimony in Algeria. After our field observations, we found out that the species shows a morphological diversity thanks to its biotope and soil. The tree is part of the natural forest resources in the region. In addition, the tree is a good barrier against the movement of the sand and the desertification process. Therefore, it is necessary to preserve and valorize this tree species. Its rehabilitation and conservation are necessary for the sustainable development of the arid and semi-arid regions. Upon this study, we recommend the creation of protected zones for the species insitu as well as the creation of a germaplasm collection by further genetic studies to better understand its variability and adaptation to the arid and semi-arid regions.

Table 1: General characteristics of the study sites.

Region	Site	Geographic coordinates	Altitude (m)	T° Max (°C)	T° Min (°C)	P (mm)	Q_2	Bioclimate
1.M'sila	Sidi m'hamed « SM »	34°46'10.2" N 4°15'09.6" E	863	35.79	1.84	293	29.57	Aride and cool winter
2.Djelfa	Messaad « MS »	34°10'57″N 03°30'10″E	747	34.3	0.6	287.3	12.1	Saharan and cool winter
3.Biskra	Ras El Miaad « RM »	34°48'6″N 5°44'1″E	86	40.86	6.92	142.90	14.18	Saharan and temperate winter

P: average annual precipitation, T° Max: average maximum temperature of the hottest month, T° Min: average minimum temperature of the coldest month, Q_2:Emberger's pluviometric quotient.

Table 2. Characteristics of the quantitative traits measured for the trees, the leaves and the fruits of *Pistacia atlantica* (by site).

Variables	Mean ± SD; Extent (C.V. in %)			
	Sidi M'hamed **(SM)**	Messaad **(MS)**	Ras El Miaad **(RM)**	Mean
TH (m)	11.5^{***b} ± 1.4 9.6-14.5 (12.5)	9.3^{***ab} ± 1.1 7.6-11 (12.1)	8.2^{***a} ± 0.7 7-9 (9)	9.7 ± 1.7 7-14.5 (18.4)
DH (m)	1.9^{***a}± 0.4 1.3-2.7 (21.7)	2.3^{***ab}± 0.3 1.7-2.9 (15.2)	2.4^{***b}± 0.5 1.7-3.1 (21)	2.2 ± 0.4 1.3-3.1 (21.7)
CR (m)	4.6^{***a}± 0.3 4.2-5.1 (6.7)	3.2^{***b} ± 0.6 2.2-4.4 (20.3)	3.9^{***ab} ± 0.6 2.8-4.8 (17.6)	3.9 ± 0.8 2.2-5.1 (20.6)
CH (m)	18.9^{***b}± 1.7 15.8-21.8 (9.2)	14.4^{***ab} ± 1.7 11.4-18 (12.1)	14^{***a}± 1.9 9-17 (13.8)	15.8 ± 2.8 9.7-21.8 (18)

FS (mm^2)	3357.4^{***a}± 869.4 1930-4905 (25.8)	4090.9^{***b} ± 912 1852-6273 (22.2)	3264.3^{***a}± 595.9 2195-4510 (18.25)	3570.9 ± 884 1852-6273 (24.7)
LW (mm)	64.9^{***a}± 14.1 30.5-92.7 (21.7)	72.8^{***b} ± 13 45.5-98.8 (17.8)	66^{***a}± 12.15 37.8-92.2 (18.3)	67.9 ± 13.5 30.5-98.8 (19.9)
LL (mm)	105.2^{***a}± 20.9 44.2-145.2 (19.8)	117.6^{***b} ± 11.4 90.4-144.3 (9.7)	108.3^{***ab} ± 13.2 69.5-134.1 (12.2)	110.4 ± 16.5 44.2-145.2 (15)
LN (mm)	9.4^{***a} ± 1.6 6-11 (17.1)	9.3^{***a}± 1.7 5-11 (18.6)	9.1^{***a}± 1.5 7-11 (16.8)	9.3 ± 1.6 5-11 (17.5)
FW (mm)	5.1^{***b} ± 0.4 4-6 (8.9)	4.7^{***a} ± 0.3 4-6 (8.12)	5.1^{***b} ± 0.4 4-6 (9)	5 ± 0.4 4-6 (9.4)
FL (mm)	5.7^{***a}± 0.6 5-7 (10.7)	7.3^{***b} ± 0.7 6-9 (10.6)	5.9^{***ab}± 0.8 5-8 (13.9)	6.3 ± 1.04 5-9 (16.3)
FT (mm)	3.6^{***a}± 0.3 3-4.5 (8.5)	3.6 ^{***a}± 0.6 2-7 (18.6)	3.6^{***a} ± 0.3 3-4 (8.5)	3.6 ± 0.4 2-7 (12.8)

Table 3. Correlation matrix of the morphological variables studied for *Pistacia atlantica*.

Variables	TH	DH	CR	CH	FS	LW	LL	LN	FW	FL	FT
TH	1	-0.97	**0.62**	**0.95**	-0.05	-0.29	-0.38	**0.92**	0.09	-0.26	-0.77
DH		1	-0.78	-0.99	0.27	**0.50**	**0.58**	-0.82	-0.31	0.47	**0.61**
CR				**0.82**	-0.81	-0.92	-0.96	0.29	**0.83**	-0.91	0.004
CH				1	-0.34	-0.56	-0.64	**0.77**	0.38	-0.53	-0.55
FS					1	**0.97**	**0.94**	0.31	-0.99	**0.97**	-0.58
LW						1	**0.99**	0.07	-0.97	**0.99**	-0.37
LL							1	-0.01	-0.95	**0.99**	-0.28
LN								1	-0.28	0.11	-0.95
FW									1	-0.98	**0.55**
FL										1	-0.40
FT											1

Tableau 4. Physico-chemical parameters of the soils under *Pistacia atlantica* tree in the studied sites.

Region	Site	HH (%)	ph	EC (mS/cm)	Total lime ($CaC0_3$) (%)	OS (%)	Soil texture
1.M'sila	Sidi m'hamed (SM)	1.33	8.20	0.14	14.2	3.87	Sandy loamy
2.Djelfa	Messaad (MS)	2.41	7.95	0.13	22.29	4.35	Sandy loamy
3.Biskra	Ras El Miaad (RM)	0.8	7.73	0.15	6.14	2.43	Silty loamy

HH%:The humidity, pH: Water pH, Ec: The electric conductivity, Li: The total limestone level, OS: The organic substance level and Gr: The granulometry.

Table 5. Correlation matrix of the morphological and edapho-climatic variables, measured for *P. atlantica*.

Variables	TH	DH	CR	CH	FS	LW	LL	LN	FW	FL	FT	HH	pH	EC	Ca	OS	Tm	Al
TH	1	-0.14	**0.45**	**0.57**	-0.03	-0.04	-0.08	0.05	0.02	-0.15	-0.04	**0.49**	0.23	**0.53**	0.30	0.39	-0.48	**0.65**
DH		1	-0.26	-0.12	0.07	0.08	0.08	-0.09	-0.03	0.15	0.03	-0.30	-0.18	-0.32	-0.14	-0.15	0.19	-0.32
CR			1	**0.59**	-0.22	-0.16	-0.22	0.009	0.22	-0.47	-0.04	**0.41**	0.38	0.39	0.09	-0.13	0.14	0.09
CH				1	-0.10	-0.09	-0.17	0.03	0.11	-0.31	-0.01	**0.52**	0.33	**0.54**	0.22	0.23	-0.28	**0.51**
FS					1	**0.57**	**0.60**	0.01	-0.18	0.23	-0.06	-0.11	-0.19	-0.08	0.12	0.26	-0.30	0.19
LW						1	0.35	0.07	-0.13	0.08	0.005	-0.10	-0.13	-0.09	0.04	0.12	-0.14	0.062
LL							1	-0.06	0.04	0.15	-0.02	-0.15	-0.17	-0.13	0.04	0.13	-0.14	0.04
LN								1	-0.09	-0.07	-0.03	0.03	0.007	0.03	0.03	0.04	-0.05	0.06
FW									1	-0.31	0.24	0.11	0.18	0.08	-0.10	-0.22	0.26	-0.16
FL										1	0.04	-0.28	-0.36	-0.23	0.14	0.33	-0.40	0.19
FT											1	-0.02	0.003	-0.02	-0.03	-0.04	0.05	-0.06
HH												1	0.36	**0.70**	**0.56**	-0.07	-0.21	0.42
Ph													1	**0.83**	**0.53**	0.07	0.16	0.02
EC														1	**0.79**	0.32	-0.31	**0.51**
Ca															1	0.40	-0.50	**0.51**
OS																1	-0.84	**0.78**
Tm																	1	-0.94
Al																		1

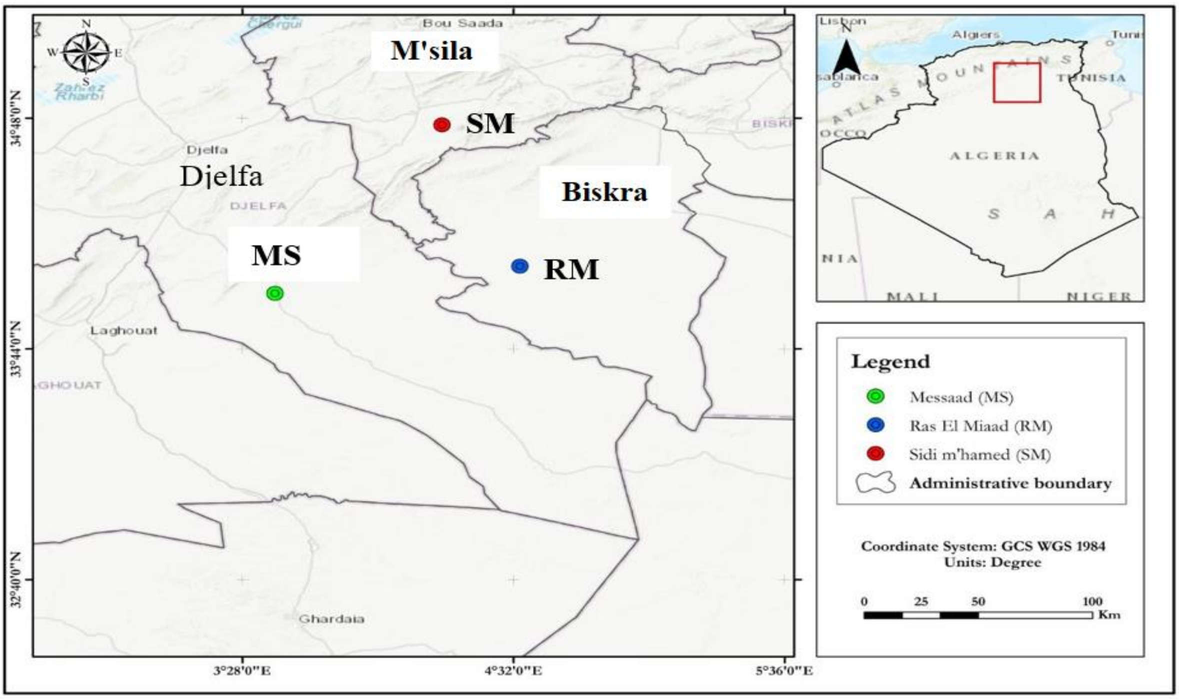

Fig. 1: Location of the sampling sites

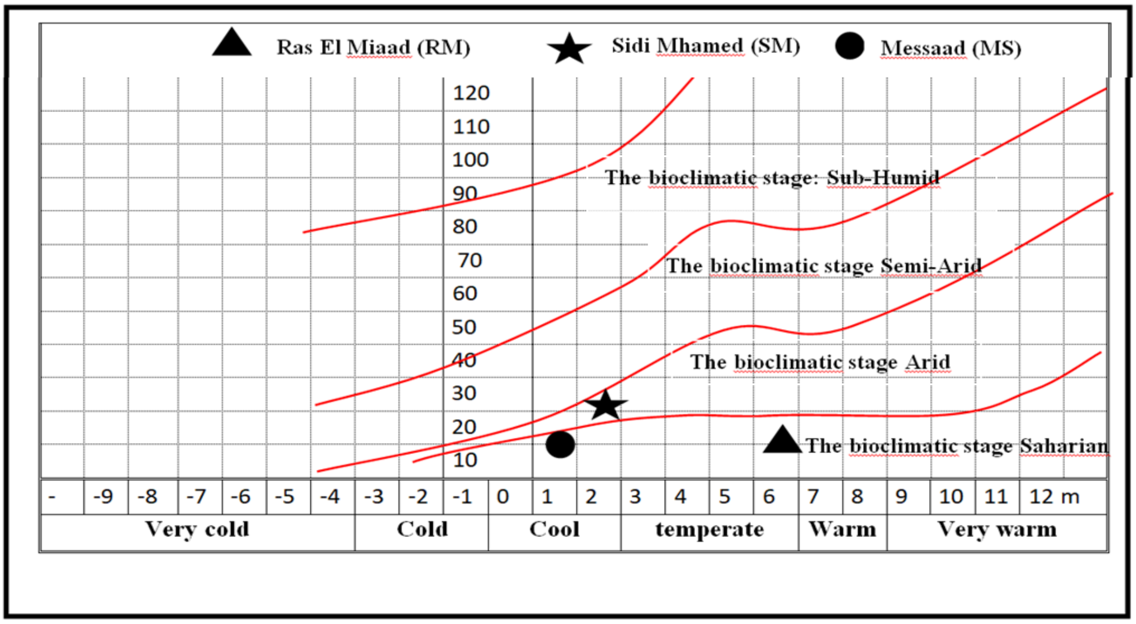

Fig. 2: Situation of the sampling stations on Emberger climagram

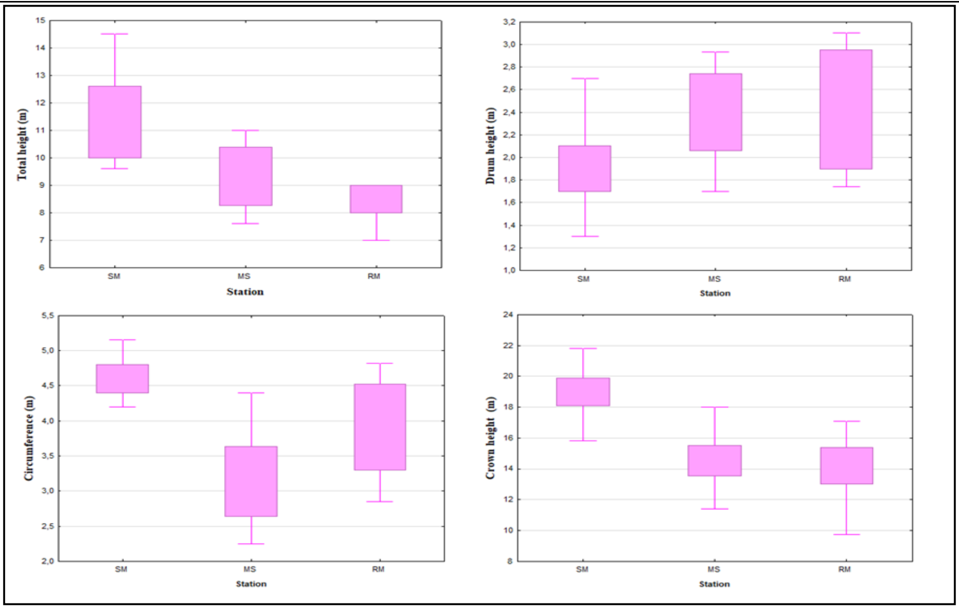

Fig.3 : Provenance effect by ANOVA (α = 0.05) on trees biometrics in *Pistacia atlantica*

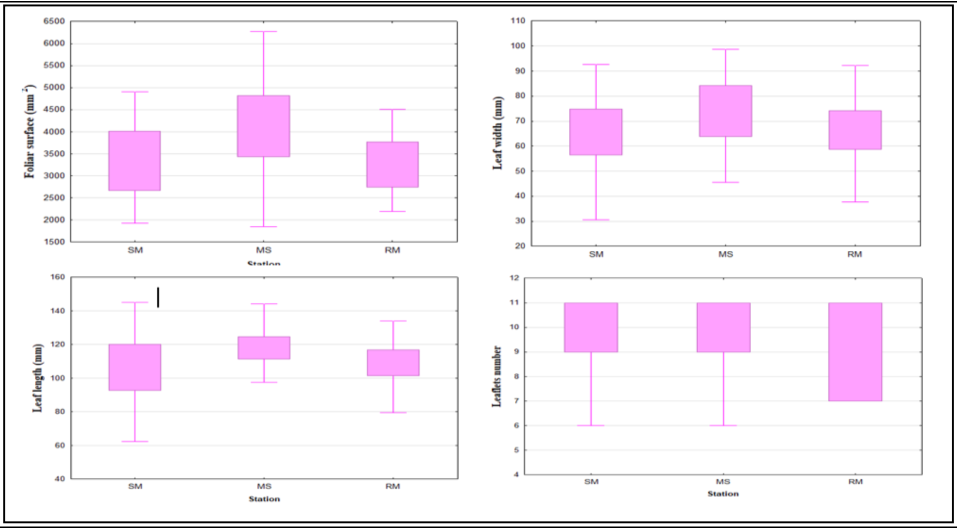

Fig.4 : Provenance effect by ANOVA (α = 0.05) on leafs biometrics in *Pistacia atlantica*

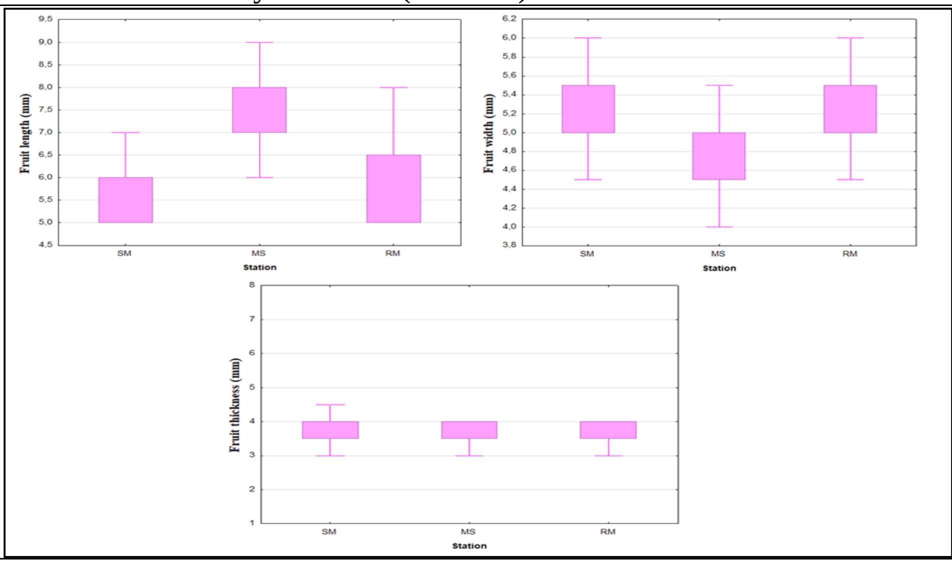

Fig.5 : Provenance effect by ANOVA (α = 0.05) on fruits biometrics in *Pistacia atlantica*

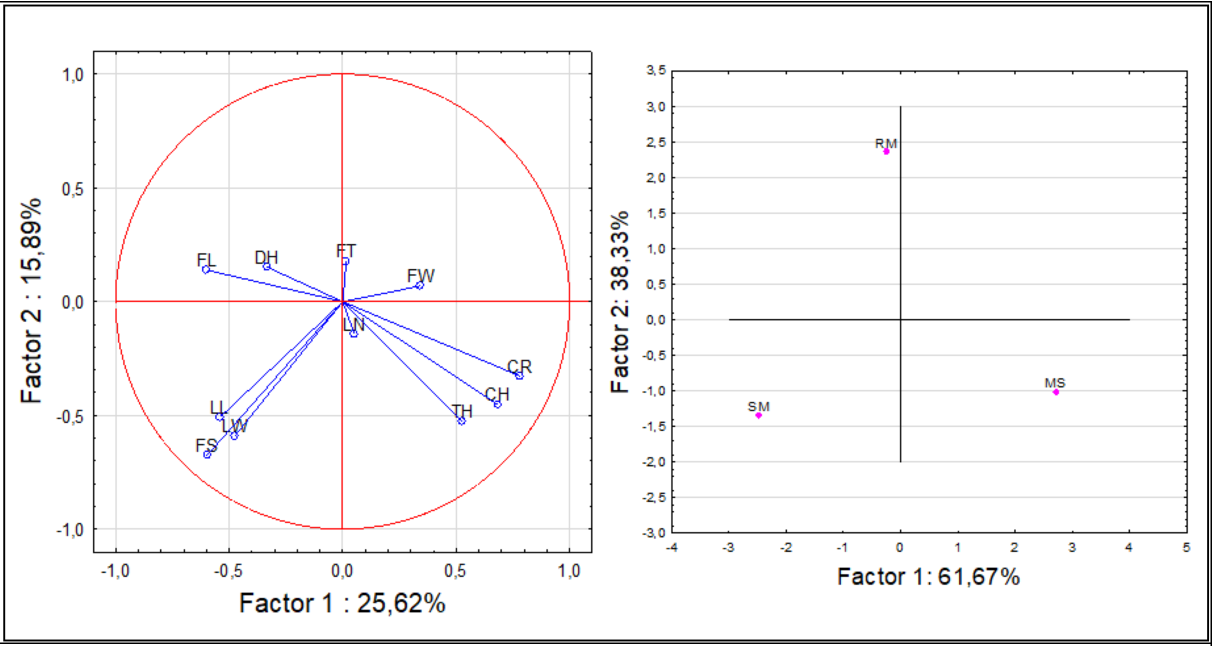

Fig.6 : Circle of correlations and projection of individuals and morphological variables on factors 1 and 2.

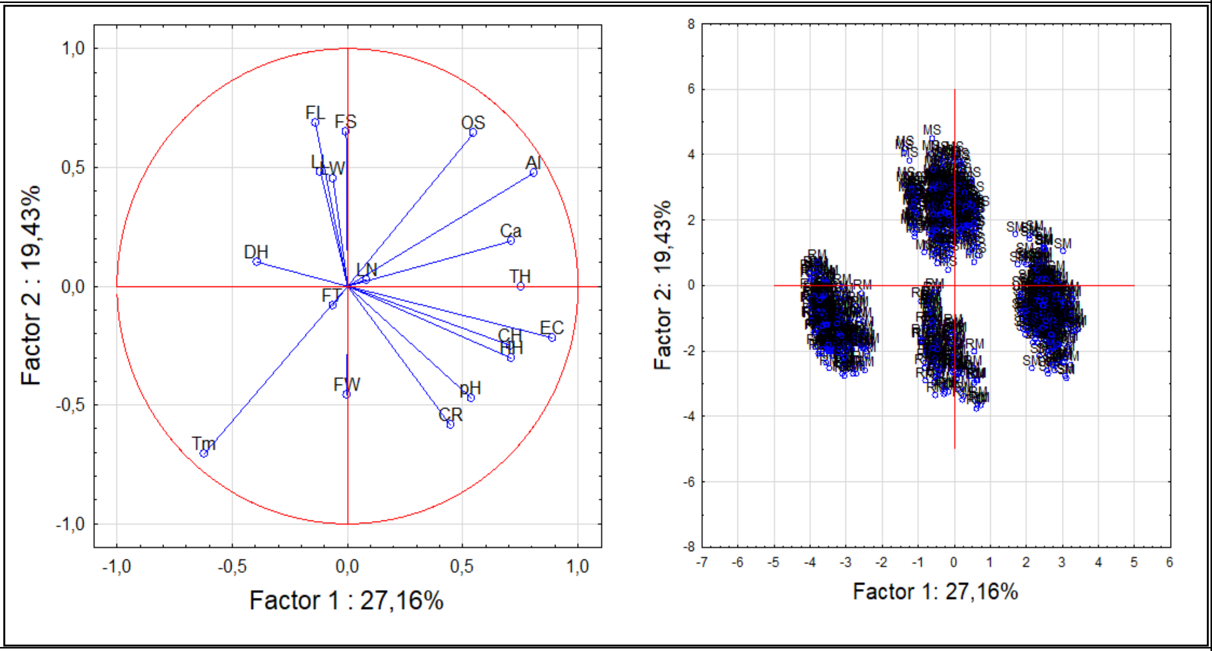

Fig.7 : Circle of correlations and projection of individuals and variables on factors 1 and 2.

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