

## POPULATION DYNAMICS AND REPRODUCTIVE PERFORMANCE OF THE GREY-LEAVED CORDIA (*CORDIA SINENSIS* LAM.) IN EGYPT

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**Abstract.** The present study addressed the population dynamics of the grey-leaved *Cordia sinensis* to evaluate its status and contribute to the understanding of the demographic behaviour and reproductive performance of this important semi-desert tree. Twenty permanent quadrats (25 × 25 m) were visited seasonally to investigate the variations in *C. sinensis* population in 5 different habitats (desert, fallow land, cultivated plots, roadsides, and ruderal areas) in Kharga Oasis, Egypt to estimate its phenology, vegetative and reproductive characteristics. The seedling and vegetative phases attained their highest activity during winter, while flowering during spring and fruiting during summer. The highest plants (H) and largest diameter at breast height (D), size index, and tree volume were recorded in autumn, while the highest H/D ratio was recorded during winter. Two size distributions were recognized all over the year: positive skewed distribution in winter and bell shape distribution in autumn, summer and spring. The highest number of new branches was recorded during autumn, while the maximum number of dead branches was recorded in summer. The highest number of branches and leaves were recorded in cultivated plots. The sub-branches produced the highest number of inflorescences, flowers, and fruits during spring, associated with the highest reproductive success. *C. sinensis* had the longest and widest fruits as well as the highest fresh and dry weights in the ruderal areas characterized with the highest number of seeds and aborted embryos. The present study provides baseline information on *C. sinensis*, which could help in putting a valuable management plan for monitoring and controlling this plant.

**Keywords:** demography, size structure, Kharga Oasis, habitats, reproduction

### Introduction

*Cordia sinensis* (grey-leaved cordia) belongs to *Boraginaceae* and is a popular indigenous multipurpose tree species valued for fodder, fruit, structural timber, and fuel wood (Ndung'u, 2018; El-Massry et al., 2021). It grows in the Middle East, Pakistan, India, Sri Lanka and in Africa from West Africa to Ethiopia, Somalia, Sudan, Egypt, south to Namibia and north-east South Africa (Warfa, 1990; Eltayeb and Ishag, 2015). The IUCN Red List of Threatened Species most recently listed *C. sinensis* as Least Concern in 2020 (Shaltout and Bedair, 2022). In Egypt, this species is only known from gardens, and in Palestine and Yemen there seem to be only cultivated or naturalized stands. Production of seedlings is through seeds (Ndung'u, 2018). It grows mainly on clay or clay-sand or other alluvial soils at altitudes up to 1240 m above sea level. *C. sinensis* may also grow on rocky hillsides, in crevices of limestone cliffs, or along wadis in more arid areas (Warfa, 1990). It varies considerably in size, dentations, and indumentums of the leaves. Much of this variation seems to be environmentally conditioned, but there are

also some regional trends (Warfa, 1990). It is a prized species offering most of the characteristics generally sought for the trees for multipurpose use such as timber, medicine and fuel (Kale and Bhale, 2022; Shaltout and Bedair, 2022). These characteristics include coppicing readily after pruning and pollarding, fast growth, its large fruit, twigs, and leaves makes fodder for goats, cattle, and sheep (Maua et al., 2004). *C. sinensis* bark is used medicinally to treat diarrhea, dysentery, worm infestation, inflammations, wounds, malaria, edema, and pulmonary diseases (Chen et al., 2023).

Semi-desert shrubs and trees are important elements, which can cope with high aridity and low nutrient availability due to many characteristics such as deep root systems, presence of thorns, and small leaves (Pugnaire et al., 1996; Galal, 2011). They play an important role in soil protection and stabilization, provide a source of animal forage and fuel for local inhabitants, and have medicinal and potential industrial values (Thalen, 1979). From the dynamics point of view, many shrubs and trees may be considered pioneer species; their high germinability, elevated growth rates during early stages and tolerance to high radiation levels allow them to colonize open spaces, thus providing microsites for the germination and establishment of many other species under their canopies (Valiente-Banuet and Ezcurra, 1991; Pugnaire et al., 1996). Therefore, shrubs and trees of semi-desert communities could be considered as keystone species on which many community and ecosystem processes depend (Galal, 2011). Many researchers emphasize the need for studying and understanding the population dynamics of key stone species to find the best way of managing and preserving them within or out of their natural habitat (Bekele, 2000).

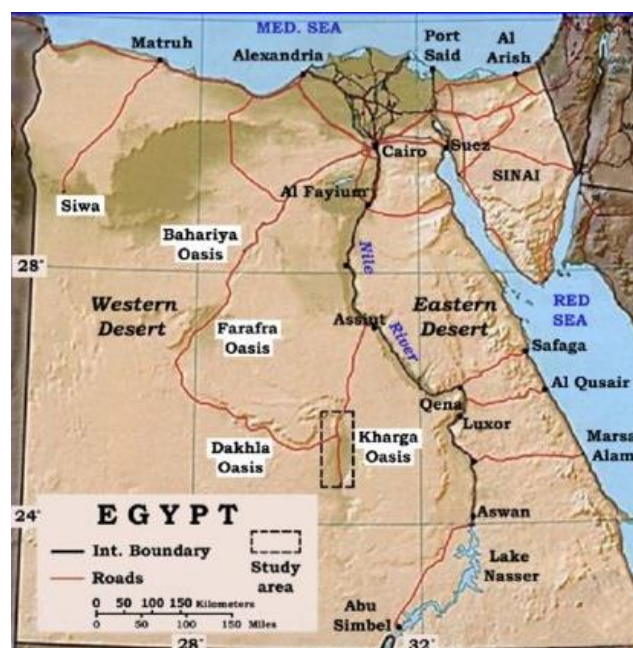
Plant demography provides useful information on population dynamics and can be used to examine the environmental factors affecting the plant population dynamics (Galal et al., 2016). The use of demographic information has been identified as the most valuable and cost-effective approach for endangered species recovery efforts (Maschinski et al., 1997). The information obtained through demographic studies could be used in restoration of degraded lands. In addition, the size variation is a feature of virtually all wild populations of plants (Weiner, 1990); this variation can result in a few large plants of one generation contributing disproportionately to the next, with a consequent reduction in effective population size and this may be attributed to fecundity, which is generally correlated with individual plant size (Galal, 2011). Survivorship and fecundity appear to be primarily determined by the size and the developmental stage of individuals within a plant population (Silvertown, 1981). Thus, the status of a plant population will be reflected by its density and size or stage structure. Size differences may be caused directly or through differences in growth rates due to age differences, genetic variation, resources heterogeneity and competition (Weiner, 1985; Galal et al., 2016).

Phenology is an important component of plant life history affecting both biotic (e.g., competition, herbivory, pollination) and abiotic constraints (e.g., frost, drought) on plant performance (Stanton et al., 2000; Farahat et al., 2015). Plasticity in phenology contributes to making a species dominant (Devineau, 1999). The study of plant phenology provides knowledge about the pattern of plant growth and development as well as the effects of environment and selective pressures on flowering and fruiting behavior (Zhang et al., 2006). In this study we address the population dynamics of the grey-leaved *Cordia sinensis* to evaluate its current status and contribute to the understanding of the demographic behaviour and reproductive performance of this important semi-desert tree.

## Materials and Methods

### Plant sampling

Kharga Oasis lies about 200 Km west of the Nile between latitudes  $24^{\circ} 30' \text{ N}$  -  $26^{\circ} 00' \text{ N}$  and longitudes  $30^{\circ} 27' \text{ E}$  -  $30^{\circ} 47' \text{ E}$  (Fig. 1). The extreme length of Kharga depression is about 200 km, while its width varies from 20 to 80 km with an area of 7200 km<sup>2</sup>. The prevailing climate indicated that the study area lies in a dry rainless part of the Great Sahara with average annual rainfall of 0.0042 mm year<sup>-1</sup>, while the mean annual temperature was 25.5 °C. Moreover, the mean annual relative humidity was 35.9 %, while the annual mean wind speed was 5.5 Km h<sup>-1</sup> (NASA-POWER, 2015). Twenty permanent quadrats (25 × 25 m) were visited seasonally from spring 2014 to winter 2015 to represent the variations of *C. sinensis* population in 5 different habitats (desert, fallow land, cultivated plots, roadsides, and ruderal areas) in Kharga Oasis.



**Figure 1.** Location map of Egypt showing Kharga Oasis

### Phenological aspects

The phenological spectrum of the basic life cycle stages was monitored for a year using 100 of the recorded individuals in the five study habitats. The main estimated phenophases were seedling, vegetative, flowering, fruiting, and withering.

### Vegetative properties

In each of the 20 quadrats, the number of individuals was counted to calculate plant density (number of individuals / unit area). Then 100 individuals were marked by colored spray to estimate certain growth variables such as the number of branches per each individual at the first time; and then three branches were marked for counting their sub-branches (newly formed and dead branches) and branch survival as the ratio between the number of sub-branches at the end of each season and the total number of branches. The number of leaves per sub-branch and average leaf length and width were also determined.

### ***Reproductive properties***

The number of inflorescences per each marked branch, in addition to the number of flowers and fruits per inflorescence were also determined. The fruit length, width and weight were determined in 50 fruits collected from each habitat. The reproductive success (fruit-set) for each individual was calculated as the ratio of the number of mature fruits to the number of flowers (El-Keblawy, 1987). Moreover, the seed characteristics including seed length, width, and weight were determined. Furthermore, the structure of mature fruits (the number of locules, seeds, aborted embryos, un-fertilized ovules and empty locules) were estimated in all habitats except the desert and fallow lands, which suffer from high tree mortality and under representative samples of mature fruits due to the high temperature and drought stress of these harsh habitats.

### ***Size-frequency distribution***

The ratio of height to diameter varies from one habitat to another; therefore, the estimation of both variables seems to be best for expressing the tree size (Shaltout and Ayyad, 1990). The height from the ground (H) and the average stem diameter (D) at breast height as well as the H/D ratio were estimated seasonally for each marked individual (Shaltout and Ayyad, 1988). The size index of each individual was calculated as the average of its height and diameter  $(H+D)/2$  (modified from Crisp and Lange, 1976). The absolute frequency of individuals and the mean height and diameter per individual in each size class were then calculated. The size estimations were then used to classify population into five size classes ( $< 2.0$ ,  $2.0 - 3.0$ ,  $3.0 - 4.0$ ,  $4.0 - 5.0$  and  $> 5.0$  m).

### ***Soil sampling and analysis***

Three composite soil samples from profile (0-50 cm) were collected from each stand. Soil texture was determined by using the sieve method and classified according to particles size into fine sand, silt, and clay. Moisture content was determined using aluminum pans (Allen, 1989). Soil extracts were prepared to meet the requirements for different determinants, 1:5 (w/v) soils (g): distilled water (ml). This extract was used to determine pH values using a glass electrode pH meter (Model 9107 BN, ORION type) and electrical conductivity (EC) with conductivity meter 60 Sensor Operating Instruction Corning. Bicarbonates were determined by titration against 0.1 N HCl using phenol phthalein and methyl orange as indicators. Chlorides were determined by direct titration against silver nitrate solution using 5% potassium chromate as an indicator. Sulphates were determined turbidimetrically as barium sulphate at 500 nm. Calcium and magnesium were determined by titration against 0.01N versenate solution using meroxide and erichrome black T as indicators. Sodium and potassium were determined using flame photometer (Allen, 1989). Heavy metals (Fe, Cu, Pb, Co and Cr) were determined using Pye Unicam Sp 1900 Recording Flame Atomic Absorption Spectrophotometry All these procedures are outlined by Allen (1989).

### ***Statistical analysis***

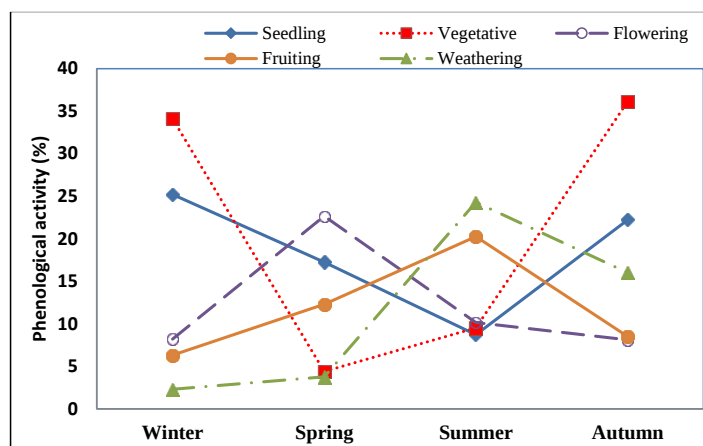
The statistical relationships between plant measurements were evaluated using the regression procedures. The simple linear correlation coefficient (r) was calculated for assessing the type of relationship between the spatial variations in the estimated tree height and diameter as well as leaf length and width. One -way ANOVA was applied to assess the significance of variations in the soil, and growth variables. Statistical analysis

was performed using SPSS software version 15.0 (SPSS, 2006). Duncan's multiple range tests as a post-hoc tests were assessed when there is a significant variation at probability 5 % and 1 %.

## Results

### Phenological aspects

The phenological behaviour of *C. sinensis* trees showed that seedling and vegetative phases attained their highest activity (31.5 and 36.1 %) during winter, while flowering (36.3 %) during spring and fruiting (32.1 %) during summer (Fig. 2). In addition, the plant suffered from weathering (43.3%) during summer. On the other hand, the lowest seedling activity was in summer, while vegetative in spring, fruiting and weathering during winter, and flowering during autumn.



**Figure 2.** Seasonal variation in the phenological activity of *Cordia sinensis* grown in Kharga Oasis

### Growth parameter measurements

The growth parameter measurements of *C. sinensis* showed that the highest plants (6.1 m) and largest diameter at breast height (0.62 m), size index (3.3 m) and tree volume (9.2 m<sup>3</sup>) were recorded in autumn, while the lowest values (5.6 m, 0.57 m, 3.1 m and 7.1 m<sup>3</sup>) were recorded during winter (Table 1). On the contrary, the H/D ratio had its highest value (10.5) during winter and its lowest (10.3) during autumn. Moreover, the height and diameter showed significant proportional correlations along the different seasons.

### Size –structure frequency distributions

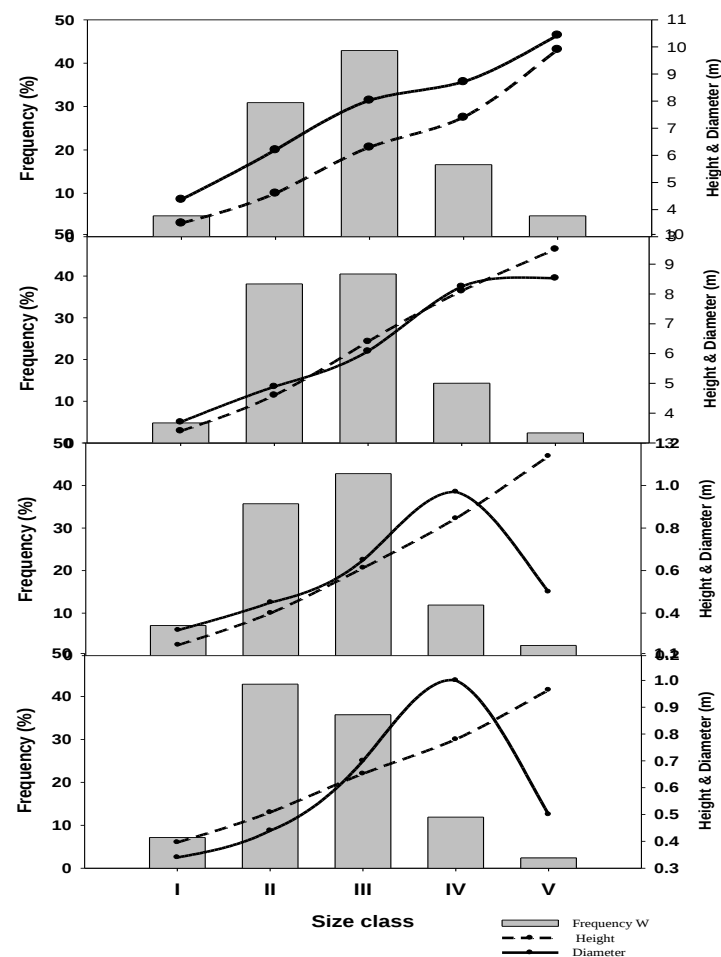
The diagrams illustrating the size–frequency distributions of *C. sinensis* populations (Fig. 3) indicated that two size distributions were recognized all over the year: a) positive skewed distribution in winter, and b) bell shape distribution in autumn, summer and spring. The smallest size distributions in winter, spring, summer and autumn contributed a range (78.5, 76.2, 75 and 65.5 % respectively) comparing with (21.5, 23.8, 25 and 35.8%, respectively) for the largest ones. On the other hand, the annual size-frequency

distribution (Fig. 4) indicated that the populations of *C. sinensis* had bell shaped distribution. In addition, the smallest three sizes contributed about 65.5 % of the total individuals compared with 34.5 % for the biggest ones.

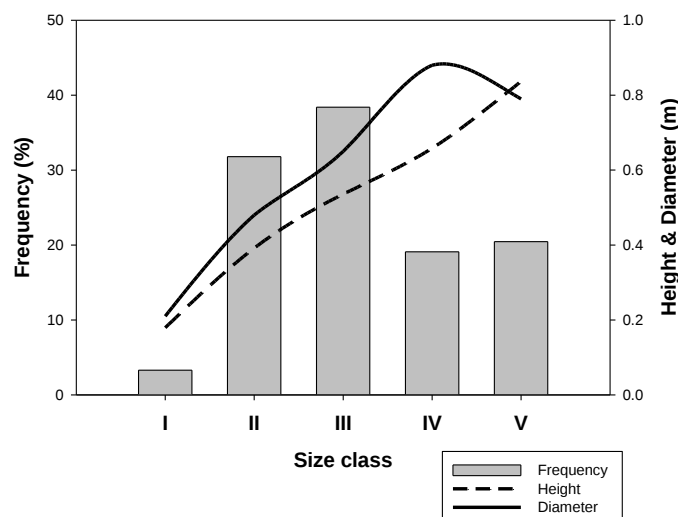
**Table 1.** Seasonal variation in the growth parameters (Mean  $\pm$  SD) of *Cordia sinensis*

| Season  | Character              |                         |                        |                |                       |                          |
|---------|------------------------|-------------------------|------------------------|----------------|-----------------------|--------------------------|
|         | H (m)                  | D (m)                   | H/D                    | r              | Size index (m)        | Volume (m <sup>3</sup> ) |
| Winter  | <u>5.6</u> $\pm$ 1.3b  | <u>0.57</u> $\pm$ 0.2b  | <u>10.5</u> $\pm$ 2.8a | 0.73**         | <u>3.1</u> $\pm$ 0.8a | <u>7.4</u> $\pm$ 1.6c    |
| Spring  | <u>5.8</u> $\pm$ 1.6ab | <u>0.59</u> $\pm$ 0.2ab | <u>10.4</u> $\pm$ 2.9a | 0.71**         | <u>3.2</u> $\pm$ 0.7a | <u>8.1</u> $\pm$ 1.4b    |
| Summer  | <u>5.9</u> $\pm$ 1.4a  | <u>0.60</u> $\pm$ 0.2ab | <u>10.4</u> $\pm$ 2.9a | 0.73**         | <u>3.2</u> $\pm$ 0.7a | <u>8.2</u> $\pm$ 1.3b    |
| Autumn  | <u>6.1</u> $\pm$ 1.4a  | <u>0.62</u> $\pm$ 0.2a  | <u>10.3</u> $\pm$ 2.6a | 0.73**         | <u>3.3</u> $\pm$ 0.6a | <u>9.2</u> $\pm$ 1.6a    |
| Average | <u>5.85</u> $\pm$ 1.4  | <u>0.6</u> $\pm$ 0.2    | <u>10.4</u> $\pm$ 2.8  | <u>0.73</u> ** | <u>3.2</u> $\pm$ 0.7  | <u>8.2</u> $\pm$ 1.4     |
| F-value | 2.4*                   | 2.1*                    | 1.2                    |                | 1.1                   | 4.2**                    |

Means in the column with the same letters are not significantly different among habitats. \*:  $p < 0.05$ , \*\*:  $p < 0.01$ . H: height; D: diameter, r: correlation coefficient between height and diameter. Maximum and minimum values are underlined



**Figure 3.** Seasonal variation in the size-class frequency distribution of *C. sinensis*. The different size classes are coded as follows: I: (< 2.0 m), II: (2.0 - 3.0 m), III: (3.0 - 4.0 m), IV: (4.0 - 5.0 m) and V: (> 5.0 m)



**Figure 4.** Annual average of size-class frequency distribution of *Cordia sinensis*. The different size classes are coded as follows: I (< 2.0 m); II (2.0 -3.0 m); III (3.0 - 4.0 m); IV (4.0 - 5.0 m) and V (> 5.0 m)

### Branch demography

The variation in the branch dynamics of *C. sinensis* tree, including newly formed and dead sub-branches showed that the highest number of new branches (9.5 = 40 % of the total branches) was recorded during autumn, while the lowest (2.5 = 18 %) was in winter (Table 2). On the other hand, the maximum number of dead branches (8.5 = 31.4 %) was recorded during summer, while the minimum (0.9 = 3.5) was during winter. It is worth to mention that the highest percentage of branch survival (55.8 %) was recorded during autumn, while the lowest (26.2 %) was in summer.

**Table 2.** Seasonal variation (Mean  $\pm$  SD) in the branch demography of *Cordia sinensis* grow in Kharga Oasis

| Season  | Branching                      |      |                                 |      | Branch survival<br>% |
|---------|--------------------------------|------|---------------------------------|------|----------------------|
|         | New sub-branches               | %    | Dead sub-branches               | %    |                      |
| Winter  | <u>2.5<math>\pm</math>0.2c</u> | 18.0 | <u>0.9<math>\pm</math>0.06d</u> | 3.5  | 45.6b                |
| Spring  | 4.4 $\pm$ 0.7bc                | 22.8 | 2.4 $\pm$ 0.4b                  | 17.1 | 28.1c                |
| Summer  | 6.5 $\pm$ 0.4b                 | 27.3 | <u>5.5<math>\pm</math>0.6a</u>  | 24.2 | <u>26.2c</u>         |
| Autumn  | <u>9.5<math>\pm</math>0.5a</u> | 40.0 | 1.6 $\pm$ 0.4c                  | 7.4  | <u>55.8a</u>         |
| Average | 6.9 $\pm$ 0.3                  | 26.3 | 3.1 $\pm$ 0.8                   | 15.5 | 35                   |
| F-value | 4.2**                          |      | 5.4**                           |      | 4.1**                |

Means in the column with the same letters are not significantly different among habitats. \*\*:  $p < 0.01$ . Maximum and minimum values are underlined

### Vegetative properties

The vegetative characteristics of *C. sinensis* from different habitats indicated a significant variation in the number of branches and leaves with the highest values (30.4 sub-branches/individual and 196.7 leaves/ sub-branch, respectively) were recorded in cultivated plots, while the lowest (15.2 sub-branches/individual and 81.6 leaves/sub-branch) in the desert habitat (Table 3). Moreover, the leaf length and width were

significantly correlated with the highest correlation coefficient ( $r = 0.83$ ) recorded in cultivated areas, while the lowest ( $r = 0.61$ ) in ruderal areas. The longest and widest leaves (11.0 and 3.9 cm) were recorded in ruderal plants, while the shortest and narrowest (4.2 and 1.6 cm) were attained in desert plants.

**Table 3.** Vegetative characteristics of *Cordia sinensis* in the different habitats of Kharga Oasis. The correlation coefficient ( $r$ ) is between the leaf length and width

| Vegetative character     | Habitat           |             |                    |             |                  | F- value |
|--------------------------|-------------------|-------------|--------------------|-------------|------------------|----------|
|                          | Desert            | Fallow land | Cultivated plots   | Roadsides   | Ruderal areas    |          |
| No. of sub-branches      | <u>15.2±0.5c</u>  | 16.5±0.7c   | <u>30.4±0.7a</u>   | 22.5±0.4b   | 26.3±0.5ab       | 13.6***  |
| No. of leaves/sub-branch | <u>81.6±20.2f</u> | 137.0±27.2d | <u>196.7±29.1a</u> | 152.1±29.9c | 179.2±30.4b      | 104.1*** |
| leaf length (cm)         | <u>4.2±0.7d</u>   | 4.9±0.9c    | 9.6±1.5b           | 10.7±0.9a   | <u>11.0±1.3a</u> | 400.9*** |
| leaf width (cm)          | <u>1.6±0.5d</u>   | 2.3±0.4c    | 3.3±0.6b           | 3.8±0.3a    | <u>3.9±0.5a</u>  | 223.9*** |
| Correlation Coefficient  | 0.63**            | 0.79**      | 0.83**             | 0.62**      | 0.61**           |          |

Means in the row with the same letters are not significantly different among habitats. \*\*:  $p < 0.01$  and \*\*\*:  $p < 0.001$ . Maximum and minimum values are underlined

On the other side, seasonal significant variation in the number of leaves, leaf length and leaf width were recognized (Table 4). It was found the highest number of leaves, as well as the longest and widest leaves (189.1 leaves/sub-branch, 9.6 cm and 3.1 cm, respectively) were recorded during autumn, while the lowest values (139.3 leaves/sub-branch, 7.6 cm and 2.8 cm) were recorded in summer.

**Table 4.** Seasonal variations (Mean± SD) in the leaf characteristics of *Cordia sinensis* including number of leaves branch<sup>-1</sup>, leaf length (cm), leaf width (cm) and the correlation coefficient ( $r$ ) between the leaf length and width

| Seasons     | No. of leaves/sub-branch | Leaf length cm  | Leaf width cm   | r      |
|-------------|--------------------------|-----------------|-----------------|--------|
| Winter      | 169.6±41.7b              | 9.2±3.3b        | 3.3±1.1ab       | 0.93** |
| Spring      | 144.4±39.6c              | 7.9±2.8c        | 2.9±0.9b        | 0.95** |
| Summer      | <u>139.3±40.3c</u>       | <u>7.6±2.9c</u> | <u>2.8±0.9b</u> | 0.93** |
| Autumn      | <u>189.1±44.9a</u>       | <u>9.6±3.1a</u> | <u>3.6±0.8a</u> | 0.88** |
| Annual mean | 154±41.3                 | 8.3±3.0         | 3.1±0.9         | 0.95** |
| F-value     | 2.1*                     | 2.4*            | 3.1*            |        |

Means in the column with the same letters are not significantly different among habitats. \*\*:  $p < 0.001$ . Maximum and minimum values are underlined

## Reproductive properties

The main characteristics of the reproductive organs as well as the reproductive success of *C. sinensis* indicated that the sub-branches carry inflorescences all over the year with the maximum number (22.2 inflorescence/sub-branch) in spring, while the minimum number (2.5 inflorescence/sub-branch) was recorded in winter (Table 5). Each inflorescence carries a number of flowers that attained their maximum (8.9 flowers/inflorescence) during spring and the minimum (3.2 flowers/inflorescence) in autumn. Moreover, the fruits that arise from marked flowers after fertilization process will be expressed as the reproductive success (i.e. flowers success in fertilization). Whereas fruits attained their maximum number (4.8 fruits/inflorescence) during spring

associated with the highest reproductive success (55.9 %), while the minimum (0.8 fruits/inflorescence) was in autumn with 25% reproductive success.

**Table 5.** Seasonal variation in the mean and standard deviation of number of inflorescence/branch, flowers and fruits, and the reproductive success (%) of *Cordia sinensis* from Kharga Oasis

| Season  | Inflorescence/sub-branch | Flower/inflorescence | Fruit/inflorescence | Reproductive success (%) |
|---------|--------------------------|----------------------|---------------------|--------------------------|
| Winter  | 2.5±1.6c                 | 5.0±0.1b             | 1.6±0.6c            | 32.0                     |
| Spring  | <u>22.2±0.9a</u>         | <u>8.9±0.2a</u>      | <u>4.8±0.8a</u>     | <u>55.9</u>              |
| Summer  | 12.2±1.1b                | 4.3±0.2bc            | 2.7±0.8b            | 57.2                     |
| Autumn  | 12.3±0.6b                | <u>3.2±0.1c</u>      | <u>0.8±0.3d</u>     | <u>25.0</u>              |
| F-value | 4.1**                    | 2.6*                 | 2.1*                | 2.7*                     |

Means in the column with the same letters are not significantly different among habitats. \*:  $p < 0.05$ , \*\*:  $p < 0.01$ . Maximum and minimum values are underlined

With respect to habitat variation, it was observed that there were significant differences in the mean length, width, fresh and dry weight of fruits among the different habitats (Table 6). *C. sinensis* had the longest and widest fruits (1.39 and 0.98 cm) as well as the highest fresh and dry weights (1.2 and 0.77 g) in the ruderal areas, while the minimum values (1.2 cm, 0.77 cm, 0.50 g and 0.41 g) were obtained in desert habitat. Moreover, *C. sinensis* seed length and weight showed significant variation among the different habitats. Seeds from ruderal area, cultivated plots, roadsides and fallow lands had 0.58 cm length, while those from desert had the lowest length 0.47 cm. However, the seeds from ruderal had the highest weight (0.09 g), while those from the desert had the lowest weight (0.07 g).

**Table 6.** Fruits and seeds characteristics (Mean ± SD) of *Cordia sinensis* in the different habitats of Kharga Oasis

| Habitat                       | Desert           | Fallow land | Cultivated plots | Roadsides  | Ruderal areas     | F- value |
|-------------------------------|------------------|-------------|------------------|------------|-------------------|----------|
| <b>Fruits characteristics</b> |                  |             |                  |            |                   |          |
| Length (cm)                   | 1.20±0.1c        | 1.27±0.1bc  | 1.35±0.1ab       | 1.25±0.1c  | <u>1.39±0.07a</u> | 6.54***  |
| Width (cm)                    | <u>0.77±0.1b</u> | 0.81±0.1b   | 0.84±0.1b        | 0.81±0.1b  | <u>0.98±0.1a</u>  | 5.9**    |
| Fresh weight (g)              | <u>0.50±0.2c</u> | 0.78±0.2b   | 1.20±0.06a       | 0.78±0.2b  | <u>1.22±0.3a</u>  | 41.6***  |
| Dry weight (g)                | <u>0.41±0.2b</u> | 0.43±0.2b   | 0.65±0.1a        | 0.58±0.09b | <u>0.77±0.04a</u> | 9.1***   |
| <b>Seed characteristics</b>   |                  |             |                  |            |                   |          |
| Length (cm)                   | 0.47±0.04b       | 0.58±0.04a  | 0.58±0.04a       | 0.58±0.2a  | 0.58±0.2a         | 2.1*     |
| Width (cm)                    | 0.30±0.04a       | 0.30±0.04a  | 0.34±0.05a       | 0.30±0.04a | 0.35±0.04a        | 0.32     |
| Weight (g)                    | 0.07±0.01c       | 0.083±0.01b | 0.086±0.01ab     | 0.08±0.01b | 0.09±0.01a        | 5.9**    |

Means in the row with the same letters are not significantly different among habitats. \*:  $p < 0.05$  \*\*:  $p < 0.01$  and \*\*\*:  $p < 0.001$ . Maximum and minimum values are underlined

The fruit structure of *C. sinensis* showed significant variation in the number of seeds, aborted embryos and unfertilized embryos, while no significant variation in the number of seed locules and empty locules per fruit among the different habitats (Table 7). The highest number of seeds (1.1 seed/fruit) and aborted embryos (0.7 embryo/fruit) were recorded in ruderal plants, while the lowest (0.5 seed/fruit and 0.3 aborted embryo/fruit)

were in roadsides. On the contrary, the unfertilized ovules had their highest number (1.2 ovule/fruit) in roadsides, while the lowest (0.7 ovule/fruit) in ruderal plants.

**Table 7.** Fruit structure (Mean  $\pm$  SE) of *Cordia sinensis* fruits from the different habitats of Kharga Oasis

| Fruit structure                  | Habitat                          |                                  |                                  | F- value |
|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------|
|                                  | Cultivated plots                 | Roadsides                        | Ruderal areas                    |          |
| No. of locules/fruit             | <u>2.60<math>\pm</math>0.1a</u>  | 2.40 $\pm$ 0.08a                 | 2.50 $\pm$ 0.09a                 | 1.1      |
| No. of seeds/fruit               | <u>1.10<math>\pm</math>0.1a</u>  | <u>0.58<math>\pm</math>0.08b</u> | 0.60 $\pm$ 0.08b                 | 8.9*     |
| No. of aborted embryos/fruit     | 0.30 $\pm$ 0.04b                 | 0.30 $\pm$ 0.07b                 | <u>0.70<math>\pm</math>0.09a</u> | 9.5*     |
| No. of unfertilized ovules/fruit | 0.92 $\pm$ 0.1b                  | <u>1.20<math>\pm</math>0.09a</u> | <u>0.70<math>\pm</math>0.08b</u> | 8.4*     |
| No. of empty locules/fruit       | <u>0.30<math>\pm</math>0.08a</u> | 0.40 $\pm$ 0.08a                 | <u>0.50<math>\pm</math>0.09a</u> | 1.7      |

Means in the row with the same letters are not significantly different among habitats. \*:  $p < 0.001$ . Maximum and minimum values are underlined

### Soil properties

The soil analysis showed significant variation in most investigated variables except organic matter (OM), SO<sub>4</sub>, Ca and Mg among the different habitats of *C. sinensis* (Table 8). The soil of the cultivated plots had the highest values of coarse sand, silt, moisture content and OM (11.1, 41.1, 16.1 and 0.5 %), but the lowest Mg, Cu and Fe (12.0, 0.2 and 2.3 mg/kg). In addition, the roadside soil had the highest fine sand and clay (63.0 and 15.9%), pH (8.3), Mg, K and Pb (27.5, 51.8 and 1.9 mg/kg). Moreover, the highest salinity (2.0  $\mu$ S/cm), Cl, SO<sub>4</sub>, Ca, Na, Cu and Fe (499.6, 254.4, 71.5, 323.8, 0.9 and 14.1 mg/kg) were recorded in the desert soils, that had the lowest contents of coarse sand (6.2%) and Pb (0.3 mg/kg). However, the ruderal soils had the lowest clay content (2.2 %), pH (7.8), salinity (0.9  $\mu$ S/cm), Ca, Na and K (36.7, 143.9, 19.9 and 0.5 mg/kg).

**Table 8.** Soil properties (mean $\pm$ SD) of the different habitats of *Cordia sinensis* in Kharga Oasis

| Variable                      |            | Habitat                          |                                |                                |                                 |                                  | F-value |
|-------------------------------|------------|----------------------------------|--------------------------------|--------------------------------|---------------------------------|----------------------------------|---------|
|                               |            | Desert                           | Fallow land                    | Cultivated plots               | Roadsides                       | Ruderal areas                    |         |
| Coarse sand                   | %          | <u>6.2<math>\pm</math>1.0</u>    | 6.3 $\pm$ 1.5                  | <u>11.1<math>\pm</math>0.7</u> | 7.5 $\pm$ 2.0                   | 7.6 $\pm$ 1.5                    | 6.2**   |
| Fine sand                     |            | 57.0 $\pm$ 1.9                   | <u>60.9<math>\pm</math>0.3</u> | <u>44.3<math>\pm</math>1.3</u> | 63.0 $\pm$ 3.4                  | 54.4 $\pm$ 4.9                   | 19.5*** |
| Silt                          |            | 33.7 $\pm$ 1.9                   | 29.2 $\pm$ 0.8                 | <u>41.1<math>\pm</math>0.1</u> | <u>13.6<math>\pm</math>3.4</u>  | 35.9 $\pm$ 7.0                   | 25.0*** |
| Clay                          |            | 3.1 $\pm$ 1.0                    | 3.7 $\pm$ 0.5                  | 3.5 $\pm$ 0.6                  | <u>15.9<math>\pm</math>1.9</u>  | <u>2.2<math>\pm</math>0.7</u>    | 87.5*** |
| Moisture content              |            | 10.9 $\pm$ 1.1                   | 12.0 $\pm$ 2.2                 | <u>16.1<math>\pm</math>2.8</u> | <u>10.4<math>\pm</math>1.9</u>  | 13.6 $\pm$ 1.5                   | 4.2*    |
| Organic matter                |            | 0.5 $\pm$ 0.1                    | <u>0.1<math>\pm</math>0.1</u>  | <u>0.6<math>\pm</math>0.2</u>  | 0.3 $\pm$ 0.1                   | 0.2 $\pm$ 0.1                    | 1.3     |
| pH                            |            | 7.9 $\pm$ 0.8                    | 7.9 $\pm$ 0.1                  | 7.9 $\pm$ 0.9                  | <u>8.3<math>\pm</math>0.3</u>   | <u>7.8<math>\pm</math>0.8</u>    | 23.3*** |
| EC                            | $\mu$ S/cm | <u>2.0<math>\pm</math>0.7</u>    | 1.2 $\pm$ 0.1                  | 1.8 $\pm$ 0.2                  | 1.7 $\pm$ 0.1                   | <u>0.9<math>\pm</math>0.1</u>    | 4.9*    |
| Cl <sup>-</sup>               | mg/kg      | <u>499.6<math>\pm</math>74.8</u> | 268.9 $\pm$ 15.1               | 459.1 $\pm$ 65.1               | <u>147.7<math>\pm</math>9.2</u> | 195.3 $\pm$ 17.8                 | 10.5**  |
| SO <sub>4</sub> <sup>2-</sup> |            | <u>254.4<math>\pm</math>11.4</u> | 173.5 $\pm$ 7.4                | 187.5 $\pm$ 35.5               | <u>148.4<math>\pm</math>9.7</u> | 152.6 $\pm$ 5.8                  | 2.1     |
| Ca <sup>++</sup>              |            | <u>71.5<math>\pm</math>28.5</u>  | 55.1 $\pm$ 4.9                 | 52.5 $\pm$ 9.5                 | 53.9 $\pm$ 1.3                  | <u>36.7<math>\pm</math>5.5</u>   | 2.4     |
| Mg <sup>++</sup>              |            | 26.6 $\pm$ 13.8                  | 15.9 $\pm$ 1.65                | <u>12.0<math>\pm</math>1.4</u> | <u>27.5<math>\pm</math>4.5</u>  | 15.0 $\pm$ 1.5                   | 2.3     |
| Na <sup>+</sup>               |            | <u>323.8<math>\pm</math>14.2</u> | 159.4 $\pm$ 31.2               | 295.3 $\pm$ 39.2               | 247.9 $\pm$ 23.5                | <u>143.9<math>\pm</math>20.1</u> | 7.2**   |
| K <sup>+</sup>                |            | 22.2 $\pm$ 2.3                   | 48.4 $\pm$ 29.6                | 31.9 $\pm$ 5.5                 | <u>51.8<math>\pm</math>1.9</u>  | <u>16.9<math>\pm</math>1.0</u>   | 3.9*    |
| Cu <sup>++</sup>              |            | 0.9 $\pm$ 0.2                    | <u>0.9<math>\pm</math>0.3</u>  | <u>0.2<math>\pm</math>0.1</u>  | 0.4 $\pm$ 0.2                   | 0.5 $\pm$ 0.1                    | 11.2**  |
| Fe <sup>++</sup>              |            | <u>14.1<math>\pm</math>3.9</u>   | 3.3 $\pm$ 0.9                  | <u>2.3<math>\pm</math>0.2</u>  | 5.7 $\pm$ 1.7                   | 4.5 $\pm$ 1.4                    | 13.7*** |
| Pb <sup>++</sup>              |            | <u>0.2<math>\pm</math>0.1</u>    | 0.3 $\pm$ 0.1                  | 0.4 $\pm$ 0.1                  | <u>1.9<math>\pm</math>0.4</u>   | 1.0 $\pm$ 0.2                    | 7.9**   |

\*,  $p < 0.05$ , \*\*,  $p < 0.01$ , \*\*\*,  $p < 0.001$ . Maximum and minimum values are underlined

## Discussion

Plant phenology is defined as the seasonal timing of environment-mediated events such as growth and reproduction (Rathcke and Lacey, 1985). It is expected to be one of the most sensitive and easily observable natural indicators of climate change (Badeck et al., 2004). The phenological behavior of *C. sinensis* indicated that the vegetative phase continued throughout the year in agreement with Parsons and Cuthbertson (2001); Lottermoser (2011) and Farahat et al. (2016), who indicated that the growing season of *C. procera* encompasses most of the year, as it is a perennial shrub. Moreover, the continuous flowering and fruiting observed for *C. sinensis* with the maximum activity during spring and summer, respectively coincides with that observed for *C. procera* in many countries in the world (e.g., Singh and Yadava, 1974; Eisikowitch, 1986; Abd El-Ghani, 1997; Sobrinho, 2013; Farahat et al., 2016). However, autumn and winter contributed the lowest flowering activity. Meanwhile it seems that high and low temperature reduced the flowering activity of the plant, and the highest flowering activity was during spring. Eid (2002) reported that perennial plants exhibited a slow growth rate in winter because of low temperature, but as temperature increases the growth rate increase if adequate moisture was available. Moreover, flowering has most often been correlated with warmer temperatures in the months prior to anthesis (Lesica and Kittelson, 2010).

The height and stem diameter of record-size individuals from different species are particularly important because they reveal the maximum size attained by phylogenetically or functionally different species groups, which are crucial to a variety of ecological and evolutionary hypotheses (Niklas et al., 2006; Galal, 2011). In addition, the height-to-diameter ratio gives an indication about the growth habit of the study plant. In the present study, the height to diameter ratio of leaved cordia is greater than one all the year around, which means that the individual height exceeds its diameter indicating that the individuals of these species tend to expand vertically rather than horizontally, and this may be attributed to the high intra-specific competition of this plant. This result agreed with those of Shaltout et al. (2003) for *Nitraria retusa* along the Red Sea Coastal land; Galal (2011) on the common woody perennials in Wadi Gimal; Galal et al. (2016) on *Calotropis procera* and Al-Sodany (2003) on the common shrubs in the western Mediterranean coast of Egypt. The majority of the studied individuals were recorded in urbanized rather than desert habitats. According to Shaltout and Mady (1993), the height to diameter ratio less than one may be a strategy of the desert trees and shrubs in order to provide safe sites for their self-regeneration, as the horizontal expansion usually provides shade, which leads to decrease the severe heating effect and increase the soil moisture.

Plant population structure such as the distribution of plant size and distribution of reproductive effort and success has important evolutionary and conservation implications, whereas plant size distribution has frequently been shown to affect survivorship and reproduction (Wessilingh et al., 1997) and can be related to inter- and intra-specific competition (Harper, 1977). In the present study, two size distributions were recognized all over the year, positive skewed distribution in winter, and bell shape distribution in autumn, summer and spring. The former size distribution may represent rapidly growing populations with high reproductive capacity. Such distributions may indicate also a high juvenile mortality (Galal, 2011), but nevertheless, they seem to represent long-term stability, since in most stable populations one could expect an excess of juvenile over mature individuals (Goldberg and Turner, 1986; Shaltout and Ayyad, 1988). Moreover, this distribution pattern is caused, through variations in growth rate, by factors such as:

competition, heterogeneity of resources, genetic variation and small differences in the rate of emergence (Weiner and Solbrig, 1984). On the other side, the bell-shaped size distribution indicates comparable representation of the juvenile and mature individuals; meanwhile the continuity of this current situation led to a reduction in population size of the study species in the future. These results coincided with that of Shaltout and Mady (1993) in their study on the size distribution of *Lycium shawii* in Central Saudi Arabia, Al-Sodany (2003) in his study on the size structure of *Phlomis floccosa* in the Western Mediterranean Coast of Egypt, Galal (2011) on some woody perennials in Wadi Gimal, and Galal et al. (2016) on *C. procera*.

Plant size is an important factor in competitive ability of plants and hence, the structure of vegetation (Nilson et al., 1991). The present study indicated that *C. sinensis* thrives during autumn with maximum height, diameter and size index in accordance with Galal et al. (2016) on *C. procera*. The height and diameter of record-size individual are particularly important because they reveal the maximum size attained by functionally different species groups, which are crucial to a variety of ecological and evolutionary hypotheses (Niklas et al., 2006). Moreover, size variables had the lowest values during winter, which is characterized by low air temperature. According to Sharma and Amritphale (2007), the increase in temperature leads to increase in growth rate of plants and hence to the plant size, if adequate moisture was available.

The macro-morphological characteristics of *C. sinensis* showed that the individuals from cultivated plots had the highest number of branches and leaves per branch, while those from ruderal habitats had the longest and widest leaves. The high growth of individuals in cultivated areas, compared to the other habitats, may presumably be due to its relative high N content, less anthropogenic disturbances (e.g. cutting, burning) and episodic water resources (Farahat et al., 2016). Conversely, the lowest morphological measurements were recorded for plant populations in desert habitats and this may be attributed to the high soil salinity and low moisture content, which suppress plant growth.

Soil nutrients, especially organic matter, are the main reason that enhances high natality (Galal et al., 2016); which is considered a direct response to high soil calcium and magnesium content, where the two cations play an important role in the structural and enzymatic functions in the plant cell. It was found that *C. sinensis* had the maximum branch survival during autumn, which may be attributed to the high soil moisture content stored during this season. Whereas Dalglish et al. (2011) reported that the lack of soil moisture could reduce a plant's stored resources, and consequently decrease its chance of survival. On the other side, the highest branch mortality was recorded during summer, and this may be attributed to water shortage of this season. Moreover, fecundity is expected to be reduced in narrowly distributed plants compared to more widespread congeners (Astegiano et al., 2010). The lower seed production of *C. sinensis* may be related to the pollen limitation (Rymer et al., 2005) or resource limitation (Lavergne et al., 2005), or may represent a compromise with seed size (Young et al., 2007). In addition, *C. sinensis* produced fewer seeds per plant than the related species (van Groenendael et al., 1996; Lott, 2013).

The variation in embryo abortion, highest unfertilized ovules and lowest seed's number per fruit may be related to known sources of mass mortality of trees. This result is in agreement with *Cordia elaeagnoides* that satisfy predators and surpass stress-related mortality (Lott, 2013). The major factor controlling mast fruiting must be the variation in embryo abortion rate, because flowering is annual and abundant, and the pollination vector non-limiting. Although *C. sinensis* produced a low number of seeds, a good

seedlings production was observed under the trees especially those growing in ruderal areas. The damping off of the seedlings and wilt disease complex in different sites, some locations showed the least decline like cultivated edges region where as ruderal areas and deserts obtained the highest decline as the high values. This may be attributed to the hyper-arid conditions of the study area (Ayyad and Ghabbour, 1986). Tree populations are a main indicator of long-term vegetation changes because trees are long-lived and drought-enduring. For the same reasons, *Cordia* trees are also drought insurance for desert dwellers and as a resource, they constitute a main pillar in the traditional nomadic lifestyle (Krzywinski and Pierce, 2001). High mortality in desert trees combined with lack of recruitment has been reported from arid and hyper-arid regions in Africa and the Middle East (Andersen and Krzywinski, 2007).

## Conclusion

The phenological behavior of *C. sinensis* showed continuous flowering and fruiting with maximum activity during spring and summer, respectively. The present study indicated that *C. sinensis* thrives during autumn with maximum height, diameter and size index. Two size distributions were recognized all over the year; a) positive skewed distribution in winter representing rapidly growing populations with high reproductive capacity and high juvenile mortality, and b) bell shape distribution in autumn, summer and spring indicating comparable representation of the juvenile and mature individuals. The plant had a maximum branch survival and branch mortality during autumn and summer, respectively. Although *C. sinensis* produced a low number of seeds, a good seedlings production was observed under the trees especially those growing in ruderal areas. The present study provides baseline information on *C. sinensis*, which could help in constructing a valuable management plan for monitoring and controlling this plant.

**Competing interests.** The authors declare that they have no competing interests.

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