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Does Egypt Represent an Ecological Limit to Desiccation Tolerant Plants?

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هل تمثل مصر حدا بيئيا للنباتات المتحملة للتجفيف؟

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أظهر البحث في المناطق المتاخمة لنهرا لنيل في مصر غيابا واضحا للنباتات الوعائية المتحملة للتجفيف، و ذلك علي العكس في مناطق أخرى في كينيا و في جنوب قارة أفريقيا لها نفس الظروف البيئية و لكن تميزت بوفرة تلك النباتات. تم التعرف على حيوية أنسجة النباتات عن طريق اختبارات قدرة أغشية الخلايا علي الاحتفاظ بصفاقا شبة المنفذة و على تكوين الكلوروفيل في الأنسجة غير الخضراء عند تعريضها للضوء. تمت مناقشة أسباب عدم وجود تلك الأنواع النباتية في مناطق الدراسة في أسوان و الأقصر. و يرجع ذلك إلى طول الفترات الزمنية بين مواسم هطول الأمطار الفعالة أو الكافية و التي يؤدي تباعدها إلي التقليل من حيوية النباتات المتحملة للتجفيف، حيث تظل أنسجة تلك النباتات في حالة جفاف مستمرأ ثناء تعرضها للهواء. يتضح من تلك الدراسة أن جفاف البيئة في مناطق الدراسة يمثل حدا بيئيا مؤثرا على تواجد النباتات المتحملة للتجفيف.

Key words: *Desiccation-tolerance, resurrection plants, anabiosis, Egypt.*

ABSTRACT

A search of arid areas adjacent to the Nile in Egypt revealed a notable lack of desiccation tolerant vascular plants on ecological sites on which they would be abundant in Kenya and further south in Africa. Relative water contents (RWC); the water content of the tissue as a percentage of its water content at full turgor; were estimated after the tissue had been floated on water for 24h and then dried in a 70° C oven to avoid errors due to decomposition at higher temperatures. Viability of the rehydrated tissue was judged from tests of the retention of semipermeability of the cell membranes and by formation of chlorophyll in non-chlorophyllous tissue in the light. Possible causes of their apparent absence from suitable sites in the Aswan-Qena area are discussed. We attribute their absence to time durations between effective rainfall events that exceed the longevity of resurrection plants while in an air-dry anabiotic condition. This is, to our knowledge, the first report of an aridity-related factor that may present an ecological limit to fully desiccation-tolerant plants.

Introduction

Compared with other continents, Africa has relative abundance of desiccation tolerant vascular plants that can survive for long periods in an air-dry "anabiotic" state, but resume active metabolism during rehydration by rain [1]. Such African "resurrection plants" include grass species in the genera *Eragrostis, Microchloa, Oropetium, Sporobolus* and *Tripogon*, many Velloziaceae (*Talbotia elegans* and *Xerophyta* spp.), a large number of ferns (particularly *Cheilanthes* spp. and *Pellaea* spp.) and *Selaginella* species [2, 3,4]. Examples have been reported by plant collectors in southern, central, western and eastern Africa [3,4,5,6,7]. They occur mainly on topography which produces well-drained shallow soils (e.g. sandstone slabs and granitic rock outcrops) in warm climates with a pronounced rain-free season. Although Egypt combines these features of climate and topography, to the authors' knowledge, only one known desiccation tolerant vascular plant has been reported from Egypt: desiccation tolerance was demonstrated in *Ceterach officinarum* [8], a fern found in the Sinai [9]. Although resurrection grasses are not known among the Egyptian grasses studied [10], this list contains three grass genera with some desiccation tolerant species elsewhere (*Eragrostis, Poa & Sporobolus*). However, no focused search has been conducted for resurrection plants in Egypt.The present study addresses the occurrence of resurrection plants in Egypt, and the confirmation of their geographical distribution in areas peripheral to the Nile Valley, which a *priori* appeared most likely to provide suitable habitats.

Materials and Methods

Several field studies were conducted in different geographical regions in Egypt to search for the possible occurrence of the desiccation tolerant plants. The examined areas include: (1) sandy desert soils on the Cairo-Alexandria Desert Highway, (2) Wadi el-Natrun; deep desert sands beside granitic rock outcrops and in wadis; (3) shallow soils in small rock-pans on granitic rock domes in the area from 95 km east of Qena, (4) Qena, (5) Luxor, (6) Aswan; areas subject to alternate moistening and drying at the shore of Lake Nasser at Aswan, and (7) dry sandstone ledges and deep sands at Abu Simbel. The Nile delta was surveyed from Rashid to Tanta but no sites were found with appropriate characteristics (Fig.1).

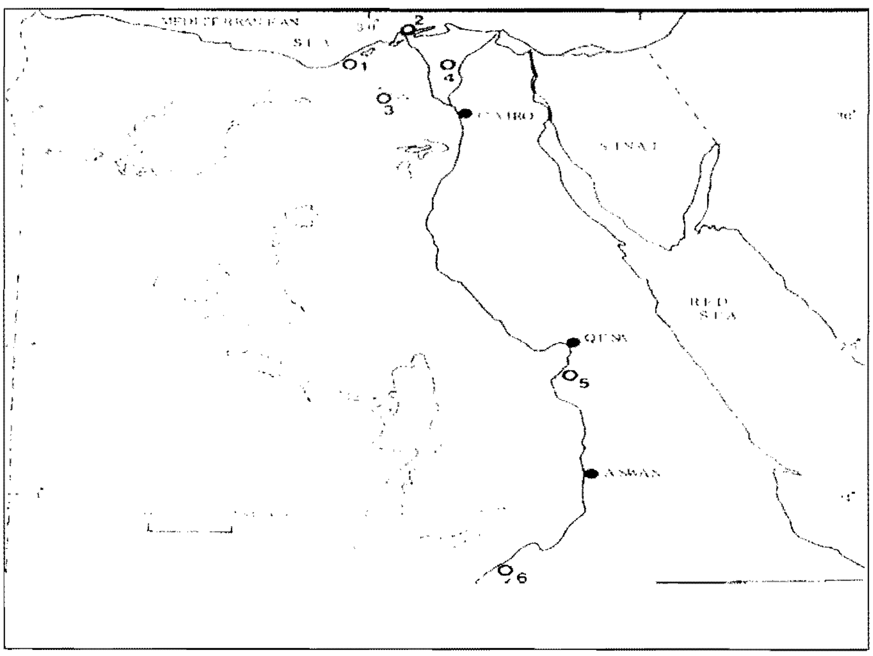

Figure1. A map showing the collecting sites in Egypt: 1) Alexandria, 2) Rashid, 3) Wadi El-Natrun, 4) Tanta, 5) Luxor, 6) Abo Simbel.

Because the drought tolerance of resurrection plants may be affected by the rate of drying [11], air-dry leaves were collected from plants which had dried under natural conditions in the field. Dry leaves were transported back to the laboratory in air-tight containers, tightly packed with leaves to give a minimum volume of air.

Relative water contents (RWC); the water content of the tissue as a percentage of its water content at full turgor; were estimated after the tissue had been floated on water for 24h and then dried in a 70° C oven to avoid errors due to decomposition at higher temperatures [12,13].

Viability of the rehydrated tissue was judged from tests of the retention of semipermeability of the cell membranes (neutral red uptake, [14]; evans blue exclusion, [15]) and by formation of chlorophyll in non-chlorophyllous tissue in the light. Based on earlier studies on air-dry foliage, plants whose leaves survived RWC of 13% or less can be regarded as resurrection plants, except in aquatic plants or succulents with a low proportion of fibre and cell wall material [1,2].

Results

Appropriate specimens were collected for examination, from deep desert sands, particularly around granitic domes and in rock-bounded wadis where water flowing off extensive rock areas would be concentrated, and from sandstone ledges. The vegetation in general was sparse and contained few species.

In all cases, dry specimens of those plants which had been collected from sparse occurrences on deep sands failed to recover when fully rehydrated in the laboratory.Presumably, these species can occur in arid areas because they possess deep root systems which draw on moisture deep in the soil for sufficient time to allow the persistence of some individual plants and for occasional opportunistic seed set. Grass and sedge specimens that could be identified in this category included *Aristida mutabilis, Aristida* sp., *Cenchrus ciliaris, Cynodon dactylon, Cyperus* sp., *Eragrostis* sp., *Hyparrhenia hirta, Imperata cylindrica, Pennisetum divisum, Sporobolus spicatus* and *Tricholaena teneriffa*. Run-off from neighbouring rock slabs and hills amplifies, for well-placed individual plants, the effectiveness of the sporadic precipitation received, while the deepness of the sand allows both long term retention of moisture at depth and easy penetration by roots. This situation is common in arid regions.

No desiccation tolerant plants were found on granitic rock domes in the area east of Qena and at Aswan. Indeed these rock outcrops lacked any plants at all, even lichens, on the exposed rock surface and in the shallow pans of soil which are distributed intermittently over granitic rock domes. It is impossible to conduct a search sufficiently thorough to exclude the possibility that some resurrection plants occur on such sites in this area.

However, a search of similar intensity on rock domes, widely separated over so large an area, would have encountered many desiccation tolerant species in other parts of Africa (Table 1).

Table 1. Number of novel resurrection plant species recorded by one of the authors (DFG) during collecting trips of similar duration and intensity to the collecting in this study of Egyptian flora.

Region	Number of Desiccation Tolerant Species		
	Angiosperms	Ferns & Fern Allies	Reference
Argentin	2	6	a
Brazil, Bahia	3	2	a
" Brazilia region	3	1	a
" Minas Gerais	15	2	a
Mexico, Central Highlands unpublished	1	2	
Australia, Arnhemland region	5	3	b
" central	3	4	b
" Queensland	4	2	b
" Western Australia	1	2	b
India, Jodhpur area	3	-	c
Kenya	5	-	d
Namibia, first journey	5	6	e
" second journey	2	6	e
Sierra Leone	2	-	d
Zimbabwe	6	4	e
Malagassy Republic, Southern area	3	8	e

References:
a, [24]; b, [25]; c, [26]; d, [18]; e, [2] and [3]

Discussion

The apparent absence of resurrection plants from granitic domes over a wide area (Qena-Aswan) is the most interesting aspect of the data. It stands in marked contrast to the almost invariable occurrence of one or more desiccation tolerant species on similar rock substrate and topography on granitic rock domes in areas of southern Africa and west Africa [1,7]. Frequently there are several species of desiccation tolerant vascular plants on one outcrop and plants of some species are abundant in situations where sufficient soil collects on the rock surface. The collecting trip in Egypt was similar in intensity and duration to many other such studies undertaken by one of the authors (DFG) in which 3 to 17 novel desiccation tolerant vascular plant species per study (Table 1); the study of the Aswan-Qena region would be expected to find resurrection plants, should they occur in the area.

The causes of the absence of desiccation tolerant vascular plants in the Aswan Qena region are not obvious. Resurrection plants are common on granitic inselbergs in the hinter-Namib Desert at similar latitudes south of the equator in Africa to Aswan's latitude north (close to the tropic of cancer). *Tripogon major*, a grass which is desiccation tolerant in Sierra Leone, also grows in the Tibesti Mountains, only five degrees lower in latitude in the Sahara Desert [16]. Also three known resurrection plants are listed on the checklist of Saudi Arabian grasses [17]: *Microchloa kunthii* Desv. from Jabal Sooda, *Oropetium thomaeum* (L.fil.) Trin. and *Poa bulbosa* L. (without further location details). These species were reported to be desiccation tolerant [2,18]. Moreover, resurrection plants are predominantly subtropical and tropical. High solar irradiance at these latitudes would not be a problem for the resurrection angiosperms (though resurrection ferns often require partial shade).

Excessive dryness of leaf tissue cannot be responsible for absence of resurrection plants. Approximately 50% of resurrection species survive equilibration to air of 0% relative humidity (RH), the theoretical optimum desiccation tolerance, and a value safely below the 13% and 22%RH lowest mean monthly RH values recorded at Aswan and Luxor (between Qena and Aswan, Tables 2 & 3).

Summer temperatures in the Aswan-Qena area are high: June, July, August mean (monthly) maximum temperatures were 41.8 to 41.0°C (1961-1975) at Aswan and 40.6 to 41.1°C (1948-1975) at Luxor (Tables 2 & 3). These temperatures would be no threat to the survival of tropical resurrection species, even allowing for higher temperatures on rock outcrops.

Higher rock temperatures in excess of the air temperature absolute record maxima, 46.8 to 49.3°C at Aswan and 47.0 to 48.5°C at Luxor, conceivably might approach injurious levels for tropical plants, but such air temperatures of course occur rarely.

It is unlikely that propagules of desiccation tolerant plants have not reached the area. Spores of resurrection ferns are likely to be carried by southerly winds from occurrences of species in the south and by northerlies from Sinai (*Ceterach officinarum* DC.). Fern genera, in which all species examined to date have desiccation tolerant vegetative tissue, have been collected from Sinai, from hills in the extreme south east of Egypt and the Sudan: *Cheilanthes catanensis* (Cosent.) H.P.Fuchs, and *Cheilanthes fragrans* (L.fil.) Swartz, which are probably a desiccation tolerant ferns, grow in the Sinai peninsular [9]; *Actiniopteris australis* (L.fil.) Link., *Cheilanthes coriacea* Dcne. and a *Notholeana* sp., all probably desiccation tolerant, have been collected from Gebel Elba (south east Egypt) and the Sudan (herbarium specimens, Cairo University Herbarium).

Unfortunately our collecting itinerary could not include these areas. Although seeds are less likely to be wind-borne over such long distances as spores, resurrection grass seeds are minute (less than 1mm long); this is probably an adaptation to long-distance dispersal between the disjunct locations which they inhabit. Species of *Tripogon*, a genus of grasses in which all examined species are desiccation tolerant, occur in Ethiopia, an elevated area which is well situated for dispersal routes to Egypt.

Absence of resurrection plants from the Aswan-Qena area is probably a result of the extremely long periods between rainfall events sufficient to re-activate resurrection plants (Tables 2 & 3). In general, 10mm precipitation is needed to fully rehydrate most of the resurrection plants in an area [3]. In Aswan, the highest total monthly rainfall (average 1960 - 1975) was only 0.5mm (April). The highest single rainfall events were 7.2mm (16.4.1968), 1.4mm (23.11.1966), 1.0 mm (21.12.1962), and 0.7mm (16.3.1974). Only one of these events in the 15 year period would have been sufficient to rehydrate resurrection plants on sites favourable for receiving run-off. The precipitation in Luxor was similar: only 3 months register a recordable total rain (average for 1948 to 1975), 0.3mm for May, 0.2mm for April and 0.1mm for January. The highest single rainfall events in this period were: 5.8mm (10.5.1949), 3.6mm (21.2.1975) and 2.0mm (10.1.1965).

The dry periods between significant rainfall events at these localities then are longer than resurrection plants are likely to endure in a dry anabiotic state. Air-dry leaves of one third of the species tested [3] survived 3 years anabiosis, under laboratory conditions (c. 20C, c. 30-40% relative humidity), but less than 10% survived five years.

Endurance times are longer at low humidity than at humidities above 50%RH [3]; annual mean humidities of 35%RH at Luxor and 22%RH at Aswan would be conducive to long survival. Conversely, endurance times under anabiosis decrease with increasing temperature [19]; high annual mean temperatures, 24.5°C at Luxor and 25.9°C at Aswan probably counteract the benefit of the low humidity, so that the laboratory values of less than 5 years for most species are probably applicable to these field conditions.

Some records of long longevity in air-dry cells have been reported. An herbarium specimen of the American resurrection fern-ally *Selaginella lepidophylla* (Hook. & Grev.) Spring. recovered on rehydration after 11 years in a Swedish herbarium [20]; low average temperatures which would probably prevail in the Swedish herbarium in this era, would encourage longer endurance by air-dry desiccation tolerant plants than would the high temperatures of Aswan.

Even greater longevity was recently reported for herbarium material of the liverwort *Riccia macrocarpa* Lev., cells of which were alive after 25 years dry storage [21]; however only the apical cell of thalli survived. Under Egyptian conditions, the one rainfall event in 15 years at Aswan and the absence of sufficient rain events in 27 years at Luxor indicates dry spells that exceeded the time for which resurrection plants can endure air-dryness.

The longevity of air-dry resurrection plant leaves in general appears to be shorter than the longevity of many air-dry angiosperm embryos, where some seed species remain viable for many decades or, in extreme cases, for even centuries. The basis for this distinction is not clear. It has been found that the disaccharide trehalose is far more effective in promoting stability of air-dry proteins than are other sugars [22]. Possibly genetic manipulation of resurrection plants to increase their trehalose content may improve the longevity of their air-dry tissue [23].

The climate at El Tor on the coast of the Sinai Peninsular, though arid, is less so than Aswan; at least six rain storms sufficient to rehydrate resurrections plants have been recorded in 48 years. Climatic data are not available for St Catherine's at Mt. Sinai, a recorded habitat for a putative resurrection fern *Cheilanthes catanensis*. Presumably the climate in this higher mountain area is less arid; dry spells between rain falls are probably less there than the 5 year endurance period of resurrection plants.

If this interpretation of the data is correct, the central and southern area would not be suitable for introduction of resurrection grasses for dryland pasture or soil stabilisation. However, these species might be useful where irrigation could be provided intermittently, but continuous supply of water could not be guaranteed. Further search allover the country should be conducted.

Table 2. Climatic Data for ASWAN for the Period 1960-1975 (Data provided by the Minister of Civil Aviation and Meteorological Authority, Cairo, 1979)
Tr. = Traces

Month	Relative Humidity (%)	Temperature (°C)					Rainfall (mm)		
		Mean of Day	Max.	Min.	Absolute Records		Total	Max. in one Day	Date
					Max.	Date			
January	35	15.5	23.5	8.1	36.5	15/1960	Tr.	Tr.	10/1971
February	26	17.8	26.2	9.6	39.0	21/1973	Tr.	Tr.	20/1975
March	18	22.0	30.5	13.0	43.2	24/1962	Tr.	0.7	16/1974
April	14	26.9	35.3	17.9	45.1	16/1974	0.5	7.2	16/1968
May	13	30.5	38.7	21.4	48.3	22/1970	Tr.	Tr.	{4/1963 {19/1974
June	13	33.4	41.8	24.3	49.3	9/1961	0.0	0.0	-
July	16	33.5	41.1	24.8	46.8	30/1973	0.0	0.0	-
August	18	33.3	41.0	24.8	48.3	12/1962	Tr.	Tr.	7/1962
September	20	31.1	39.5	22.6	46.7	29/1963	0.0	0.0	-
October	22	27.9	36.4	19.6	44.8	1/1963	Tr.	0.3	5/1973
November	33	21.8	29.8	14.6	39.3	6/1962	0.0	1.4	23/1966
December	37	17.0	25.0	9.7	37.0	26/1960	0.1	1.0	21/1962
Total	-	-	-	-	-	-	0.7	-	-
Annual Mean	22	25.9	34.1	17.4	-	-	-	-	-

Table 3. Climatic Data for LUXOR for the Period 1948 -- 1975 ((Data provided by the Minister of Civil Aviation and Meteorological Authority, Cairo). Tr. = Traces, RH = Relative Humidity.

Month	RH%	Temperature (°C)					Rainfall (mm)		
		Mean of Day	Max.	Min.	Absolute Records		Total	Max. in one Day	Date
					Max.	Date			
January	52	14.0	23.0	5.4	32.5	16/1960	0.1	2.0	10/1965
February	42	16.0	25.5	7.0	38.5	21/1973	0.2	3.6	21/1975
March	34	20.2	29.5	10.6	42.2	26/1962	Tr.	1.6	16/1974
April	26	26.0	34.8	15.7	46.3	18/1958	Tr.	0.3	15/1966
May	22	30.0	38.7	20.0	48.3	20/1970	0.3	5.8	10/1949
June	23	32.4	41.1	23.0	48.5	10/1961	0.0	0.0	-
July	26	32.9	40.6	23.6	48.3	25/1956	0.0	0.0	-
August	27	32.5	40.7	23.4	47.0	13/1956	Tr.	1.0	30/1969
September	32	30.0	38.6	21.5	46.0	24/1969	Tr.	Tr.	30/1965
October	40	25.4	35.3	17.5	43.4	8/1957	Tr.	1.0	1/1965
November	47	20.0	29.6	12.1	38.0	2/1959	Tr.	1.0	{27/1957 {17/1964
December	53	15.0	24.6	7.2	35.2	7/1952	Tr.	1.0	21/1954
Total	-	-	-	-	-	-	0.6	-	-
Annual Mean	35	24.5	33.5	15.6	-	-	-	-	-

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