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Altitudinal changes in photosynthetic pathways of floristic elements in southern Sinai, Egypt

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Abstract

High altitude profoundly influenced plant diversity and distribution on mountains of southern Sinai (Egypt). Plants exhibiting the C_3-mode of photosynthesis were widely distributed along the altitudinal transect. Plants exhibiting the C_4-mode were restricted below an altitude of about 1400 m above sea level. The transition from C_3-dominated areas to C_4-dominated areas occurred between 1200 and 1400 m a.s.l.

Additional key words: C_3; C_4; ecophysiology.

Introduction

Sinai is part of the Saharo-Arabian desert with a climate influenced by the Mediterranean in the north and high altitude in the south. Mountains of southern Sinai (Egypt) are characterised by outcrops of smooth-faced granite rocks, and landforms (slopes, terraces, and ridges). This area is floristically rich with 419 species of which 28 are endemic (Danin 1983, 1986, El-Ghareeb and Shabana 1990, Mostafa and Klopatek 1995, Boulos 1997). In this area, photosynthetic pathways and distribution of plant species have been studied (Winter and Troughton 1978, Winter 1981, Ziegler *et al.* 1981, Vogel *et al.* 1986, Batanouny *et al.* 1988). However, although several studies describing plant distribution along altitudinal gradients in different parts of the world exist in the literature (Tieszen *et al.* 1979, Earnshaw *et al.* 1987), no attention has been given to the effects of high altitude on the flora of southern Sinai. This is why we describe altitudinal changes in photosynthetic pathways of the flora of Mount Musa (Saint Catherine area, southern Sinai, Egypt).

Materials and methods

The study site of Mount Musa, 2285 m a.s.l., is one of the highest mountains in Egypt. Records of temperature, humidity, precipitation, and evaporation for 20 years (1974-1994) supplied by the Authority of Meteorology were used to calculate variability coefficient of rainfall, annual thermal amplitude (Willert *et al.* 1992), and aridity (Sayed 1998). Work was carried out early in the dry season (mid-June) and included only perennial species prevailing at that time of year. Air (50 cm above ground) and soil (5-cm depth) temperatures were measured using a digital thermometer, and humidity was measured using a digital hygrometer (*Maplin Electronics*, Manchester, U.K.). Soil water potential was determined using a psychrometer (*Wescor*, Logan, Utah, U.S.A.). Carbon isotope discrimination ratio ($\delta^{13}C$ values) in the ranges –24 to –31 ‰, and –10 to –15 ‰ were considered indicative of C_3- and C_4-modes of photosynthesis, respectively (Griffiths 1993). Quadrats (1 m^2) were set at designated altitudes, plant species were identified (Zohary 1966, 1972, Täckholm 1974, Feinbrun-Dothan 1978, 1986, Boulos 1995, El-Hadidi and Fayed 1995, Boulos 1999), and diversity and evenness were calculated (Magurram 1988). Measurements were routinely repeated and standard error was calculated.

Results

For January and June, air temperature was -5 and 35 °C, relative humidity 58 and 29 %, evaporation 5.7 and 17.5 mm, respectively, and a mean annual rainfall of 45 cm y^{-1} occurred partly as snow during the period Novem-

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ber-March. Calculations based on these records revealed that the study site had a variability coefficient of rainfall of 12, an annual thermal amplitude of 15 K, and an aridity of 8.6 mm °C^{-1}.

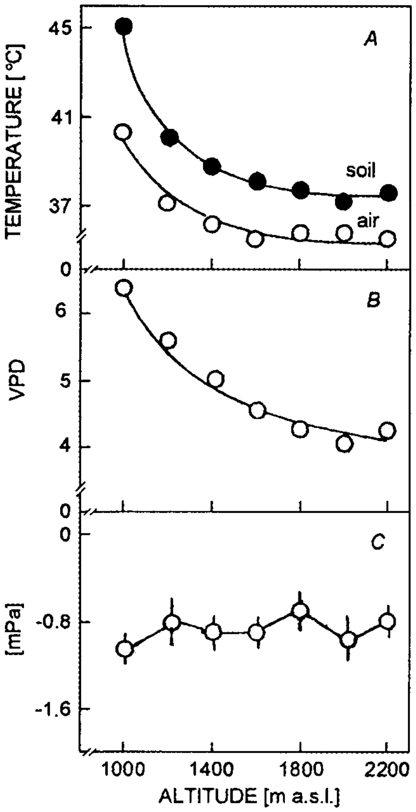

Fig. 1. Altitudinal changes in soil and air temperatures (*A*), vapour pressure deficit (*B*), and soil water potential (*C*) at the study site.

Soil and air temperatures and vapour pressure deficit decreased with increased altitude (Fig. 1*A*,*B*). Soil water potential remained almost unchanged, but was slightly higher at 1200 and 1800 m a.s.l. (Fig. 1*C*). A total of 33 perennials belonging to 15 families were recorded (Table 1). Five species (*Anabasis articulata*, *Atriplex halimus*, *Calligonum polygonoides*, *Heliotropium strigosum*, and *Salsola tetrandra*) had Kranz anatomy and δ^{13}C values characteristic of C_4 plants, whereas others had δ^{13}C values characteristic of C_3 plants. Diversity and evenness increased with increasing altitude, with diversity being slightly higher at 1200 and 1800 m a.s.l. (Fig. 2 *A*,*B*). The number of C_3 species increased, whereas that of C_4 species decreased with increased altitude (Fig. 2*C*). While C_3 species were widely distributed along the altitudinal transect, C_4 species were restricted below 1400 m a.s.l. (Table 2). Diversity correlated well with vapour pressure deficit and altitude (Fig. 3).

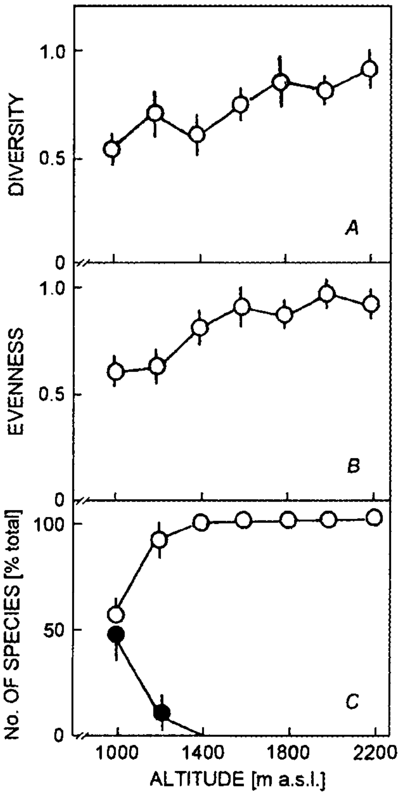

Fig. 2. Altitudinal changes in plant diversity (*A*), evenness (*B*), and number (*C*) of C_3 and C_4 species.

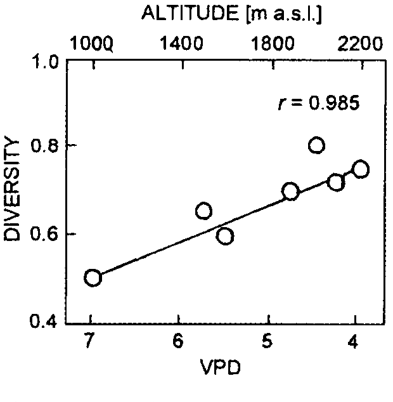

Fig. 3. Correlation between diversity, vapour pressure deficit, and altitude.

Discussion

Although most of Sinai is of Saharo-Arabian phytogeographical characteristics (McGinnies *et al.* 1968), high mountains of Saint Catherine area are dominated by Irano-Turranean and endemic plant species (Mostafa and

Table 1. Recorded species (CFP = CO_2 fixation pathway, $\delta^{13}C$ = carbon isotope discrimination, H = herb, KA = Kranz anatomy, LF = Life form, S = shrub).

Family/Species	LF	KA	$\delta^{13}C$	CFP
Asclepiadaceae				
Calotropis procera (Ait.) Ait.f.	S	–	-27.9	C_3
Asteraceae				
Achillea fragrantissima (Forssk.) Sch. Bip.	H	–	–	C_3
Artemisis judaica L.	S	–	-28.8	C_3
Atractylis flava Desf. Carduus (Forssk.) C. Chr.	H	–	-26.8	C_3
Echinops spinosus L.	H	–	-26.8	C_3
Launaea nudicaulis (L.) Hook. f.	H	–	-30.0	C_3
Launaea spinosa (Forssk.) Sch. Bip. ex Kuntze	H	–	-28.5	C_3
Pulicaria crispa (Forssk.) Oliv.	S	–	–	C_3
Pulicaria incisa (Lam.) D.C.	S	–	–	C_3
Boraginaceae				
Heliotropium strigosum Willd.	S	–	-13.0	C_4
Brassicaceae				
Farsetia aegyptiaca Turra	S	–	-24.6	C_3
Zilla spinosa (L.) Prantl.	S	–	-27.3	C_3
Capparaceae				
Capparis spinosa L.	S	–	-25.5	C_3
Caryophyllaceae				
Gymnocarpos fruticosus (Vahl.) Pers.	S	–	-28.1	C_3
Chenopodiaceae				
Anabasis articulata (Forssk.) Moq. In A.D.C.	S	+	-11.7	C_4
Atriplex halimus L.	S	+	-14.8	C_4
Salsola tetrandra Forssk.	S	+	-13.2	C_4
Cleomaceae				
Cleome droserifolia (Forssk.) Del.	H	–	-26.8	C_3
Cucurbitaceae				
Citrullus colocynthis (L.) Schrad.	H	–	-24.4	C_3
Lamiaceae				
Lavendula coronopifolia Poir. In Lam.	S	–	–	C_3
Phlomis aurea Decne.	S	–	–	C_3
Salvia aegyptiaca L.	S	–	–	C_3
Teucrium polium L.	S	–	–	C_3
Polygonaceae				
Calligonum polygonoides L. *comosum* (L'Her.) Soslov	S	–	-11.9	C_4
Polygonum equisetiforme Sm.	H	–	-28.7	C_3
Rubiaceae				
Galium sinaicum (Del. ex Decne.) Boiss.	H	–	–	C_3
Solanaceae				
Hyoscyamus muticus L.	S	–	–	C_3
Lycium arabicum Schweinf.	S	–	-26.1	C_3
Tamaricaceae				
Tamarix nilotica (Ehrenberg.) Bge.	S	–	-26.6	C_3
Zygophyllaceae				
Fagonia cretica L.	S	–	-28.5	C_3
Fagonia mollis Del.	H	–	-26.3	C_3
Peganum harmala Sm.	S	–	-25.8	C_3
Zygophyllum coccineum Muschl.	S	–	-29.4	C_3

Klopatek 1995, Boulos 1997). Meteorological records indicated that although this area is the highest and coldest in Sinai, it had variability coefficient of rainfall, annual thermal amplitude, and aridity typical of arid zones. Although in such habitats rainfall is the major force influencing plant diversity and distribution (Lawlor 1993, Sayed 1998), high altitude at the study site may have profound effects. Soil and air temperatures, and vapour pressure deficit decreased with increased altitude (Fig. 1*A*,*B*). The high mountains of Saint Catherine area have more annual rainfall than the rest of Sinai (Mostafa and Klopatek 1995), an observation that was reflected in the increased diversity with increased altitude (Fig. 2*A*,*B*). Moreover, at the study site plants grew in little pockets of soil on slopes, and in larger plots of soil with higher water holding capacity on terraces (Danin and Plitmann 1987, Mostafa and Klopatek 1995). This high soil water holding capacity perhaps accounts for high diversity observed on terraces located at 1200 and 1800 m a.s.l. (Fig. 2*A*). However, soil water potential did not vary significantly with increased altitude (Fig. 1*C*) since work was carried out during the dry season (mid-June) when the last effective rainfall occurred three months earlier (mid-March). This timing for the experiment was chosen to ensure the presence of only perennial species (Table 1), and to see if the distribution of plants exhibiting the C_3 or C_4 photosynthesis was influenced by factors other than soil moisture.

Table 2. Altitudinal distribution [m a.s.l.] of plant species recorded at the study site.

Species	CFP	Altitude 1000	1200	1400	1600	1800	2000	2200
Anabasis articulata	C_4	+						
Atriplex halimus	C_4	+						
Calligonum polygonoides	C_4	+	+					
Heliotropium strigosum	C_4	+	+					
Salsola tetrandra	C_4	+						
Zygophyllum coccineum	C_3	+	+					
Artemisia judaica	C_3	+	+					
Callotropis procera	C_3	+	+					
Citrullus colocynthis	C_3	+	+					
Cleome droserifolia	C_3	+	+	+				
Hyoscyamus muticus	C_3	+	+	+				
Lavendula coronopifolia	C_3		+	+				
Lycium arabicum	C_3		+	+				
Phlomis aurea	C_3		+	+				
Peganum harmala	C_3		+	+	+			
Teucrium polium	C_3		+	+	+	+		
Zilla spinosa	C_3		+	+	+	+		
Capparis spinosa	C_3			+	+	+		
Fagonia cretica	C_3			+	+	+		
Launaea spinosa	C_3			+	+	+		
Pulicaria crispa	C_3			+	+	+	+	
Achillea fragrantissima	C_3		+	+	+	+	+	+
Fagonia mollis	C_3		+	+	+	+	+	+
Atractylis flava	C_3				+	+	+	+
Pulicaria undulata	C_3				+	+	+	+
Echinops spinosus	C_3					+	+	+
Farsetia aegyptiaca	C_3					+	+	+
Gymnocarpos fruticosus	C_3					+	+	+
Launaea nudicaulis	C_3					+	+	+
Salvia aegyptiaca	C_3					+	+	+
Galium sinaicum	C_3						+	+
Polygonum equisetiforme	C_3						+	+
% C_3		54.55	91.67	100	100	100	100	100
% C_4		45.45	8.33	0	0	0	0	0

The recognition that C_4 photosynthesis as a CO_2 concentrating mechanism was fundamentally different to C_3 photosynthesis (Edwards and Walker 1983) stimulated work on comparative ecophysiology of C_3 and C_4 plants (Winter 1981, Hattersley 1983, Jones 1985, Batanouny *et al.* 1988, Sayed 1994, Nieva *et al.* 1999, Tang and Zhang 1999). Plants exhibiting the C_4-mode of photosynthesis possess higher temperature optima for CO_2 fixation and improved water use efficiency (Jones 1985, Hattersley 1992, Nelson and Langdale 1992, Leegood *et al.* 1997, Long 1999). These features were reflected in a survey of plants along a temperature gradient (Jones 1985) and along a gradient involving a double stress of drought and salinity (Sayed 1994). In the present study, plant diversity showed a good correlation with air temperature and humidity along the investigated altitudinal transect (Fig. 3). Moreover, while C_3 and C_4 species were equally numerous at 1000 m a.s.l., C_3 species were more numerous with increased altitude, and C_4 species were restricted below an altitude of about 1400 m a.s.l. (Fig. 3*C*). This difference in altitudinal distribution of C_3 and C_4 species perhaps pertained to air temperature and humidity rather than soil moisture since soil water potential was almost unchanged with increased altitude. Similar results were reported along an altitudinal transect in Kenya in which C_4 species were not present when mean annual minimum temperature was below 8 °C (Tieszen *et al.* 1979). In Hawaii the transition from complete C_4 to C_3 dominance occurs at 1000-2000 m a.s.l. (Rundel 1980), and in New Guinea this transition was also observed at about 2500 m a.s.l. (Earnshaw *et al.* 1990). Moreover, there is also evidence for latitudinal interaction with the distribution of C_4 species involving a transition from C_3-dominated areas to C_4-dominated areas that is influenced by temperature (Sage *et al.* 1999). In the arid regions of central Asia, C_4 species were absent where growth season temperature was less than 8 °C (Pyankov and Mokronosov 1993). It can, therefore, be concluded that low temperatures prevailing at high altitudes of Mount Musa (southern Sinai) restricted the occurrence of C_4 species and hence shifted the balance of competition in favour of C_3 species.

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