

Morphological Variation of *Euphorbia fulgens*

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Morphological variation is useful in conservation and genetic improvement programs. *Euphorbia fulgens*, a range-restricted local endemic species of Mexico, is used locally during the altars in the festivities of different saints and is also cultivated as an ornamental plant mainly in Europe. Thus, in the present study, morphological variation was evaluated in wild populations and cultivated populations. Characterization of 90 individuals from three wild populations (the only ones recorded to date) was done by measuring 30 morphological traits both vegetative and reproductive. Thereafter, seeds were collected, and established under greenhouse conditions, and 39 morphometric variables were evaluated in adult plants. An analysis of variance (ANOVA) was done for wild and cultivated groups independently, and when significant differences were found, Tukey's comparison of means was applied ($p < 0.05$). To identify the traits responsible for the differences between wild and cultivated groups, a linear discriminant analysis (LDA) was conducted. Morphological variation was found among wild populations, and this variation decreased in cultivated populations, mainly in reproductive structures. The LDA separated the wild populations from the cultivated groups, according to inflorescence length, petiole length/blade length ratio, and leaf roundness. The variables that determined the separation of individuals between wild and cultivated populations were cyme number, foliar Feret diameter, and inflorescence length, variables that can be important for breeding strategies and artificial selection.

cut flower

Euphorbia

inflorescence

Mexican endemic

morphometry

ornamental

1. Introduction

Morphological variation refers to the morphometric differences observed as a result of genetic aspects and environmental factors [1][2]. Such variation has been studied in different species that have been subjected to diverse handling methods in situ and ex situ, such as agriculture, harvest, tolerance, induction, and protection [3][4][5][6].

Several authors have proposed that the domestication process of a genetic resource generates phenotypic variation, due to selection of traits that are desirable for humans, and therefore, morphological differences are evaluated between cultivated, semicultivated, and wild-growing plants [7][8][9][10].

Most of the studies in this topic, have been performed in edible plants, while a few have focused on plants used for other purposes. To date, studies in which morphological variation has been evaluated between cultivated ornamental plants and their wild relatives are scarce worldwide [11][12]. Most research has focused on characterizing different genotypes of cultivated plants or with some level of handling [13][14][15][16].

On the other hand, some researchers have studied how diverse environmental factors, such as altitude, precipitation, physicochemical characteristics of soil, light intensity, hillside orientation, among others, contribute to phenotypic variation in different species as a result of the adaptation process in distinct habitats [17][18][19][20]. Most studies have assessed wild species of broad distribution, although some have been done on microendemic species as well because due to their restricted distribution, the morphometric variation associated with edaphoclimatic characteristics can be inferred under different environmental scenarios [21][22][23][24].

Euphorbia fulgens Karw. ex Klotzsch is a native species of Mexico, with restricted distribution and local endemic of Sierra Sur in Oaxaca state. To date, only three wild populations have been reported, located in ravines with steep slopes and of difficult access, in acidic ($\text{pH} \approx 5$) loam soils. In the towns close to the places where the wild populations are found the inhabitants use the flower stems as ornaments in the altars during different saints festivities. In other countries, the common name “scarlet plume” is used to refer to several cultivated varieties of *E. fulgens*, which are produced and commercialized mainly as a cut flower and pot plant in Europe [25][26], whereas in Mexico it is not commercialized.

Due to its ornamental relevance in other countries, *E. fulgens* is a phylogenetic resource that can be exploited sustainably in Mexico, since it has esthetic values (mainly the inflorescences) and it adapts easily to cultivation conditions.

On one hand, variation assessment of wild-growing populations of *E. fulgens* is convenient, due to its local endemism, which could be the start of establishing successful conservation programs. On the other hand, the *E. fulgens* varieties are commercialized are produced abroad. Therefore, the evaluation of variation in populations of *E. fulgens* under controlled conditions could lead to the establishment of genetic improvement programs to produce tolerant varieties for the climatic conditions of Mexico, which would reduce costs, and consequently, would allow local ornamental flower producers to commercialize the plant [27]. Hence, the objective of this study was to quantify the morphological variation of *E. fulgens* in wild and cultivated populations, under the assumption that, due to their restricted distribution, the morphometric variation of wild plants will be lower in plants under cultivation conditions compared to wild-growing ones.

2. Discussions on Morphological Variation of *Euphorbia fulgens*

2.1. Morphological Variation in Wild Populations

Differences between wild-growing populations were observed in most vegetative and reproductive structures, even though *E. fulgens* has a restricted distribution with only three populations reported so far. Populations 1 and 2 were the most contrasting in leaf shape and size, as well as in inflorescence size and colour. Among the three populations, populations 1 and 2 were the most distant (80 km apart) and belonged to similar vegetation types but in different altitudes and on areas with different edaphoclimatic characteristics (Table 1). Moreover, populations 2 and 3 contrasted mostly in reproductive structures, but shared edaphoclimatic characteristics and were located at a

similar altitude. However, the three populations did not show outstanding differences. This suggests that phenotypic variation is probably determined by edaphoclimatic factors.

Table 1. Morphometric variables of three wild populations of *Euphorbia fulgens* from Oaxaca, Mexico.

Variable	p-Value	Population 1	Population 2	Population 3
Plant height	0.0696	145.53 ^a	158.63 ^a	180.63 ^a
Basal diameter	0.0240	0.78 ^{ab}	0.64 ^b	1.02 ^a
Petiole length	0.0007	3.46 ^a	2.94 ^b	2.95 ^b
Blade length	0.0001	7.99 ^c	9.03 ^b	9.73 ^a
Blade width	0.0204	2.75 ^a	2.36 ^b	2.45 ^{ab}
Blade width/Blade length	0.0001	0.35 ^a	0.26 ^b	0.25 ^b
Petiole length/Blade length	0.0001	0.43 ^a	0.33 ^b	0.30 ^b
Leaf area	0.8267	14.43 ^a	13.77 ^a	14.08 ^a
Leaf perimeter	0.4161	27.88 ^a	27.46 ^a	28.73 ^a
Leaf Feret diameter	0.0504	11.12 ^b	11.58 ^{ab}	12.01 ^a
Leaf roundness	<0.0001	0.34 ^a	0.26 ^b	0.25 ^b
Number of branches with inflorescences	0.0037	4.20 ^a	1.80 ^b	4.07 ^a
Inflorescence length	0.0080	12.07 ^b	22.92 ^a	18.72 ^{ab}
Number of cyathia per axillary cyme	0.1527	3.03 ^a	3.37 ^a	3.07 ^a
Longest cyme length	0.0068	2.72 ^{ab}	2.87 ^a	2.41 ^b
Number of axillary cymes	0.9085	14.27 ^a	13.40 ^a	13.73 ^a
Number of hermaphrodite cyathia	0.0001	1.53 ^b	9.30 ^a	0.73 ^b
Number of male cyathia	0.0011	14.33 ^a	7.13 ^b	8.17 ^b
Number of female cyathia	0.5249	1.03 ^a	0.60 ^a	0.67 ^a
Peduncle length	0.0001	1.53 ^a	1.05 ^b	1.51 ^a
Involucre length	0.0007	0.31 ^b	0.30 ^b	0.33 ^a

Variable	p-Value	Population 1	Population 2	Population 3
Petal appendage length	0.6668	0.54 ^a	0.54 ^a	0.53 ^a
Petal appendage width	0.0044	0.50 ^a	0.50 ^a	0.44 ^b
Pedicel length	0.0033	0.98 ^a	0.85 ^b	1.02 ^a
Ovary length	0.0136	0.32 ^a	0.29 ^b	0.31 ^{ab}
Style length	0.0117	0.15 ^a	0.12 ^{ab}	0.11 ^b
Stamen length	<0.0001	0.46 ^c	0.67 ^a	0.53 ^b
Petal appendages colour	<0.0001	1.57 ^b	3.20 ^a [22]	1.30 ^b
Leaf blade colour in the superior third of inflorescence	0.3721	1.00 ^a	1.00 ^a	1.03 ^a
Intensity of leaf blade colour in the superior third of inflorescence [18]	0.3721	1.00 ^a	1.00 ^a	1.13 ^a

Other factors that were not analyzed in this study but have been observed to have an impact on morphometric variation in vegetative and reproductive structures were ground slope, soil depth, stone soil, temperature, wind speed, rain, and relative humidity [29][30]. In contrast, in other studies conducted in members of the genus *Opuntia*, it was determined that phenotypic differences in cladodes between populations were more related to population density than environmental factors [31]. Therefore, in future studies, it is suggested to increase the number of variables to determine their effects and, consequently, obtain more information for the design of propagation or agronomic management experiments.

The information gathered in this study about the morphological variation between wild-growing populations of *E. fulgens* will contribute to the establishment of in situ conservation programs of a germplasm that is not found in any other part of the world. Endemic species are susceptible to climate change because their restricted distribution is associated with specific environmental conditions. Hence, more studies should be conducted to decipher the adaptations of the local endemic plants in different predicted environmental scenarios in order to establish concrete management plans, as in other endemic species [23][24].

2.2. Morphological Variation in Cultivated Populations

The cultivated populations of *E. fulgens* in greenhouse showed a morphometric variation in vegetative structures, similar to the wild-growing groups, which suggests that these characteristics are highly stable in this species. In most studies of ornamental plants, phenotypic differences in structures with aesthetic or commercial value are evaluated; for instance, stem length, firmness, and flower number, size, colour, and odor in Peruvian lily [15]; branch number and length, flowering duration, height, disc and ligulate flowers, and central head diameter in sunflower [14]; and growth habit, ramification, foliar blade, and fruit shape, size, and colour in ornamental gourds to obtain ideal genotypes for cut flower, bouquets, arrangements, or pots [16]. Cultivation of *E. fulgens* in greenhouse demonstrated that it adapts and develops well under controlled conditions. Thus, a genetic improvement program

could be initiated focused on using this plant in a sustainable way since it has only been exploited in other countries. In this first cultivation cycle, individuals with desirable traits were identified; for instance, some with longer panicles, greater cyathium diameters, higher number of cymes, and attractive size and colour of petal appendages that could be used as progenitors of interesting features in breeding strategies. Thus, it is suggested to evaluate the effect of agronomic management variables for the probable cultivation of *E. fulgens* in the greenhouse.

2.3. Morphological Variation between Wild-Growing and Cultivated Populations

The differences between individuals of wild-growing and cultivated populations of *E. fulgens* were determined by number of cymes, petal appendage width, inflorescence length, petiole length, leaf perimeter, and leaf Feret diameter. Cultivated plants presented larger inflorescences and higher number of cymes, which could be the result of applying fertilizer. In contrast, the variables that determined the differences between wild-growing and cultivated individuals of Peruvian lily were flower colour and stem length [11].

In this study, we observed that, from a first cultivation cycle without an artificial selection process, there were morphological differences between wild-growing and cultivated plants of *E. fulgens*. Several authors consider that the morphometric differences and group separation of wild-growing and cultivated individuals is due to the domestication process, which was the case in *Chrysophyllum cainito* L. (star apple), where the differences in fruit and seed characteristics were caused mainly by the artificial selection process of fruits [32]. This was also observed in *Crescentia cujete* L., where due to its use as bowls, a strong selection of larger fruits, rounder forms, and shorter and wider peduncles has been done [9][33]. Differences have also been found between wild-growing and cultivated poinsettia in leaf size, internode distance, stem length and diameter; however, the leaf area/stem volume ratio has remained constant, despite the domestication process [12]. Evaluation of variation in wild-growing populations of a species that is intended to be introduced in cultivation in Mexico, will allow to perform a follow-up of how morphology is modified with handling and selecting desirable traits.

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