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# NURSE ASSOCIATION OF THE STEM SUCCULENT *Caralluma acutangula* IN ITS NATURAL HABITAT

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Abstract

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The leafless perennial *Caralluma acutangula* is an abundant stem succulent in the arid desert of southern Saudi Arabia. The plant shows a tendency to associate with other plants growing at the study site. Work carried out to reveal the nature of this nurse association indicated that *C. acutangula* tends to associate with the shade provided by other plants, regardless of the plant species it associates with. Moreover, exposed *C. acutangula* plants growing without nurse association tend to develop stem lobes with deeply angled edges that increase turbulent airflow and increase convective heat capacity. These exposed plants also tend to develop narrower pitted xylem vessels per unit root area to decrease xylem vessel vulnerability to embolism. Results collectively indicated that *C. acutangula* nurse association with other plants is due to enhanced seedling establishment in shaded places, where moisture and protection from heat and high irradiance are available. Results are discussed in terms of the subtle balance that this succulent species keeps between biotic and abiotic nurse association.

*Key words*: *Caralluma acutangula*, nurse association

## Introduction

Arid deserts of southern Saudi Arabia are characterized by high temperature, high irradiance, scarce water and erratic rainfall. The study site at Jazan Province southwest of Saudi Arabia (17°19' N–42°48' E) is characterized by silt-loam soil and a climate influenced by the tropical maritime air mass (Brown, Jackson, 1979; Fisher, Membery, 1998). Among the stem succulents which inhabit this site, *Caralluma acutangula* (D e c n e.) N.E.Br. (Asclepiadaceae) is an abundant species (Collenette, 1999). Desert succulents generally tend to associate with a nurse plant (Joel, Enrique, 2003; Méndez et al., 2004; Suzán-Azpiri, Sosa, 2006; Ren et al., 2008), and our field observations indicated that although few individuals of *C. acutangula* grow in exposed places, most plants show a remarkable tendency to associate with other plant species growing at this site. This nurse association is documented by the occurrence of *C. acutangula* under canopies of *Acacia ehrenbergiana* and *A. tortilis* and around other plants such as *Aloe officinalis* and *Euphorbia triaculeata*. Although water availability is the most important factor influencing plant distribution in arid regions (Bowers et al., 2004; Pueyo et al., 2008), desert succulents are thought to associate with a nurse plant where nutrients are available due to the high organic matter and the high rate of litter decomposition (Valiente-Banuet et al., 1991a, b; Joel, Enrique, 2003; Méndez et al., 2004; Suzán-Azpiri, Sosa, 2006; Ren et al., 2008). Moreover, some desert succulents exhibit an abiotic nurse association with rocks that were found to hold water for a long period after rain (Nobel et al., 1992) and which provide a moist micro-environment suitable for seedling establishment (Peters et al., 2008). Therefore, the nurse association can be biotic as in the case of a nurse plant or abiotic as seen above in the case of rocks. Work presented in this paper was conducted to evaluate the importance of biotic versus abiotic nurse associations, to assess the importance of this nurse association for desert succulents, to investigate the nature of the association of *Caralluma acutangula* with other plant species at the study site and the influence this association has on survival of this species in its natural habitat.

## Material and methods

Records of air temperature and rainfall at the study site from the past 40 years (1967–2008) were kindly presented by the Ministry of Electricity and Water (Riyadh, KSA). The association of *C. acutangula* with other plant species growing at this site and also with shade was assessed by determining the frequency of occurrence (F), Chi square ( $\chi^2$ ), and standardized residuals (SR) (Kent, Coker, 1992; López et al., 2007). Fifty quadrates of 100m$^2$ were set in the field and the following equations were applied:

F = (Number of quadrates with the species / total number of quadrates) X 100

SR = O – E / √E,

where O = observed values, E = values expected from the contingency table and single factor. ANOVA and least significant differences were used to determine the significance of association.

The surface:volume ratio (S/V) was determined as in Mauseth (2000), using the equation

$S/V = 2N\sqrt{[H^2 + (\pi r / N)^2]}\ \pi r H$,

where N = number of stem ribs, H = depth of stem rib, r = stem radius.

Stem sections were prepared and the ratio area of chlorenchyma:area of stem ($A^{Chl}/A$) was determined, as in Arlyusheva et al. (2003) and Nobel (2009), using the equation

the area of chlorenchyma cell surface = $(\pi / 2)(2L + d)\, d$,

where L and d are the cell length and width, respectively.

The convection coefficient was determined (Gottschlich, Smith, 1982) using the equation

convection coefficient = $11.3\,(V / D)^{0.5}$,

where V = wind speed (measured using anemometer, Kestrel 2000, Boothwyn, Philadelphia, USA), D = ratio of the shortest extension of stem lobes divided by their longest extension.

Root sections were also prepared and the root xylem vessel lignifications were microscopically examined. Root xylem vessels vulnerability to embolism described herein as xylem vulnerability index was determined as the mean diameter of xylem vessels divided by the number of vessels per unit area (Carlquist, 1977). All experiments were carried out during the dry season and were replicated (n = 10), and the standard deviation was calculated.

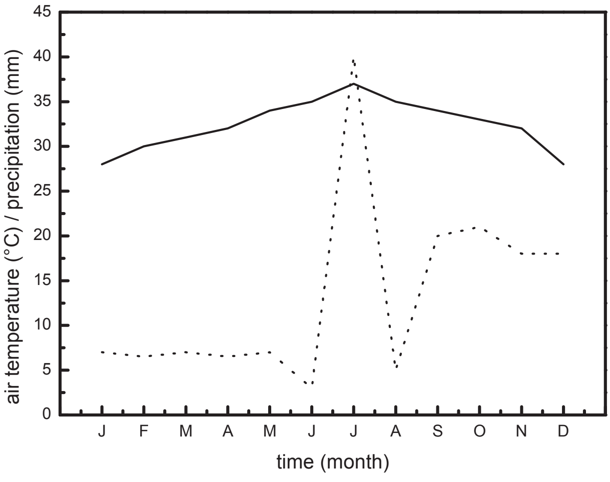


Fig. 1. Records of 40 years (1967–2008) of air temperature and precipitation at the study site (Curtsey of the Ministry of Electricity and water, Riyadh, KSA).

## Results

Climatic records from the past 40 years indicated that the mean maximum air temperature was 31.5 °C (Fig. 1). However, it is notable that the midday air temperature may remain in the range 45–50 °C for quite long periods during the hot summer months of June to August. Taking into account the total annual precipitation of 60 mm, the study site can be described as extremely arid. However, this is a unique ecotone with diverse plant cover that includes several phanerophytes represented principally by the genus *Acacia* (e.g. *A. ehrenbergiana, A. tortilis*). In addition to the *Caralluma acutangula* dominant stem succulent study plant, this site is also rich in succulent members of the families Asclepiadaceae (e.g. *Duvalia velutina*), Euphorbiaceae (e.g. *Euphorbia triaculeata*) and Aloaceae (e.g. *Aloe officinalis*).

Field observations indicated that although few individuals of *Caralluma acutangula* occurred in exposed places, these plants generally tended to associate with other plant species growing at this study site. Assessment of this association using frequency of occurrence, Chi square, and standardized residuals revealed a lack of significant association of *C. acutangula* with any particular plant species growing at this study site (Table 1). However, determination of frequency of occurrence of *C. acutangula* in relation to the availability of shade indicated that this plant occurred more frequently in places where ample amounts of shade were available (Table 1).

The study plant *C. acutangula* has a characteristically lobed stem and an S/V ratio of 0.56 (Table 2). Results indicated that no significant S/V differences occurred between exposed *C. acutangula* plants and those which had a nurse association (Table 2). Moreover, although these plants had a remarkably high $A^{Chl}/A$ value, no significant differences were observed

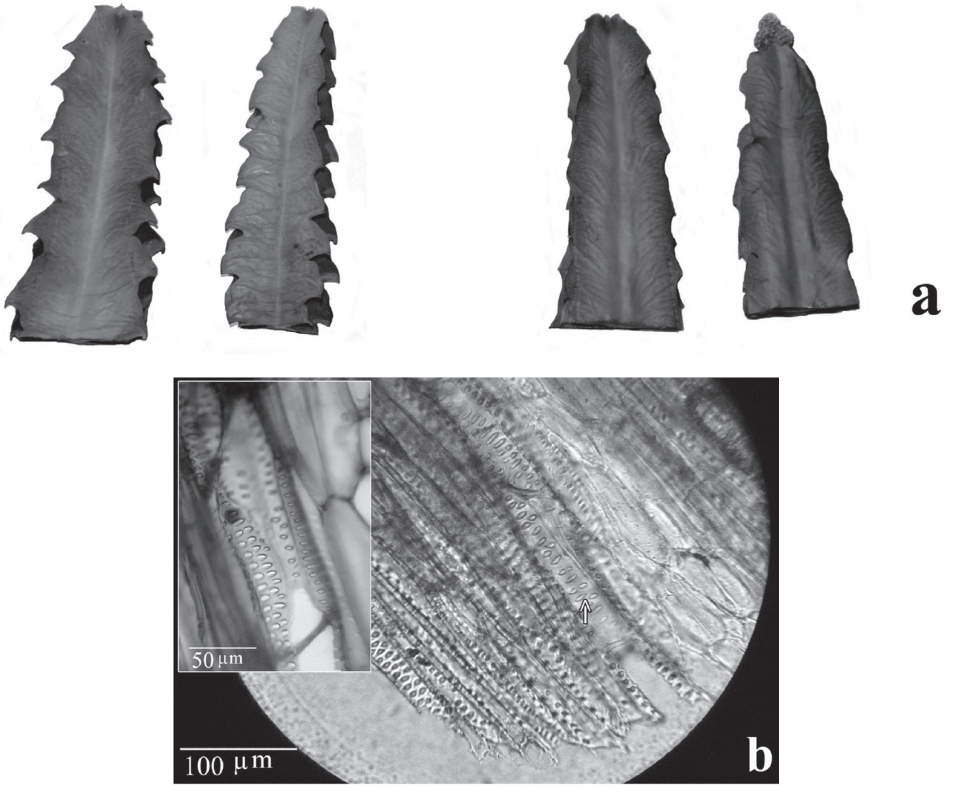


Fig. 2. Stem edges of *C. acutangula* growing without nurse association (left) and with nurse association (right) (a), and root pitted xylem vessel lignifications (b).

between exposed plants and those with a nurse association (Table 1). The results, however, indicated that *C. acutangula* exposed plants had a significantly high convection coefficient compared with those with nurse association (Table 2). These exposed individuals had more deeply angled stem edges compared to individuals with nurse association (Fig. 2a). The

Table 1. Frequency of occurrence (F), Chi square ( $\chi^2$ ), and standardized residuals (SR) as measures for assessment of *C. acutangula* with plant species growing at the study site and with shade. (NS = non-significant, S = significant, n = 10).

| Species/Site | F (%) | $\chi^2$ | SR | Significance |
|---|---|---|---|---|
| *Acacia tortilis* | 78 | 0.002 | -0.093 | NS |
| *Acacia ehrenbergiana* | 24 | 3.020 | -0.730 | NS |
| *Aloe officinalis* | 28 | 0.174 | 0.280 | NS |
| *Euphorbia triaculaeata* | 8 | 0.074 | -0.140 | NS |
| Exposed site | 5 | - | - | NS |
| Shaded site | 82 | - | - | S |

T a b l e 2. Morpho-anatomical features of *C. acutangula* in relation to nurse association in its natural habitat (± SD, n = 5).

| Features | - Nurse plant | + Nurse plant |
|---|---|---|
| S/V | 0.56 ± 0.1 | 0.48 ± 0.1 |
| $A^{Chl}/A$ | 280 ± 28 | 226 ± 21 |
| Convection Coefficient (Cal $m^{-2}$ $min^{-1}$ $K^{-1}$) | 28.3 ± 2.2 | 17.9 ± 0.7 |
| Xylem Vulnerability Index | 0.14 ± 0.02 | 0.30 ± 0.05 |

root xylem vessels of *C. acutangula* with pitted lignifications (Fig. 2b) had a vulnerability index which was significantly low for exposed plants compared with those with nurse association (Table 2).

## Discussion

Although water availability is the most important factor influencing plant distribution in arid regions (Bowers et al., 2004; Pueyo et al., 2008), desert succulents tend to associate with a nurse plant where nutrients are more available (Joel, Enrique, 2003; Méndez et al., 2004; Suzán-Azpiri, Sosa, 2006; Ren et al., 2008). Of these nutrients, nitrogen is considered to be abundant in soil under canopies of desert phanerophytes of the genus *Acacia* (Abolfatih, Hashish, 1995; Reyes-Olivas et al., 2002). Establishment of succulent seedlings under canopies of desert phanerophytes, known as biotic nurse association, was also attributed to high soil organic matter due to moisture and a high litter decomposition rate (Valiente-Banuet et al., 1991a, b). Work conducted to reveal the nature of the association of *Caralluma acutangula* with plants at the study site indicated a lack of significant association with *Acacia ehrenbergiana* and *A. tortilis* (Table 1). This denoted that nitrogen availability in soil was not perhaps the exclusive reason for the association of *Caralluma acutangula* and members of the genus *Acacia*. Moreover, results indicated a lack of significant association of *Caralluma acutangula* with *Acacia officinalis* and *Euphorbia triaculeata* (Table 1) indicating that *Caralluma acutangula* showed no preference for association with any particular succulent plant at this study site. The frequency of occurrence was therefore used to assess the association of *C. acutangula* with the availability of shade, and here results indicated that *C. acutangula* tended to associate more frequently with shaded places than with exposed places (Table 1). Collectively, these results have indicated that *C. acutangula* had no tendency to associate with particular plant species, and that its biotic nurse association with plants at this study site was rather an association with the shade provided by these plants. Similar results have previously been reported for the association of some cacti with shade (Valiente-Banuet, Ezcurra, 1991; Valiente-Banuet et al., 1991a, b). Moreover, some desert succulents exhibit abiotic nurse associations with rocks which can hold moisture for long periods after rain (Nobel et al., 1992) and thus provide a moist micro-environment suitable for seedling establishment

(Peters et al., 2008). It can be concluded therefore that *C. acutangula* nurse association with other plant species at this study site is perhaps due to enhanced seedling establishment in shaded places, due not only to the water and nutrient availability but also to the protection from heat and high irradiance. These results also reflect the subtle balance that this desert succulent maintains between biotic and abiotic nurse associations.

Furthermore, arido-active succulents survive long periods of drought due to a complex array of morpho-anatomical traits which enable them to tolerate inimical conditions prevailing in their natural habitats (Sayed, 2001). The stem succulent *C. acutangula* has a 4-lobed stem and a very low S/V (Fig. 2). The lack of differences in S/V of *C. acutangula* growing in exposed places and in association with other plants during the dry season denotes an enhanced plant water economy. Previous reports have shown that lobed stems result in a low S/V and contribute to enhanced water economy of stem succulents (Nobel, 1988; Gibson, 1996). Moreover, a value of $A^{Chl}/A$ in the range of 20–50 was reported for xerophytes, and higher values in the range of 80–150 have been reported for some species of agaves and cacti (Nobel, 1988, 2009). *C. acutangula,* however, possesses a peripheral sub-epidermal photosynthetic chlorenchyma with a remarkably high value of $A^{Chl}/A$ of 280 (Table 2). This high $A^{Chl}/A$ is photosynthetically beneficial because it increases $CO_2$ diffusion by reducing the resistance for $CO_2$ liquid-phase conductance (Evans, 1999; Nobel, 2009).

Results herein have also indicated that *C. acutangula* plants growing in exposed places exhibited a higher convection coefficient than plants with a nurse association (Table 2). Succulent stems with low S/V ratio normally have a high heat capacity and a thick boundary layer compared to non-succulent leaves with high S/V ratio (Roth-Nebelsick, 2001). Differences in the convection coefficient for exposed individuals and those with nurse association was most likely due to the deeply angled edges of the stem lobes observed in exposed individuals (Fig. 2). Stem lobes with deeply angled edges are thought to act as cooling fins which increase turbulent air flow around succulent stems, resulting in increased convective heat loss (Gottschlich, Smith, 1982; Grace, 1997; Mauseth, 2000). Moreover, root xylem vessels in *C. acutangula* had pitted lignifications (Fig. 2) and a low vulnerability index (Table 2). Pitted xylem vessel lignifications and simple pit plates decrease the plant's vulnerability to embolism due to a decreased resistance to water flow and increased inter-vessel water transport (Ewers et al., 1992; Evert, 2006). It can be concluded therefore that *C. acutangula* plants growing without nurse association are exposed to the harsh environmental conditions of heat and drought more than those plants with nurse association. These exposed plants tend to develop stem lobes with deeply angled edges to increase turbulent airflow and increase convective heat capacity, and also to develop numerous narrow pitted xylem vessels per unit root area to decrease the root xylem's vulnerability to embolism. It can also be concluded that the *C. acutangula* nurse association with shade provided by other plants growing at this study site is a protective strategy against drought and the dangers of embolism.

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