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Effects of altitudinal gradients and microhabitats on the performance of *Ficus cordata* subsp. *salicifolia*, a relict fruit tree in Egypt.

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Abstract
Altitudinal gradients used as model templates for studies that analyze the adaptive features of the terrestrial plants under the influences of climate change. Ficus cordata subsp. salicifolia, is considered one of the most relict species distributed at the middle altitude of Gebel Elba. Its importance as a key stone species at tropical regions is frequently recorded. While in the subtropical regions it is less common. The main purpose of this work is to study the performance of this species at the marginal parts of subtropical region at Gebel Elba on the farthermost of the southern border of Egypt. Four functional traits have been selected to demonstrate its performance against environmental gradients and microhabitats. These traits are: plant height, diameter, leaf Area and crown cover. We found that wadi bed and Smooth faced rock microhabitats are more effective on species performance more than fissure rock. On the other hand, There are a direct correlation between both of Plant height, diameter, and leaf area and higher elevation (R^2 = 87.7, 77, and 70.8 %) respectively. Whereas, elevation has no effects on the crown cover area (R^2 =46%). Soil samples from different microhabitats have been analyzed to determine physical and chemical properties. Substrate supporting the growth of Ficus species on Gebel Elba is usually sandy soil with low content of organic matter. Electrical conductivity (EC) decreases with elevation and the highest value is recorded in wadi bed.

Keywords*: Ficus species, Relict species, Altitudinal gradients, microhabitats, Gebel Elba, Functional traits.*

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I. Introduction

The vegetation of Gebel Elba is very close to and sharing floristic elements similar to mountainous vegetation of East Africa and southern western Arabia [1]. It is considered as the northern extension of Eritero-Arabian highlands [2]. However, Zohary indicated three vegetation layers in Gebel Elba region according to altitudinal variation, namely: The lower layer (Pesudo savanna) characterized by domination of *Acacia-Ziziphus* wood land, the middle layer (savanna) represented by *Acacia-Commiphora*, and the upper layer (montane layer) consisted of *Olea –Ficus* layer. Also, [3] recognized three vegetation type in the northern slopes of Gebel Elba, *Euphorbia cuneata* community type at the lower elevation, *Euphorbia nubica* type at the middle, and mist oasis at the third elevated zone which consisted of a mosaic vegetation with many trees such as: *Rhus abyssinica*, *Jasminum grandiflorum*, and *Olea europaea* subsp. *cuspidata*. On the other hand, [4] classified vegetation of Elba into the lower woodland of the *Acacia* and the higher mixed forest. Recently, [5] identified seven plant communities and described three vegetation layers along elevational gradients of Gebel Elba, the lower layer of deciduous *Acacia* woodland and the higher with an evergreen *Olea* woodland and in-between a transient ecotone layer of the fruit tree *Ficus cordata* subsp. *salicifolia.*

In Egypt, wild fruit trees are distributed at the higher elevations of Sinai Peninsula, Eastern Desert (mainly gebel Elba) and Western Desert (especially gebel Uweinat), [6]. Most fruit trees are growing wildness at Gebel Elba protectorate. Of these species; Olives (*Olea europaea* subsp. *cuspidata*), Pistachio (*Pistacia khinjuk* var. *glabra*), grape (*Cayratia ibuensis*), Nabq (*Ziziphus spina-christi*), and Figs (*Ficus cordata* subsp. *slalicifolia* & *F. palmata*), in addition to a lot of edible wild uncommon fruits such as: *Grewia villosa*, *Cordia sinensis*, *Boscia senegalensis*, *Nitraria retusa*, *Balanites aegyptiaca*, and *Salvadora persica*. Many of fruit species found in Gebel Elba are relict species.

Relict species means: A rare species through the natural processes they are reduced to few populations in few locations and or considered as a threatened or endangered [7]. In brief, relict plants mean a remaining population of previously abundant species. It is appeared as an isolated species survive at enclaves of benign environmental condition within inhospitable regional climate [8]. The recorded wild fruits in Gebel Elba have neither a new sprouts nor seedling and all trees are matured. Although, *Ficus* trees has been recognized as a transition community between the two main vegetation layers: the lower deciduous woodland (*Acacia*) and the higher evergreen forest (*Olea*). However, wild *Ficus* trees are important as a wild crop relatives of cultivated figs, no documentation were prepared for their performance with both of microhabitats and with environmental gradients. Little accounts have been performed on the Ecology of relic plant species. Apart from that, [9] studied the ecological status of the only relict coniferous species, *Juniperus phoenica*, in the three northern Sinai high altitudes, Gebel Halal, Gebel El Maghra and Gebel Yellag. They indicated High density of *Juniperus phoenica* inside Gebel Halal rather than Gebel El-Maghara and Yellag. [10] surveyed the relic species on the Bulgarian flora, He found 346 relict species, and most of them are perennial herbs, Shrubs, and Trees. Also, [11] reviewed the botanical database of Mangolia in different habitats, they found 70 relict vascular plants distributed at a very narrow habitats. In this contest, we aimed to describe effects of the altitudinal variation and microhabitats on the growth performance of *Ficus cordata* subsp. *slalicifolia* in Gebel Elba region.

Description: *Ficus cordata* subsp. *slalicifolia* is an evergreen tree up to 6 m, it much taller at the tropical region it reached to 10 m. Leaves 2-20 X 1-4 cm alternate, glabrous, Figs 1-3 in leaf axils, globose 6-9 mm diameter. Fruits are figs with fleshy receptacle bearing the flowers [12]. Range of distribution, globally it extended in tropical and warm regions. It native to Eastern Africa and Arab Peninsula, whereas, in Egypt, it restricted to the rocky slopes on Gebel Elba and Gebel Uweinat [12]. In the Egyptian flora, there are four fig species, distributed in a wide range of ecological zones. Three fig species are wild: *Ficus cordata* subsp. *salicifolia* in rocky slopes of Gebel Elba and Uweinat; *F. palmata* on rocky slopes and desert wadis of Sinai Peninsula, Eastern desert, and G. Elba: *F. sycomorus* at wet habitats in the Nile reign specially on the canal banks. Also, it presents at the Mediterranean coast, and oases. The cultivated fig tree in Egypt is *F. carica*. This species is common and presents in all phytogeographical regions (Eastern Desert, Western Desert, Sinai Peninsula, Nile region, and oases [12].

Study area

Gebel Elba national park is located at the southeastern part of Egypt between 22º to 23.2º N and 36 to 36.5º E (Figure 1). It includes clusters of coastal mountains overlooking the Red Sea coast. This location in the front of currents of air and clouds which are loaded with moisture makes Gebel Elba climate intermediate between the tropical rainy region and dry Egyptian rocky desert with their occasional downpours during winter [13]. However, climatic feature of this region is similar to the prevailing condition of the Eastern Desert where monthly recorded air temperature is 21ºC in January and 32 ºC in August and the mean annual amount of rainfall is less than 50 mm [14]. Yet, the location brings mist and clouds to mountains slope where orographic precipitation produces up to 400 mm/year [15]. According to habitats heterogeneity, different types of vegetation were recognized ranging from mangroves at the Red Sea coast to mist oasis at higher altitudes. Apart from that Gebel Elba is considered as a biodiversity hotspot. It's a home of about 450 plant species [16, 3].

Figure (1). A Google Earth map showing the location of the studied area at Gebel Elba region in the front of the Red Sea near to the Sudanese border with Egypt.

II. Methods

Vegetation analysis

Ecological studies were conducted during two successive springs of 2019 and 2020 at Gebel Elba, southeastern Egypt. *Ficus salicifolia* and associated species were recorded at three different microhabitats (wadi bed, smooth faced rock, and rocky cliffs), Figure (2) on altitudinal gradients from foot of the mountain to higher elevations at 1200 m. Each 50 m, stand (50 X 50 m) was placed at the wadi bed, and at the face faced rock as possible. On the other hand, the present rocky cliffs were surveyed. According to the absence of *F. salicifolia* from the lower and higher elevation, we focused on the middle elevation from 400 - 800 m above sea level. Effects of altitudinal gradients and microhabitats on *F. salicifolia* performance were studied through four parameters (height, diameter, crown cover, and leaf area). Means of 5 coherent plants were selected at each microhabitat and also at each altitudinal stop (50 m). Both of Height, diameter and crown cover were determined with meter scale, whereas, leaf area was assessed with portable leaf area meter model CI-202. Plant species were identified according to Flora of Egypt (Boulos, 1999, 2000, 2002, 2005, and 2009). A linear simple regression was used to represent the relationship between altitude and *Ficus* performance, whereas test of equal means (ANOVA) were used to study effects of microhabitats. All statistical analyses were implemented with PAST 3.23 Program [17].

Soil analysis

A mixed soil samples from the surface layer (0 – 10 cm) were taken from three different stands for each microhabitat, air-dried then we analysed the samples to determine the texture and chemical soil properties. Soil texture was determined by sieving with successively finer meshes [18]. Soil suspensions were prepared by the addition of distilled water in a 1:1 ratio and stirring continuously for 2 hours, then measured the pH and electrical conductivity (EC) of the suspensions with a pH meter (Jenway 3510) and conductivity meter (Jenway 4510), respectively [19, 20]. The organic matter content was estimated by the weight loss-on-ignition method [21, 22] and CaCO3 was determined volumetrically using a Collin's calcimeter [23].

III. Results

Associated species

A total of 55 species has been recorded as associated species of *Ficus* tree at Gebel Elba region. Most species are perennials (80%, 44 out of 55), whereas annuals are less represented (20%, 11 out of 55). Wadi bed and smooth faced rock are the most favorable habitats for plant growth, where most of species were recorded. The lower number of species was recorded inside rocky cliff 17 species (four species restricted to cliffs and 13 presented in cliffs and other microhabitats (Table1). Most of species grown at wadi bed and smooth faced rock (see Table (1), and figures (2).

Soil variables

The soils associated with the studied microhabitats of *Ficus* were characterized by neutral to slightly alkaline pH (7.13 - 7.33, see Table 2). The soil texture was sandy on the wadi bed and coarse fragments increase with the elevation. The highest coarse soil fragments were found in the rocky cliffs at higher elevation above 600 m (Table 2). The EC decreased with the elevation and the highest value was recorded in the wadi bed (833.67µS/m). The organic matter content was very low, and the highest value was determined in the smooth faced rock (0.65%). Finally, The $CaCO_3$ content was less than 3% (0.98– 2.70%).

Table (1). A list of Associated species of *Ficus* salcifolia Community in the three studied microhabitats on Gebel Elba. Species are represented as presence (1) and Absence (0). Abbreviations: P: Perennials, and A: Annuals.

Species	Life duration	Wadi bed	Smooth faced rock	Rocky cliff
Abutilon fruticosum Guill. &Perr.	P	1	0	0
Acacia etbaica Schweinf	P	1	0	1
Acacia melliferaa (Vahl) Benth.	P	1	1	0
Achyranthes aspera var. *sicula* L.	P	1	0	1
Aerva lanata (L.) Juss.ex Schult.	P	1	0	0
Barleria acanthoides Vahl	P	0	1	0
Bidens schimperi Sch. Bip.	A	1	1	0
Cadaba farinosa Forssk.	P	1	0	0
Carissa spinarum L.	P	1	0	1
Commelina benghalensis L.	P	1	1	0
Commelina forsskaolii Vahl..	A	1	1	0

Commicarpus heleae (Schult.) Meike.	P	1	1	0
Diceratella elliptica (DC.) Jonsell.	P	1	1	0
Dodonaea viscosa (L.) Jacq.	P	1	0	1
Dracaena ombet Kotschy & Peyr.	P	0	0	1
Echinops hussonii Boiss.	P	1	1	0
Ephedra ciliata Fischer &C.A.Mey.	P	0	1	0
Euclea racemosa Murray.	P	1	1	1
Euphorbia cuneata Vahl.	P	1	0	0
Farsetia longisiliqua Decne.	P	1	1	0
Ficus cordata subsp. *Salicifolia* (Vahl).	P	1	1	1
Forsskaolea tenacissima L.	P	1	1	0
Forsskaolea viridis Webb.	A	1	1	0
Geigeria alata (DC.) Benth.	A	1	1	0
Geranium biuncinatum Kokwaro.	A	0	1	1
Grewia tenax (Forssk.) Fiori.	P	1	1	0
Hibiscus vitifolius L.	P	0	1	0
Jasminum fluminense subsp. *gratissimum* (Deflers).	P	1	1	0
Jasminum grandiflorum subsp. *Floribundum* (R. Br.ex. Fresen).	P	1	1	0
Lantana viburnoides (Forssk.) Vahl.	P	0	1	1
Lavandula coronopifolia Poir.	P	1	1	0
Lindenbergia indica (L.) Vatke.	P	0	0	1
Maytenus senegalensis (Lam.) Excell.	P	1	0	1
Ocimum forsskaolii Benth.	P	1	1	1
Olea europaea subsp. *cuspidata* (Wall.ex G. Don).	P	1	1	0
Otostegia fruticosa subsp. *fruticosa* (Forssk.) Penz.	P	0	1	1
Oxalis anthelmintica A. Rich.	P	0	1	0
Pergularia daemia (Forssk.) Chiov.	P	1	1	0
Periploca aphylla subsp. *laxiflora* Browicz.	P	1	1	0
Perstirophe paniculata (Forssk.)	A	1	1	0
Phagnalon schweinfurthii Sch. Bip.	P	0	0	1
Pistacia khinjuk var. *glabra* schweinf.	P	0	0	1
Pupalia lappacea (L.) Juss.	P	1	1	0
Reichardia tingitana (L.) Roth.	A	1	1	0
Rhus abyssinica Hochst. Ex Oliv.	P	1	0	0
Rhus flexicaulis Baker.	P	1	1	0
Rhus tripartita (Ucria) Grande.	P	1	1	0
Rumex simpliciflorus Murb.	A	1	1	1
Salvia aegyptiaca L.	P	0	1	1
Scrophularia arguta Sol.	A	1	1	0
Sisymbrium irio L.	A	1	1	0
Solanum forsskaolii Dunal.	P	1	1	0
Solanum incanum L.	P	1	1	0
Trichodesma ehrenbergii Schweinf.	A	1	1	0
Triumfetta flavescens Hochst ex.A. Rich.	P	1	1	0

Table 2. Means and standard deviations for altitude and soil properties of the three different microhabitats (wadi bed "A", smooth faced rock "B" and rocky cliffs "C"). ANOVA test is for original, sqrt, or log data values, if there are some values statistically not normally distributed. F-value and P-value refer to the ANOVA. Small letters denote the statistically different groups as identified by ANOVA post-hoc test.

Parameter		**A**	**B**	**C**	**F-value**	**P-value**
	Altitude	^{b}415.73 ±107.86	^{ab}566.60 ±14.23	^{a}641.98 45.10	8.61	0.02
Soil texture	**Very fine gravel.$_{sqrt}$**	^{a}10.04 ±4.34	^{a}10.84 ±6.73	^{a}22.14 ±10.82	2.05	0.21
	Very coarse sand.$_{log}$	^{b}10.15 ±2.90	^{b}12.08 ±5.49	^{a}29.52 ±3.62	8.76	0.02
	Coarse sand	^{b}9.79 ±3.31	^{b}11.85 ±4.35	^{a}21.10 ±2.54	8.99	0.02
	Medium sand.$_{log}$	^{a}11.29 ±2.65	^{a}13.84 ±4.62	^{a}11.15 ±3.33	0.44	0.66

	Fine sand	^{a}16.52 ±1.41	^{a}16.03 ±3.86	^{b}6.15 ±3.53	10.51	0.01
	Very fine sand	^{a}24.92 ±3.40	^{a}21.93 ±7.44	^{b}6.78 ±4.79	9.48	0.01
	Silt&Clay$_{\text{.sqrt}}$	^{a}16.83 ±8.28	^{ab}13.09 ±7.77	^{b}2.95 ±2.12	5.57	0.04
Soil chemistry	**pH**	^{a}7.13 ±0.31	^{a}7.33 ±0.21	^{a}7.23 ±0.15	0.56	0.60
	EC	^{a}833.67 ±193.70	^{a}596.04 ±517.22	^{a}432.00 ±151.36	1.12	0.39
	$CaCO_{3.log}$	^{a}2.70 ±3.63	^{a}1.48 ±0.71	^{a}0.98 ±0.28	0.16	0.86
	Organic matter$_{\text{.sqrt}}$	^{ab}0.36 ±0.14	^{a}0.65 ±0.34	^{b}0.07 ±0.03	9.71	0.01

Figure 2. Microhabitats of *Ficus salicifolia*. Above wadi bed, Middle smooth faced rock, bottom Rocky cliffs.

Effects of Altitudinal gradient

Figure (3) summarizing the relationship between altitudinal gradients and both of Height, diameters, leaf area, and Crown cover of *Ficus Salicifolia*. We have neither record any *Ficus* tree at the elevation lower than 400 m nor, above 800 m. There are a positive relationship between plant height and elevation where correlation coefficient (R^2=0.877, $P<0.05$). Also, Diameter is strongly correlated with higher elevation rather than lower elevation (R^2=0.77, $P<0.05$). On the other hand, Leaf areas are bigger at higher altitude than the lowers. (R^2=0.708, $P< 0.05$). In contrary, Crown cover is unaffected with higher altitude (R^2=0.463, $P <0.05$).

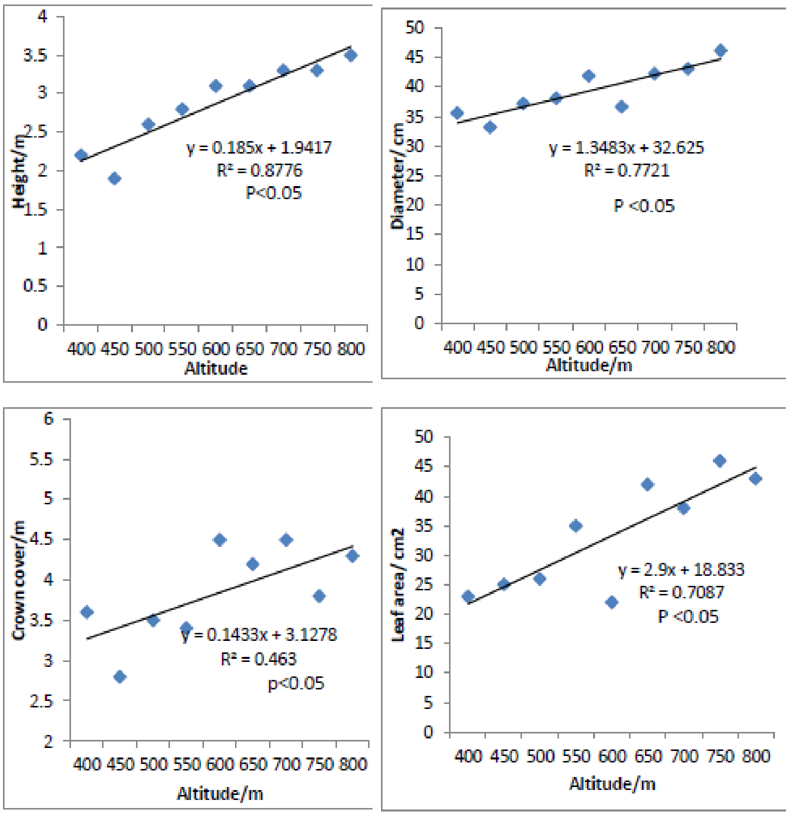

Figure (3). The relationship between elevation gradient and both of height, diameter, crown cover and leaf area of *Ficus palmata* subsp. *salicifolia.*

Effect of microhabitat

Habitat heterogeneity playing an important role on shaping plant structures. Table (3) described the effect of habitat on plant height, diameter, crown cover, and leaf area. All of these indicators are significantly varies from one habitat to another. Trees of *Ficus salicifolia* growing inside wadi bed. However, the upper and lower altitude having the largest size and leaf area, whereas trees inside smooth faced rock having the smallest size (height, diameter, crown cover, and leaf area). Plants growing at rocky cliff have a moderate size between wadi bed and smooth faced rock.

IV. Discussion

Ficus tree is a key stone species in many tropical Ecosystems. Their Fruits are a key resource for some frugivorces including Bats, Pigeons, and Doves. In addition to, many Insects and Butterflies. Pollination process is basically depending on a certain species of Wasps. The previous studies along with the present study on Gebel Elba indicated the presence of *Ficus salicifolia* in middle altitudes and hardly found at elevation more than 800 m or less than 400 m [5, 24]. Altitudinal gradients used as a model templates for large scale studies that analyze the adaptive features of the terrestrial plants under the influences of global climate change [25]. One of the most common consequences of climate changes is increasing temperatures. The higher temperatures makes plants and animals to displaced their substrates from the lower elevation to the higher elevation where temperatures more cooler. Higher elevations in the arid region are more preferable by many species especially relict species. The majority of associated species in the studied microhabitats are perennial tree or shrub. In this context, [6] concluded that most of Gebel Elba flora is perennials exactly two thirds of species are perennials (300 out of 450). The relationship between Habitat heterogeneity and species diversity is frequently recorded [26, 27]. Spatial variations in the habitat and local climate can affect species distribution and composition due to the different adaptive mechanisms and species traits exerted by species and hence, supports different ecological niches and consequently different species.

The habitats belong to granitic and metamorphic rocks and gravel plains are rich in smooth faced rock outcrops. Water regime in the crevices and soil pockets of small faced rock outcrops differs from that of the other edaphic types in the relatively high and constant supply of water available for plants [28]. The smooth surface of the hard rocks is neither absorb nor stores the rainwater, and even after a weak shower, water runoff and concentrates in the crevices. Therefore, the amount of available water in the soil pocket of the smooth faced rocks may reach several times the amount of rain fall [29]. In addition, wadi habitat has a great merit of being a drainage system collecting water from an extensive catchment area [30]. Water streams governing alluvial soil accumulation along wadis bed. The soil inside wadi bed and smooth faced rock are most diverse and supporting many species beside large trees and shrubs [5]. Most of species are shifted to the upper altitude where moisture and cool are available [3] . In addition, upper altitudes are more shaded however, it supports a lot of tree species especially fruits such as: Olives, Pistachio, grape, and Figs.

Table 3. Test of equal mean (ANOVA) between three microhabitats and 4 four parameters of *Ficus Salicifolia* (Height, Diameter, Leaf Area, and Crown cover.

Significance:*= P<0.05, **= P<0.01

Parameters	Microhabitat			F- ratio
	Wadi bed	Smooth faced rock	rocky cliff	
Height/m	3.13	2.16	2.43	18.96**
Diameter/cm^2	42	35.5	38.9	5.28*
Crown cover/m	4.4	2.9	3.7	11.42**
Leaf area/cm^2	41.67	30.67	36	8.6*

Leaf size and other functional traits are key determinants of plant performance in ecosystems [31]. Change in the leaf size, shape and biomass are both a cause and a consequence of variation in resource availability and environmental change [32] or leaf traits may exhibit considerable plasticity in response to environmental demands [33]. The universal pattern between elevation and leaf size are inversely relation, leaf size was decreased with increase in the elevation [34, 35], That is true in case of humid and temperate regions. Whereas, some authors, reported a direct relationship between leaf size and elevation [36, 37, and 38] especially in arid region. Our findings enhance the second opinions. The higher elevations in the arid region are sharing the same circumstances of the lower elevation at the humid region. The large leaf size is present at the favorable substrate and small leaves are correlated with the more stressful substrate. The higher altitude of Gebel Elba is the most favorable habitats due to the effects of mist oases.

The analysis of soil samples revealed that the edaphic factors changed between the different microhabitats occupied by the *Ficus salicifolia* tree. The wadi bed microhabitat at lower elevations is characterized by fine and medium sands. This allows a poor holding capacity of water and increasing the EC of the surface layer of soil [39]. While, faced rock microhabitat are characterized by accumulation of fine soil fragments (silt & clay) and organic matter accumulate in rock crevices. The higher water holding capacities of the rocky habitats in the drainage systems support the growth of less drought-resistant trees such as *Ficus salicifolia* [24].

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