Article

Phenotypic Comparison of Three Populations of *Juniperus turbinata* Guss. in North-Eastern Morocco

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Abstract: *Juniperus turbinata* Guss. is a native species of Morocco; however, an exhaustive taxonomic description based on phenotypical characterization of north-eastern Moroccan population species is lacking, which might lead to taxonomic confusion. In order to expound the phenotypic description of *J. turbinata* of the north-eastern Moroccan population and to examine the taxonomic differences within it; a comparative analysis of cones, leaves, and seeds was performed between three populations. A total of 280 samples were compared on the basis of nine measured and eight calculated traits. The results reveal significant interpopulation changes in the studied characteristics of cones, leaves, and seeds. The most discriminating traits were associated with the proportion between cone diameter and number of seeds. We detected the lowest number of seeds in coastal population when compared to other localities, but at the same time, the seeds from the littoral were the longest and the widest. In addition, the semi-continental population had the highest quantity of seeds, and leaves had intermediate values for the majority of the assessed traits. The phenotypical difference between populations demonstrates a certain adaptability of the species in a biogeographical pattern. This study is a contribution to completing the description of patterns of phenotypical differences of the Phoenician juniper in the Mediterranean region, and confirms its evolutionary plasticity linked to adaptation to local environmental conditions.

Keywords: *Juniperus turbinata*; phenotypic characters; population; diversity; Mediterranean vegetation; Morocco

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1. Introduction

The complex *Juniperus phoenicea* is widely distributed in the Mediterranean area. It exhibits a significant degree of phenotypic variability in relation to its biogeographical distribution pattern [1]. The western region of the Mediterranean circum and Macaronesian region are assumed to include the highest rate of phenotypical variation of the complex. Three species were identified based on morphological, biochemical, and genetic analyses: *Juniperus phoenicea* L. sensu stricto (s.s.), *J. turbinata* Guss., and *J. canariensis* Guyot & Mathou [2].

Juniperus turbinata is a native species in Morocco, with few specific ecological demands; it may occur at low precipitation levels of 200–400 mm/year and can reach an elevation of 2000 m.a.s.l. [3]. *J. turbinata* has a scattered wide range of biogeographical distribution, extending from coastal lands to the peaks of the Moroccan Atlas Mountains [4]. The species thrives in extreme ecological conditions under semi-arid and arid ombotypes, and occupies a significant position in Moroccan vegetation. It is a pioneering species with a preponderant role in the dynamics of woodlands ecosystem [5]. The ecosystems where the

species begins to appear are in the thermo-Mediterranean to the mountain Mediterranean bioclimatic belts, and it reaches its optimum conditions in the meso-Mediterranean and supra-Mediterranean belts [5–7]. Moreover, when rainfall is insufficient, *J. turbinata* may substitute either *Tetraclinis articulate* (Vahl) Mast. or *Quercus ilex* L. in continental locations.

Juniperus turbinata is a large shrub or a small tree; its taxonomic traits are distinguished by reddish shoots, scaly leaves, and turbinate cones when immature, but globose ones when mature. Its pollen sheds between October and November [8]. In terms of nomenclature, *Juniperus turbinata* is referenced as a subspecies of *J. phoenicea* in *Basic Flora of Morocco* by Fennane et al. [9] and Valdés et al. [10]. However, to the best of our knowledge, there are no explicit phenotypic descriptions of its cones, leaves, or seeds. Its biogeography in the Moroccan Atlas Mountains was described by Benabid [11], and recent works on the Moroccan taxon based on essential oil and morphological and genetical analysis on these populations confirmed the taxonomic rank of the species [12–14]. The description of the species started earlier in the Iberian Peninsula [15], whereas there is a great interest in data on its traits and intrapopulation variability along the biogeographic pattern.

Moroccan populations of *J. turbinata* were most likely reported in several studies under different names due to the difficulty of distinction of discriminatory traits in the genus *Juniperus* L. [16]. However, much confusion was eliminated with recent molecular studies [10,13,14,16–18] showing that the Moroccan population of red juniper has strong affinities with *J. turbinata*. The following cited names—(1) var. *megalocarpa* Maire [19] in the Essaouira dunes (south Atlantic coast in Morocco); (2) var. *mollis* Maire & Weiller in the high Atlas Mountains or *J. phoenicea* subsp. *mediterranea* Lebreton & Thivend [20,21]; (3) *J. phoenicea* subsp. *lycia* L. [11] for the population of Phoenician juniper in the Mahdia littoral Atlantic; and (4) chemovar *montana* Lebreton & Pérez de Paz [22]—were considered to be ambiguous names of *J. turbinata*.

Juniperus turbinata, is an arid-adapted plant due to its limited lumen area, bimodal radial growth pattern, and extended roots, which allow it to quickly utilize shallow water [23]. These characteristics provide the junipers more adaptation to drought stress than taller trees with broader tracheids, such as pines. Consequently, *J. turbinata* can be used for ecological restoration in low-potential-productivity environments such as semi-arid and arid regions [24]. Its pink-colored wood is hard and resinous with an aromatic fragrance, and is valued for small manufactured objects and decorative works, as are other juniper species [25]. Its wood is primarily used as a fuel and for the production of charcoal [26]. In addition, juniper essential oils have been used in cosmetics for centuries, and there is now interest in their pharmaceutical properties [27]. Some cultivars have been chosen for horticultural uses and have been planted in some rocky gardens [28].

Juniperus turbinata is a major species in woodland and forest vegetation in Morocco's north-eastern area; nevertheless, to the best of our knowledge, there is a lack of taxonomic descriptions regarding its population, which might lead to taxonomic confusion. The goal of this study is to (i) characterize the phenotype of *J. turbinata* in north-eastern Morocco using thorough measurements of cones, leaves, seeds, and shoots, and (ii) determine phenotypic variations across populations based on biogeographic patterns.

2. Materials and Methods

2.1. Plant Material

The plant material was sampled in the north-eastern region of Morocco, from the coastal location at Saidia, Site 1; the semi-coastal location at Jerrada, Site 2; and the continental location at Figuig, Site 3 (Figure 1). Plant material was collected throughout the months of February and March of 2021. The precise locations of the studied plants are indicated in (Table S1). From each shrub/tree in each population, 10 samples of ripened cones and 10 samples of small sections of one-year-old branches with adult leaves were collected separately. For the current study, 280 cones and 280 shoots from 28 individual in each of the three populations were collected from the southern, typically sunny sections of the shrubs/tree crown at a height of (1–2.5 m). The measurements of characters were

assessed on dry material under a stereomicroscope with a scaled ocular in 2021 [13]. The cones, shoots, and seeds were measured with to a precision of 0.1 mm. The cone scales were counted after soaking the cones in water for 24 h. The seeds were removed from the soaked cones and air dried before measuring. The thickness of terminal lateral shoot with leaves was measured along the side rather than diagonally, as described by Marcysiak et al. [29]. The three populations were compared on the basis of four characters of cones, two characters of leaves and shoots, three characters of seeds, and eight ratios. In total, nine measured and eight calculated characters were used in the study (all characters are listed on results part, Section 3.1).

Figure 1. The area of study in north-eastern Morocco, showing the three sites of sampling.

2.2. Climate Assessment

The three chosen sites have distinct ecological characteristics (Table 1, Figure 1). The climatic data of each site were obtained from <https://climate.northwestknowledge.net> (accessed on 15 July 2021), during a period of 10 years (2010–2020). In order to analyze bioclimates and ombotypes, the Emberger quotient Q_2 as modified by Stewart [23] was utilized. Q_2 is specific to the Mediterranean region [30]. The index of continentality I_c of the sampling sites was calculated to evaluate the continentality, as the annual average of thermal amplitude according to Rivas-Martinez [31]. The continentality index is defined as the difference between the average temperatures of the hottest month T_{max} (M) and those of the coldest month T_{min} (m). The index increases with distance from the sea [32,33]. It is an abiotic indicator for the ecological behavior of woody vegetation, including the red juniper.

2.3. Data Analysis

The statistical analyses were performed by SPSS software version 20 in order to discriminate between the three populations in terms of every character. The Shapiro–Wilk test was used to verify the samples' normal distribution. The equality of variances was assessed using Levene's test. The mean, the variation coefficients (CV), the standard deviation (SD), the maximum value (Max), and the minimum value (Min) were calculated for each population and each trait. The differences were considered significant at $p \leq 0.05$. The differentiation between populations in term of the influence of traits was verified using Tukey's T-test, and the differences were considered significant at $p \leq 0.05$. The correlations between studied traits were examined with Pearson's correlation coefficient in order to assess the redundant ones. The unification of data was an important step to avoid any possible influences from the traits used in the study.

Table 1. Latitude, longitude and ecological characteristics of the coastline, semi-continental and continental sites in the north-eastern region of Morocco. Q_2 , Emberger Pluviothermal quotient; I_c , Rivas-Martinez thermal continentality index in degrees Celsius; P , rainfall in mm/year; m , mean of the coldest month minima in degrees Celsius; M , mean of the warmest month maxima in degrees Celsius.

							Aridity		Continentality		
Site	Altitude (m.a.s.l)	Latitude	Longitude	M (°C)	m (°C)	P (mm)	Q ₂	Bioclimates	Ic	Type	Subtypes
Site 1 Coastline	4	35°11′	2°28′	31.83	7.03	315.04	44.4	Semi-arid hot winter	24.80	Continental	Subcontinental
Site 2 Semi-continental	951	34°41′	1°88′	33.20	0.14	359.16	37.9	Semi-arid cool winter	33.06	Continental	Eucontinental attenuate
Site 3 Continental	1500	32°22′	1°66′	41.31	2.02	12.15	12.6	Saharan cool winter	39.29	Continental	Eucontineantal accentuated

Canonical discriminant analysis was performed on the average of each individual, including a total of $n = 84$ shrubs from the three populations, to identify the discriminant power for each character and to detect differences amongst the three populations; for each trait, we considered the lowest Wilks' lambda values as reflecting the higher contribution of that trait to the discriminant function. The relationship between the tested populations was highlighted in the two main discriminant functions of canonical discriminant analysis.

3. Results

3.1. Assessment of Characters

Amongst 17 examined traits, 15 had normal frequency distribution. The length of seeds in continental region and the width of seeds in semi-continental region both showed an almost normal distribution frequency, allowing the use of parametric tests. The recta cones number and the scales cones number were not normally distributed in the three populations; they were used after arcsine transformation.

For each population and for all populations combined, ranges, means, standard deviations, and variation coefficients are presented in the Tables 2 and 3. Significant variations in the means of the examined populations were identified in the cone diameter/number-of-seeds ratio, with a variation coefficient of about 44% for the three populations and approximately 19 to 35% in a specific population. The length/diameter ratio of cones was the most constant trait, with a variation coefficient of approximately 11% in all studied populations and 9 to 13% in one population.

Table 2. Results of ANOVA on the analyzed characters of cones, seeds, and shoots.

Characters	Total	Coastline	Semi-Continental	Continental	Signification
	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	
(1) Recta number of cones (4 or 6)	4 $\pm$ 0.021	4.02 $\pm$ 0.80 ^a	4.05 $\pm$ 0.50 ^b	4.02 $\pm$ 0.24 ^b	***
(2) Length of cone (mm)	7.82 $\pm$ 0.040	8.78 $\pm$ 0.91 ^b	7.94 $\pm$ 0.86 ^b	6.73 $\pm$ 0.58 ^a	***
(3) Diameter of cone (mm) "average of 2 independent measures of angle of 90°"	7.05 $\pm$ 0.036	8.02 $\pm$ 0.77 ^c	7.08 $\pm$ 0.6 ^b	6.02 $\pm$ 0.56 ^a	***
(4) Number of scales of cone	6.76 $\pm$ 0.038	6.77 $\pm$ 1.31 ^b	7.22 $\pm$ 1.04 ^c	6.27 $\pm$ 0.73 ^a	***
(5) Number of leaves per 5mm section of ultimate lateral branchlet	22.45 $\pm$ 0.106	19.85 $\pm$ 1.81 ^a	24.72 $\pm$ 2.32 ^c	22.78 $\pm$ 2.85 ^b	***
(6) Thickness of the ultimate lateral branchlet and leaves (mm)	1.12 $\pm$ 0.004	1.19 $\pm$ 0.14 ^c	1.09 $\pm$ 0.11 ^b	1.06 $\pm$ 0.11 ^a	***
(7) Number of seeds	4.84 $\pm$ 0.048	3.86 $\pm$ 1.33 ^a	5.94 $\pm$ 1.06 ^c	4.71 $\pm$ 0.92 ^b	***
(8) Length of seeds (mm)	4.01 $\pm$ 0.025	4.76 $\pm$ 0.55 ^c	3.82 $\pm$ 0.49 ^b	3.42 $\pm$ 0.42 ^a	***
(9) Width of seeds(mm)	1.85 $\pm$ 0.014	2.05 $\pm$ 0.44	1.77 $\pm$ 0.29	1.73 $\pm$ 0.41	ns
(10) Length/diameter (of cone)	1.12 $\pm$ 0.004	1.09 $\pm$ 0.11	1.12 $\pm$ 0.1	1.12 $\pm$ 0.14	ns
(11) Length/width (of seed)	2.21 $\pm$ 0.013	2.39 $\pm$ 0.43 ^c	2.19 $\pm$ 0.36 ^b	2.03 $\pm$ 0.33 ^a	***
(12) Cone diameter/number-of-seeds	1.63 $\pm$ 0.024	2.33 $\pm$ 0.82 ^b	1.22 $\pm$ 0.25 ^a	1.32 $\pm$ 0.27 ^a	***
(13) Cone diameter/width-of-seeds	3.92 $\pm$ 0.026	4.05 $\pm$ 0.8 ^b	4.08 $\pm$ 0.74 ^b	3.61 $\pm$ 0.71 ^a	***
(14) Thickness-of-branchlet/number-of-leaves	0.05 $\pm$ 0.0003	0.60 $\pm$ 0.009 ^c	0.04 $\pm$ 0.006 ^a	0.05 $\pm$ 0.009 ^b	***
(15) Cone diameter/recta-number-of-cone	1.89 $\pm$ 0.021	2.39 $\pm$ 0.8 ^c	1.77 $\pm$ 0.32 ^b	1.50 $\pm$ 0.15 ^a	***
(16) Cone length/number-of-leaves	0.36 $\pm$ 0.0028	0.44 $\pm$ 0.05 ^c	0.32 $\pm$ 0.04 ^b	0.30 $\pm$ 0.5 ^a	***
(17) Cone number-of-scales/cone length	0.88 $\pm$ 0.0057	0.78 $\pm$ 0.16 ^a	0.91 $\pm$ 0.16 ^b	0.93 $\pm$ 0.13 ^b	***

SD: standard deviation; *** statistical significance level $p < 0.00$; ^{a,b,c} values with different letters are significantly ($p < 0.05$) different within rows; ns = not significant.

Table 3. Results of descriptive statistics on the analyzed characters of cones, seeds, and shoots. Coastline: Coas; semi-continental: Smc; continental: Con.

Characters	Total			Coas			Smc			Con			<i>p</i> Value of Tukey <i>t</i> -Test		
	Min	Max	CV (%)	Min	Max	CV (%)	Min	Max	CV (%)	Min	Max	CV (%)	Coas/Smc	Coas/Con	Smc/Con
Recta number of cones (4 or 6)	4	6	15.82	4	6	22.99	4	6	12.35	4	6	5.97	0.000	0.000	0.79
Length of cone (mm)	5	15	14.83	5.70	11.50	10.36	5	15	10.83	5.50	9.5	8.62	0.000	0.000	0.000
Diameter of cone (mm) “average of 2 independent measures of angle of 90°”	2.2	10	14.96	6	10	9.60	5.6	8.80	9.04	2.2	7.8	9.30	0.000	0.000	0.000
Number of scales of cone	4	13	16.67	4	13	19.35	4	9	14.40	5	9	1.64	0.000	0.000	0.000
Number of leaves per 5 mm section of ultimate lateral branchlet	10	29	13.80	15	24	9.12	19	29	9.39	10	28	12.52	0.000	0.000	0.000
Thickness of the ultimate lateral branchlet and leaves (mm)	0.13	1.66	12.06	0.85	1.66	11.76	0.13	1.43	10.09	0.74	1.41	10.38	0.000	0.000	0.015
Number of seeds	2	9	29.09	2	9	34.46	3	9	17.85	2	7	19.53	0.000	0.000	0.000
Length of seeds (mm)	2.18	6	18.70	2.4	6	11.55	2.47	5.52	12.83	2.18	5.12	12.28	0.000	0.000	0.000
Width of seeds(mm)	0.88	6.3	22.29	1.13	5.16	21.46	0.88	2.58	16.38	0.88	6.30	23.70	0.000	0.000	0.39
Length/diameter (of cone)	0.77	3.18	10.68	0.78	1.57	9.17	0.77	1.76	8.93	0.92	3.18	12.50	0.025	0.027	1
Length/width (of seed)	0.56	4	17.92	0.91	3.83	17.15	1.42	4	15.53	0.56	3.09	16.26	0.000	0.000	0.000
Cone diameter/number-of-seeds	0.37	4.5	44.19	0.94	4.50	35.19	0.76	2.33	19.67	0.37	2.90	20.45	0.000	0.000	0.071
Cone diameter/width-of-seeds	0.83	7.02	19.76	1.55	6.67	19.75	2.6	7.02	17.40	0.83	5.71	19.67	0.97	0.000	0.000
Thickness-of-branchlet/number-of-leaves	0.01	0.09	21.29	0.04	0.09	15.00	0.01	0.06	15.00	0.03	0.09	22.50	0.000	0.000	0.000
Cone diameter/recta-number-of-cone	0.55	4.5	33.38	1.33	4.50	33.47	1.08	4	18.08	0.55	2.37	10.00	0.000	0.000	0.000
Cone length/number-of-leaves	0.19	0.68	23.27	0.32	0.63	11.36	0.19	0.68	12.50	0.21	0.65	16.67	0.000	0.000	0.000
Cone number-of-scales/cone length	0.44	1.6	19.09	0.44	1.57	20.51	0.53	1.6	16.48	0.67	1.53	13.98	0.000	0.000	0.26

The measured characters correlated with each other at a statistically very significant level of $p < 0.01$. The number of correlations was different; hence, some features in one population were strongly correlated, whereas in others, the correlation was insignificant or negligible. The strongest positive correlations were found between length and cone diameter, with a Pearson's r value of 0.81 ($p < 0.01$); and length of cone and length of seed, with a Pearson's r value of 0.74 ($p < 0.01$). Length of cone showed a low, but significant correlation with width of seed, with a Pearson's r value of 0.52 ($p < 0.01$), while the correlation of diameter of cone with width of seed has a Pearson's r value of 0.38 ($p < 0.01$), and correlation of number of seeds with number of cone scales has an r value of 0.20 ($p < 0.01$) (results of correlation are shown in the supplementary file as Tables S1 and S2).

3.2. Differences between Populations

3.2.1. Descriptive Statistics and ANOVA

The mean values of *J. turbinata* characters differed between the three populations at a statistically significant level ($p < 0.05$) (Table 2). The continental population had the smallest trait sizes (10 of the 17 tested characters had the lowest values). Hence, the continental population had the smallest cone diameter (6.02 mm) compared to the coastline population (8.31 mm), while the mean number of scales in the continental cones was 6.27, compared to the semi-continental cones with 7.22. The semi-continental population showed the greatest number of leaves and seeds (24.72 and 5.94, respectively); however, in the coastline population, the number was the lowest, with 19.85 and 3.86, respectively. The coastal population had the longest seeds (4.76 mm) and the highest seed length/width ratio (2.39), compared to the continental population with a seed length of 3.42 mm and a seed length/width ratio of 2.03 (Table 2). The most different ratios were related to the cone dimensions: the cone diameter/recta number, with a value of 1.5 in continental population (in comparison to the coastline population, which had a level of 2.39), and the value of cone length/number-of-leaves, with 0.30 in the continental population and 0.44 in the coastline region. The shape of cones (length/diameter-of-cone) and the shape of seeds (length/width-of-seed) were rather similar among the three populations, and the mean value of the cone diameter/width-of-seeds ratio did not differ significantly (Table 2). The three populations could be distinguished from each other at a statistically significant level ($p < 0.05$). In Tukey's test (Table 3) semi-continental and continental populations were closer, sharing 12 characters amongst the 17 studied (Table 3).

3.2.2. Discriminant Canonical Analysis

We used Wilk's lambda to assess if the canonical discriminant functions participate significantly to discriminate traits. Of the traits, 14 of 17 were used after removing the most redundant ones. Results show that every trait discriminated at a statistically significant level except the length/diameter-of-cone ratio, with $p = 0.028$. The overall results of the discriminant analysis based on Wilks' lambda give: the cone diameter/number-of-seeds ratio—Wilks' $\lambda = 0.06$; $p < 0.001$; the number of seeds—Wilks' $\lambda = 0.12$; $p < 0.001$; the thickness-of-shoot/number-of-leaves ratio—Wilks' $\lambda = 0.19$; $p < 0.001$; and the number of leaves per 5 mm section—Wilks' $\lambda = 0.2$; $p < 0.001$ (Table 4). The efficiency parameters of the canonical discriminant analysis are (i) Function 1 through Function 2 (Wilks' Lambda = 0.000; Chi-Square = 428.6; df = 34; $p = 0.001$); and (ii) Function 2 (Wilks' Lambda = 0.116; Chi-Square = 157.2; df = 16; $p = 0.000$). The populations of *J. turbinata* formed three groups in the space of Function 1 and Function 2 of the discriminant canonical analysis; the semi-continental and coastline populations were separated from the continental population mostly by the first discriminant function, which explained 84% of the total variation. The coastline population was separated from the semi-continental and continental populations by the second discriminant function, which explained 16% of total variation. (Figure 2). Function 1 was determined mostly by the following traits: cone diameter/number-of-seeds; length/width (of seed), cone length/number-of-leaves, number of scales of cone; and Function 2 was determined by: number of seeds, number

of scales of cone, thickness-of-shoot/number-of-leaves, and number of leaves per 5mm section of ultimate lateral branchlet (Figure 2).

Table 4. Results of the discriminant canonical analysis test for the characters after the removal of the most redundant.

Characters	Discrimination Power		
	Wilks' Lambda	F	p
Recta number of cones (4 or 6)	0.73	14.83	0.000
Number of scales of cone	0.76	16.57	0.000
Number of leaves per 5mm section of ultimate lateral shoot	0.2	160.8	0.000
Thickness of the ultimate lateral shoot and leaves (mm)	0.51	37.61	0.000
Number of seeds	0.12	283.26	0.000
Width of seeds(mm)	0.63	23.19	0.000
Length/diameter (of cone)	0.91	3.37	0.028
Length/width (of seed)	0.57	30.00	0.000
Cone diameter/number-of-seeds	0.06	547.6	0.000
Cone diameter/width-of-seeds	0.73	15.01	0.000
Thickness-of-shoot/number-of-leaves	0.19	172.6	0.000
Cone diameter/recta number of cone	0.37	67.74	0.000
Cone length/number-of leaves	0.09	371.43	0.000
Cone number-of-scales/cone length	0.55	32.09	0.000

F: Fisher–Snedecor approximation statistic.

Figure 2. Results of the canonical discriminant analysis including $n = 84$ individuals of the three populations.

4. Discussion

The three analyzed populations of *J. turbinata* from the north-eastern Morocco region exhibited significant phenotypical differences along a biogeographic pattern. The result supports the hypothesis of the presence of phenotypic variation among the Mediterranean population of *J. phoenicea* s.l. [34]. The phenotypic disparities also exist among *J. turbinata*

between European and North African populations as a result of considerable genetic divergence [16,34], and the biogeographic establishment of the populations.

4.1. Taxonomic Classification and Differences between the Three Populations

Based on the mean values of the most significant characters obtained in the current study, the taxonomic rank of the north-eastern Moroccan population is *J. turbinata*. We are in agreement with previous studies based on phenotypical characters [35] and on RAPD analysis [12] carried out on inland and coastline Moroccan red juniper populations [14,16]. The phenotypical characters of the Moroccan *J. turbinata* are not well documented in [9]. The length and diameter of cones, along with the number of seeds, are the most commonly used criteria for taxonomic classification [9]. Our study combines a set of phenotypical traits that are necessary for taxa recognition within the *J. phoenicea* complex [36]. However, this investigation confirms the efficacy of the most common used characters in pointing out *J. turbinata* interpopulation differences, and takes into consideration new characters for the Moroccan red juniper, which may allow a better taxonomic identification and prevent errors.

Taking into consideration the three populations combined, the average values of the specific traits of *J. turbinata* of the north-eastern Moroccan population reported in our study were: cone diameter 7.05 mm; cone length 7.82 mm; cones shape globose, confirmed by the length/diameter-of-cone ratio 1.12.; seed number 4.84; and length and width of seeds 4.01 mm and 1.85 mm, respectively. Seeds were of elongated shape; the length/width-of-seeds ratio was 2.21. Most of these values were lower than reported data in taxonomic descriptions [1,8] and in *Flora of Morocco* [9]. These descriptions of the size of seeds and cones and their proportions are particularly useful in recognizing *J. turbinata* within *J. phoenicea* complex. In the same context, interpopulation variation in mean values for cone length and width characters among Moroccan population of *P. halepensis* Mill. [37] and Greek populations of *P. halepensis* [38] have been reported as well. For the same species, Matziris [39] also reported variations for these two characters after studying populations from the Mediterranean region. Debazac and Tomassone [40] reported major differences in the 1000 seed weights for *P. halepensis*, with the highest value found in Tunisian pine. Conifer phenotypic differences in natural populations revealed by phenotypic traits are seen currently as a quantitative marker used for conifer conservation in Morocco [37].

The comparison of the mean values of the studied characters with those obtained in the Mediterranean populations of *J. turbinata* by Mazur et al. [13,35,41] shows a slight difference. This underlines the phenotypical differences of the species between the north and the south Mediterranean shores, joining the investigations of Meloni et al. [42] and Boratynski et al. [43], who detected significant differences between populations of *Juniperus phoenicea* s.l. within the Mediterranean circum. Likewise, we confirm the presence of interpopulation differences among *J. turbinata* that reflect the adaptation of *J. phoenicea* complex descendants to the local environment [44] since its split in the Oligocene from Europe (the origin of formation of *J. phoenicea*); however, the differences between the three populations of *J. turbinata* suggest three different ways of adaptation. Conifers may manifest a phenotypic diversity pattern reflecting a certain plasticity in different local environments [45]. Local adaptation along geographical distribution and altitudinal range was significant in Eliades et al. [45], who investigated the genetic diversity of Cypriot peripheral populations of *Pinus brutia* Ten. In a further study of longitudinal and altitudinal patterns of genetic diversity in woody taxa across the Mediterranean, Faddy et al. [46] linked the current shape of European woody taxa to last glacial maximum.

4.2. Influence of Abiotic Factors Related to Biogeographical Pattern

The difference between the three populations is shown at an individual level; none of the studied populations was found to join the other, reflecting a strong distinction related to the local biogeographical distribution pattern.

In the north-eastern Morocco region, *J. turbinata* extends from the coast in the fixed littoral belt dune to the continental arid mountains, but in localized fragmented ecological niches. Distinct distribution patterns in vegetation are mainly related to the climate footprint. *J. phoenicea* s.l. is a Mediterranean element strongly fingerprinted by its climate [4].

The number of seeds in coastal locations is the lowest when compared to both other localities, but at the same time, the seeds are the longest and widest. Additionally, the intermediate values of most tested characters were found in the semi-continental population, which had the greatest number of seeds and leaves. Semi-continental *J. turbinata* is positioned in a more open environment and receives more light, which might explain the larger number of leaves per 5 mm section of the final lateral ramification of the shoot. *Juniperus* is known as a light-demanding genus [8]. The positive reaction in the semi-continental population to more light was apparent in the high number of leaves. Moreover, following an increasing gradient of continentality, the coastline population is isolated under a wet littoral bioclimate that amplifies the dimensions of cones. The semi-continental population showed intermediate values of the dimension of cones, and the continental population showed the smallest dimensions. The differences in latitude among the three populations reflect serious limitations on the recruitment of *J. turbinata* due to moisture availability.

The index of continentality calculated according to Rivas-Matinez [32] classifies the three populations into three different subtypes. In general, similar climatic types allow similar biological processes, such as adaption, selection, and mutation, but under different climate conditions, these processes are suppressed, limiting gene flow among populations. Genetic flow may not exist between the three populations despite the presence of pollination factors, e.g., wind and bird dispersion of cones. The isolation of the continental population in mountains and the localization of the semi-continental population at 951m high could support our hypothesis. The index of continentality is a major influencing factor in the distribution of vegetation, and therefore, in the establishment of biogeographic borders of taxa. The recorded values of phenotypic characters of the population are related to bioclimate. Semi-continental and continental populations range from an attenuated semi-continental ombrotype to an accentuated continental one. The winter minimum temperature is a thermal stress; it seems to have an influence on the features of both inland populations. Climate has an effect on the size, shape, and structure of organs of conifers [47]; this has been confirmed by this study as well. In the littoral station where $m > 7^{\circ}\text{C}$, the population has longer cones, longer and wider seeds, less leaves, and greater thickness of the ultimate lateral shoot; while the continental population with $m < 3^{\circ}\text{C}$ has shorter cones, shorter seeds, and more leaves. Winter stress is a limiting factor for many plant communities. In addition, droughts also play a significant role, especially for phenotypic characters. Other research has revealed that increasing droughts as a result of climate change are a current threat to conifers, e.g., *Juniperus thurifera*, and affect mature and juvenile populations in different ways [24]. Camamero et al. [23] conducted a study on the effect of drought on phenotypic characters of *Pinus halepensis*, *Juniperus thurifera*, *J. phoenicea*, and *Ephedra* under semi-arid Mediterranean conditions and revealed that the species were naturally able to tolerate severe and long drought. However, excessively high temperatures decrease soil moisture and increase evaporative demand, which may cause modifications on morphological traits.

The continental population shows signs of drought resistant, however, it benefits from the light at high altitudes [48]. The Moroccan populations of *J. turbinata* can reach 2000 m.a.s.l. of altitude, where cool winters compensate for the water deficit. Plants can develop adaptive strategies to resist their natural habitat [49]. They may manifest adjustments at the level of leaves. The modifications may even affect the whole plant [50].

The semi-continental population has the greater number of seeds, which could enhance its pollination success, the eucontinental climate seems to provide better pollination conditions for *J. turbinata* north-eastern Moroccan populations. Female cones of *J. turbinata* with four and six seeds have been mentioned by the authors of [13,31,37], as well as other species of genus *Juniperus*. Klimko et al. [51] reported for *J. oxycedrus* L. that cones con-

taining six seeds developed only in the populations from the west Mediterranean region, including the Moroccan population of the species [51].

5. Conclusions

The study enriches the understanding of the diversity of the Juniper complex. It reveals significant interpopulation differences in the cones, leaves, and seeds of *J. turbinata* following a continental gradient related to local conditions. The three studied populations are related to their bioclimates. Biogeographical patterns relate strongly to thermal winter stress, which influences the variation of phenotypic characters of species of *J. turbinata* in north-eastern Morocco. The study also demonstrates the individualization of the characteristics of the semi-continental population of *J. turbinata*, which showed the greatest number of leaves and seeds, but medium size of cones, most likely as a consequence of cross-pollination by wind or birds' dispersion of cones. The morphological variation across populations illustrates the species' tolerance to environmental restrictions, prompting researchers to examine its use in combating desertification and soil erosion in the most arid areas.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/f13020287/s1>, Table S1: Geographical coordinates of sampled shrubs of *Juniperus turbinata*. The three sites are located in the North Eastern Morocco, Table S2: Correlation coefficient between measured and calculated traits of *Juniperus turbinata* from the three populations.

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