academicJournals

Vol. 8(21), pp. 2482-2492, 6 June, 2013
DOI: 10.5897/AJAR11.2366
ISSN 1991-637X ©2013 Academic Journals
http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Acacia tortilis (Forsk) Hayne subsp *raddiana* (Savi) in a North African pseudo-savanna: Morphological variability and seed characteristics

Jaouadi Wahbi[1]*, Mechergui Kaouther[1], Hamrouni Lamia[1], Hanana Mohsen[2] and Khouja Mohamed Larbi[1]

[1]National Institute of Research in Rural Engineering Water and Forestry (INRGREF), Rue Hedi Karay, Ariana BP10, 2080 Tunis, Tunisia.
[2]Centre of Biotechnology of Borj-Cédria, CBBC, Hammam-Lif BP 901, Tunisia.

Accepted 9 May, 2013

Acacia tortilis **(Forsk) Hayne subsp. *raddiana* (Savi) Brenan (Family Fabaceae; subfamily Mimosoideae) is a pioneer tree of dry areas and it is a drought-resistant species. In spite of its several uses, there are no published studies which deal with relation between its adaptive features and fruit production for the Tunisian Arboretum. For this reason, a study was carried out in Bouhedma National Park to investigate morphology and seed production of *A. tortilis* pseudo-savanna for three successive years: 2006, 2007 and 2008. Two hundred and fifty trees from five plots in the three integral protection zones from five altitudes were studied to assess their genetic variation based on morphological parameters and fruit characteristics. The averages of the main descriptive morphological values of *A. tortilis* trees are 3.52 m of the height, 13.83 cm of the diameter at the base, 7.47 cm for the diameter at 1.30 m, 4.46 m for the diameter of crown North-South and 4.15 m for the diameter of crown East-West. The means of the main descriptive morphological values of pods are for the number of seeds before maturity 189.36, for number of seeds after maturity 50.625, for loss in pods 85.06%, for total number of seeds 406.11, for total weight of seeds 14.12 g and for the percentage of seeds infested 32.72%. Most of the measured parameters showed significant differences that indicate a high genetic diversity. Bruchidus has been recorded as a serious pest of *A. tortilis* seeds. The infested of seeds is directly related to number and loss in pods, number and weight of seeds (Pr <0.0001).**

Key words: *Acacia tortilis*, altitude, morphological diversity, pods, production, seeds.

INTRODUCTION

Acacia tortilis (Forsk.) Hayne ssp. *raddiana* (Savi) Brenan has a distinctive geographical range restricted mainly to the arid and semi-arid regions of northern, eastern and southern Africa, Middle-Eastern and the Arabianpeninsula (Kennenni, 2008). *A. tortilis* is a drought-resistant species (Abdallah et al., 2008). Its survival and its existence in the arid and semi arid area of Northen Africa and Arabian Peninsula are due to its ability to endure the harsh condition. Therefore, it generally forms open pure stands in these drylands (Abdelrahman and Krzywinski, 2008). Wherever it grows, it plays an important role in human, animal and other plant species lives. Acacia species are socio-economically important. They are used for fence posts, as a firewood, as a livestock feed for tanning and

*Corresponding author. E-mail: jaouadiwahbi@yahoo.fr. Fax: +216 71 231 927.

as an algicide and molluscicide (Timberlake, 1980; Ayoub and Yankor, 1984). Ayoub and Yankor (1984) found that the most common wild Acacia species in the Egyptian desert is *Acacia raddiana* Sari. Fruits are palatable to sheep, goats and camels. The camels browse spiny and young branches.

Acacia has also commercially (Anderson, 1987) and medicinally (Boulos, 1983) valuable. Their particular value in arid zones lies in their extreme resistance to heat, drought, salinity, alkalinity, drifting sand, grazing and repeated cutting (Fagg and Stewart, 1994). In some areas, dried seeds of *A. tortilis* (Hocking, 1993) or pods of *A. nilotica* (Maydell, 1990) are included in the human diet. Leaves, bark, gum, roots, pods and seeds are used medicinally against a wide variety of diseases, wounds and burns (Hocking, 1993). Owing to their socio-economical and commercial uses, Acacia trees are important reforestation species in Africa (Haoua and Mourier, 1990). Acacia trees are commonly used for windbreaks, for the stabilization of sand dunes, shading and ornamentals. Thorny species are used for fencing (Maydell, 1990; Hocking, 1993; Roshetko, 2001). However, this species is in danger of extinction because the potential of destruction of seeds by bruches (family of Bruchidae) is very high (Ferchichi et al., 2009).

The pods, shoot and foliage are used as fodder. Bruchids which commonly attack the pods and seeds of *A. tortilis* in India (Singh and Bhandari, 1987, 1988) and *Bruchidius spadiceus* infesting seeds of *A. tortilis sperocarpa* in Tanzania has been described by Lamprey et al. (1974). According to Ross (1979), the percentage of seeds destroyed by bruches is between 20 and 100% in Africa and in Central America. In addition, the other factor contributing to their disappearance has been agriculture, which caused the replacement of the Acacia groves by cultivated fields. Seeds of *A. tortilis* in Bouhedma national park were infested by two *Bruchidius* species: *Bruchidius raddiana* Anton and Delobel and *Bruchidius aurivillii* Blanc (Ben jamaa et al., 2008). *A. tortilis* (Forsk) Hyne (Mimosoideae: Leguminose) commonly known as Tunisian Talah is a fast growing arid zone tree species. It is localized in the south of Tunisia and it is endemic in this country. *A. tortilis* shows a great phenotypic variability with respect to leaf number, size and pod morphology. Its area of geographical distribution is limited to the regions of Bouhedma national park. *A. tortilis* has been included in a national list of priority forest genetic resources for conservation and management in Tunisia. This species is one of particular scientific interest in the park, because it represents a transition between the semi arid and desert vegetation, corresponding to semi arid and arid ecosystems, respectively.

Until now little information are available concerning the morphological variability of the *A. tortilis* in Tunisia and no investigations about fruit characteristics. It was necessary to describe the actual characters of *A. tortilis* populations because of a wide dispersion throughout the dry area of genetic resources of this species and increasing risk of its genetic erosion. Therefore, the aim of the present study was to assess the morphological variability of trees related to pods and seeds.

MATERIALS AND METHODS

Study area

The study area lies in Tunisian Bouhedma National Park in northern Africa, pseudo savanna of *A. tortilis* subsp. *raddiana* (Figure 1). There are three protected areas in the park; Bou Hedma area (zone I) located around the Borj Bou Hedma on ground gypsum, area Haddej (Zone II) in the portion of said subject Haddej National Park of Bou Hedma on a calcareous soil and site Belkhir (zone III) located a little further south on poor soil evolved fluid intake. The three sites are under climate Mediterranean arid lower (100 to 200 mm of rainfall annually) to winter cold soft substrate with edaphic deep silty clay. Protected since 1980 and since ranked by UNESCO as a biosphere reserve. Climatically, the study area is classified as an inferior arid (Emberger, 1954). Climate is characterized by hot summers, cool winters and low unpredictable rainfall. Annual rainfalls vary between 100 and 200 mm. Mean temperature varies from 32 to 36°C in summer and from 4 to 7°C in winter (Derbel et al., 2007).

The soil of the experimental areas is composed of quaternary sandy deposits and covered by A. *tortilis* pseudo-savanna. *A. tortilis* subsp *raddiana* (Savi) is the most important woody species in the site. The lower vegetation layer (< 1 m) is composed by perennial grasses (*Cenchrus ciliaris*, *Digitaria nodosa* and *Stipagrostis ciliata*) and two species of the genus Hammada (*Hammada schmittiana and Hammada scoparia*), which belong to Chenopodiaceae family (Abdallah et al., 2008). The park home to a diverse wildlife (antelope oryx and addax) and woody vegetation represented mainly *A. tortilis*. Region Haddej Bouhedma (where is the National Park) and its surroundings, include six agglomeration: Talah East, Talah West, Jbilt El Ouast in the governorate of Bouhedma Gafsa, El Essoud, Bouaa and Khoubna in the governorate of Sidi Bouzid. A survey in 1994 shows total households in the six agglomeration equal to 2394 and a degree of dispersion high level throughout the region. Indeed, 82% of households live in rural dispersed. Each household has an average of seven people.

Analyzed populations and sampling

Morphometric traits were determined for five plots of *A. tortilis* (Forsk.) Hayne subsp. *raddiana* (Savi) Brenan from Bouhedma National Park, each with fifty trees for any class of diameter chosen randomly from five different altitudes in the three integral protection zone in the Bouhedma National Park (50 trees by plot by altitude; altitude 1: 165 m; altitude 2: 150 m; altitude 3: 125 m; altitude 4: 110 m; altitude 5: 90 m) and six measurements of each character per tree in different ecogeographical sites; *A. tortilis* pods containing seeds were collected during the period of July to September 2006, 2007 and 2008 (at peak maturity) to determined the production variation to three years. The seeds were separated from the pods and both seeds and pods were weighed and analyzed. The principal characteristics of all sites studied are summarized in Table 1.

Trees were described by eight morphological characteristics: tree height (m), diameter at base (cm), diameter at 1.30 m (cm), diameter of crown N-S (m), diameter of crown E-W (m), number of pods before maturity, number of pods after maturity, loss in pods (%), number of seeds, total weight of seeds and percentage of

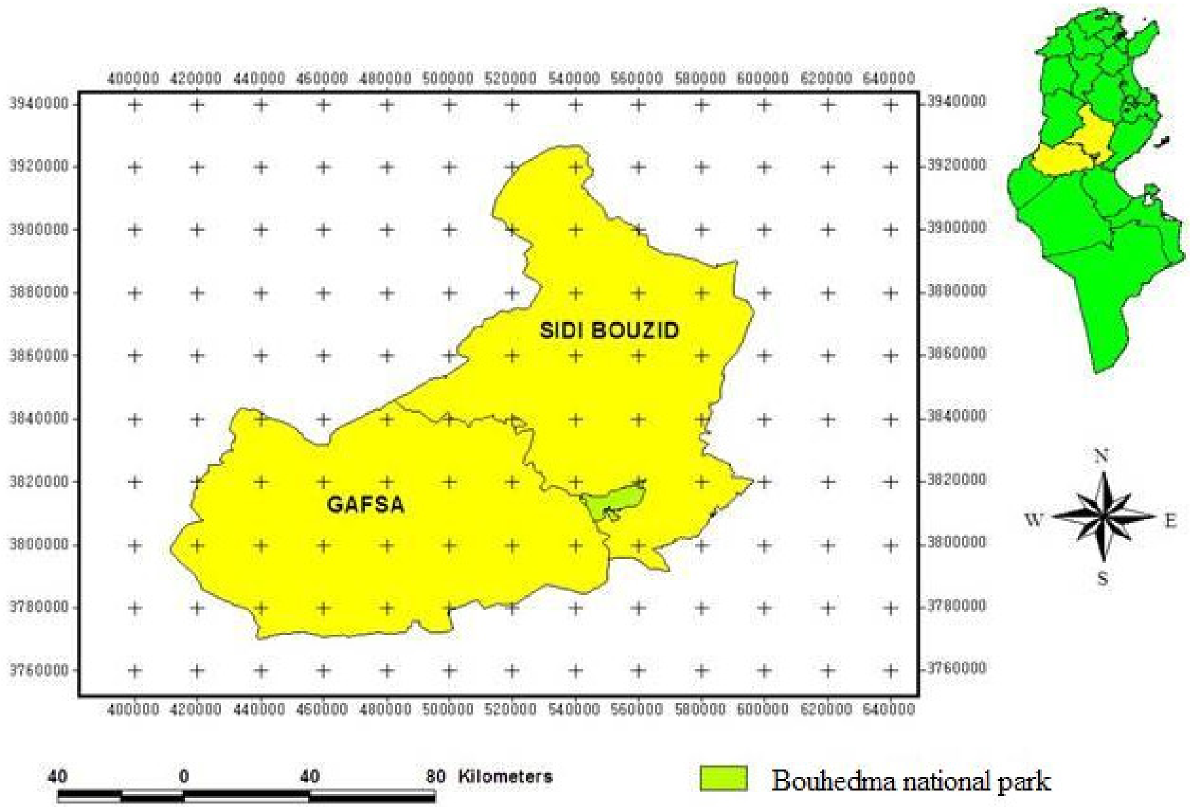

Figure 1. Location of the Bouhedma national park (Tunisia).

Table 1. Description of the original locations of the plots of *Acacia tortilis* (Forsk.) Hayne subsp. *raddiana* (Savi) Brenan.

Bouhema national park	Original location	Plot	Position 1	Position 2	Altitude (m)	Annual precipitation	Mean temperature (°C)	
							Min. in coldest month	Max. in hottest month
Integral protection zone I (Borj)	Bouhedma (Sidi Bouzid)	Plot 1	34° 27' 594	09° 38' 145	165	237	5	38
		Plot 2	34° 27' 221	09° 39' 513	150			
		Plot 3	34° 28' 208	09° 37' 031	125			
Integral protection zone II (Belkhir)		Plot 4	34° 25' 673	09° 29' 813	110	244	4.5	37.4
Integral protection zone III (Haddej)	Bouhedma (Gafsa)	Plot 5	34° 24' 093	09° 28' 240	90	150	4.1	38.8

Table 2. Average of morphological parameters of tree, pod and seed measured for all analyzed plot through three years of monitoring.

Variable	Number of observations	Mean	SD*	CV (%)**
(1) Height of tree (m)	750	3.523	1.927	54.69
(2) Diameter at the base of tree (cm)	750	13.827	12.537	90.67
(3) Diameter at 1.30 m of tree (cm)	750	7.472	7.845	104,99
(4) Diameter of crown North-South of tree (m)	750	4.461	2.712	60.79
(5) Diameter of crown Est-West tree (m)	750	4.150	2.514	60.57
(6) Number of pods before maturity	750	189.357	209.099	110.42
(7) Number of pods after maturity	750	50.625	99.213	195.97
(8) Loss in pods (%)	750	85.059	22.822	26.83
(9) Number of seeds	750	406.110	807.868	198.92
(10) Weight of seeds (g)	750	14.120	29.382	208.08
(11) Percentage of seeds infested	750	32.725	38.011	116.15

*SD: Standard deviation. **CV: Coefficient of variation.

seeds infested were calculated.

Experimental methods for morphological analysis

The selection of fruit pods and seeds continuous characters for characterization was done by adapting the International Plant Genetic Resources Institute (IPGRI) descriptors (Battle and Tous, 1997). Mature pods collected in each site were air dried for 4 weeks and kept at 4°C before analyses. Each fruit was manually decorticated and analyzed. For pods of each plot, we have estimated total number, total weight and percentage of seeds infested.

Statistical analysis

To compare the heterogeneity of morphological measured parameters among site and years, an analysis of variance was made for each character using the program SAS, procedure ANOVA. Averages among parameters were compared using Newman and Keuls test. We have previously tested the equality of variances using the Hartley test. This test was not significant (rejection of the equality of variances), which prompted us to use the angular transformation ($Y = 2ArcSin\sqrt{X}$). Averages whose transformed values were subjected to ANOVA. In order to find the main variation trends between fruit tree characters and to evaluate their correlation, data were processed according to Pearson correlation coefficients.

RESULTS

The number of observation is 250 per year. Thus, in three years, there are 750 observations. The averages of morphological parameters measured of eleven characters of tree and fruit of *A. tortilis* are given in the Table 2. Tree height varied from 0.38 to 8.68 m, diameter at the base varied from 1 to 74 cm, diameter at 1.30 m varied from 0 to 41 cm, because there are plants that do not reach the height of 1.30 m. The number of pods before maturity varied from 0 to 1000. Loss in pods ranged from 0 to 100%. The total number of seeds varied from 0 to 5471 with 0 to 209.82 g total weight of seeds and the percentage of seeds infested varied between 0 to 98%. The standard deviation (SD) measures the amount of variation in the morphology that can be explained by the variable altitude. This amount found can be explained by a variation in the morphology. The standard deviation (SD) was maximum for number of seeds followed by number of pods before maturity, loss in pods, number of pods after maturity, percentage of seeds infested and weight of seeds which confirms the maximum variability in production of fruit and these characters were due to bruchid attack. For production seed and trees, the morphological traits analyzed showed coefficients of variation (C. V.), ranging from 208.08% for weight of seeds to 26.83% for loss in pods (Table 2).

A comparison of morphological parameters of *A. tortilis* in three protected zone at five different altitudes in the Bouhedma National Park are represented in Table 3, when the variation among the morphological variables of tree was restricted to the altitude (elevation class : $Pr < 0.05$). This indicates that certain of the studied environment (elevation and site) variables accounted for the variation in the morphological parameters. The total values of fruit production per plots are represented in Figure 2. It may be noted that production varies between plots and years, but remains very low for most sites and through the years (from 94 to 2285 g). The year 2007 was characterized by low seed production (1067 g) compared to 2006 (5127 g) and 2008 (4396 g); this can be explained by the insects that attack leaves during the flowering period and wind strength which coincided with the period of pod formation; we can also conclude that the parcel is located in the plain on sandy soil (P5) is the most productive seed compared to other plots. The higher production of fruit was observed in parcel number5 with 2285 g in 2006, 378 g in 2007 and 1899 g in 2008. The percentages of seeds infested of five plots of *A.*

Table 3. Analysis of variance, comparison of morphological parameters of *Acacia tortilis* in three protected zones at five different altitudes in the Bouhedma national park.

	Source	DF	Sum of squares	Mean square	F value	Pr > F
Tree height (m)	Integral protection zone	2	0.161	0.080	0.02	0.9780
	Elevation class	2	25.399	12.699	3.49	0.0321
Diameter at base (cm)	Integral protection zone	2	196.490	98.245	0.63	0.5316
	Elevation class	2	1050.698	525.349	3.39	0.0354
Diameter at 1.30 (m)	Integral protection zone	2	195.450	97.725	1.61	0.2018
	Elevation class	2	308.303	154.151	2.54	0.0809
Diameter of crown N-S (m)	Integral protection zone	2	9.265	4.632	0.64	0.5287
	Elevation class	2	45.966	22.983	3.17	0.0437
Diameter of crown E-W (m)	Integral protection zone	2	8.549	4.274	0.70	0.4986
	Elevation class	2	40.049	20.024	3.27	0.0397

Significantly different at Pr < 0.05.

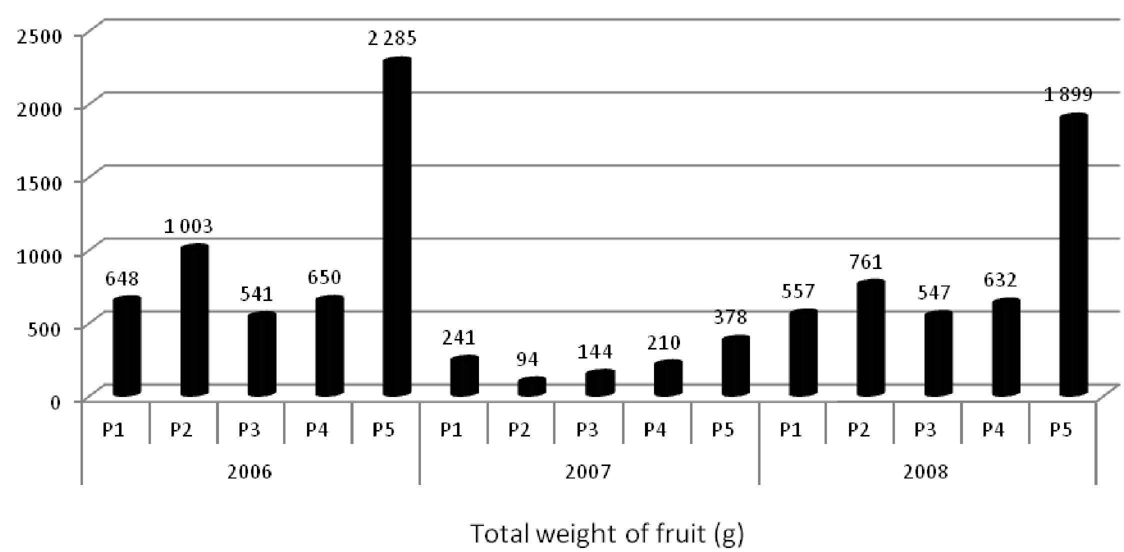

Figure 2. The seed production of five plots (Pi) of *Acacia tortilis* in Bouhedma national park in three years (2006, 2007 and 2008).

tortilis in Bouhedma National Park are represented in Figure 3. The remaining pods produce seeds attacked (rate of attack varies from 18 to 68%), causing major problems for the regeneration of the species. It is worth noting that the attack rate of the seeds can grow after a certain time because of the development of larvae inside the seeds. The most productive sites in seeds are the most attacked by bruchids.

Correlation coefficients among the different characters studied are presented in Table 4. From the morphological study, high correlation coefficients were obtained between the more morphological characteristics from tree and its pod and seeds. Number of pods before maturity is directly related to height of tree, diameter at the base of tree, diameter at 1.30 of tree and diameter of crown North-South and East-West of tree (Pr < 0.0001). The number of pods after maturity is positively correlated with number of pods before maturity (Pr < 0.0001). Loss in pods is also significatively but negatively correlated with number of pods after maturity. Weight of seeds is directly related with number of pods before maturity, number of pods after maturity, loss in pods and number of seeds (Pr < 0.0001), indicating that percentage of seeds infested is positively correlated with morphological parameters of tree, pods and seeds; height of tree, diameter at the base and at 1.30 of tree, diameter of crown North-South and

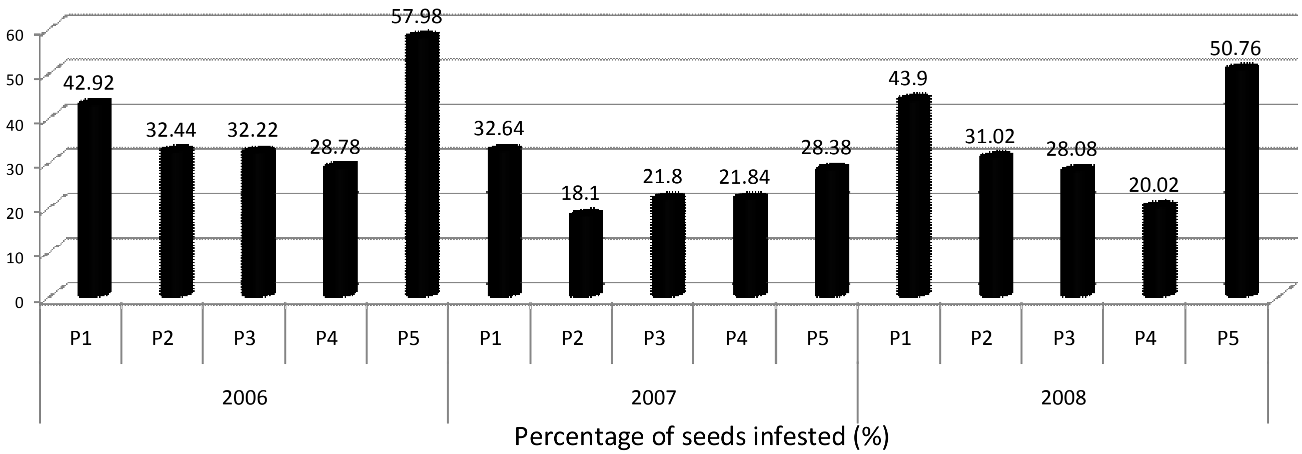

Figure 3. The percentage of seeds infested of five plots (Pi) of *Acacia tortilis* in Bouhedma national park in three years (2006, 2007 and 2008).

Table 4. Correlation coefficients between morphological parameters of tree, pods and seeds for each plot in three successive years (2006, 2007 and 2008).

Parameter	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) Height of tree (m)	1	0.790 <0.0001	0.837 <0.0001	0.863 <0.0001	0.811 <0.0001	0.220 <0.0001	0.061 0.0906	-0.089 0.0145	0.067 0.0637	0.050 0.1693	0.149 <0.0001
(2) Diameter at the base of tree (cm)		1	0.861 <0.0001	0.773 <0.0001	0.697 <0.0001	0.196 <0.0001	0.063 0.0801	-0.100 0.0058	0.064 0.0786	0.050 0.1631	0.130 0.0004
(3) Diameter at 1.30 of tree (cm)			1	0.822 <0.0001	0.758 <0.0001	0.224 <0.0001	0.024 0.5093	-0.049 0.1787	0.021 0.5581	0.008 0.8060	0.095 0.0090
(4) Diameter of crown North-South of tree (m)				1	0.864 <0.0001	0.234 <0.0001	0.060 0.0992	-0.091 0.0121	0.051 0.1602	0.036 0.3248	0.159 <0.0001
(5) Diameter of crown Est-West tree (m)					1	0.249 <0.0001	0.067 0.0656	-0.091 0.0125	0.062 0.0849	0.047 0.1896	0.152 <0.0001
(6) Number of pods before maturity						1	0.646 <0.0001	-0.454 <0.0001	0.633 <.0001	0.616 <.0001	0.494 <0.0001
(7) Number of pods after maturity							1	-0.813 <0.0001	0.968 <.0001	0.939 <.0001	0.582 <0.0001

Table 4. Contd.

(8) Loss in pods (%)	1	-0.794 <0.0001	-0.762 <.0001	-0.726 <0.0001
(9) Number of seeds		1	0.960 <0.0001	0.577 <0.0001
(10) Weight of seeds (g)			1	0.552 <0.0001
(11) Percentage of seeds infested				1

Significantly different at Pr < 0.05. Highly significantly different at Pr < 0.01. Very highly significantly different at Pr < 0.001.

East-West of tree, number of pods before and after maturity, number of seeds and weight of seeds and negative correlations with loss in pods.

The data shown in Table 5 reproduce the results of the analysis of variance in seed production of *A. tortilis* for three successive years, in five parcels in the three integral protection zones at five altitude levels. The results show that the loss of pods, total production of seeds and the attack rate of seeds varied significantly with integral protection zone of the park and years of monitoring. However, it was concluded that altitude has no significant effect on seed production of *A. tortils*, but has significant effect on percentage of seeds infested. The overall comparison of the seed production of *A. tortilis* for three successive years, in five parcels in the three integral protection zone in Bouhedma National Park is shown in Table 6. The results show the low production in pods of *A. tortilis* characteristic of species in arid zone. From these results, the zone III of the Bouhedma National Park is the most fruitful and productive compared to the other two zones, this can be explained by the variation nature of soil and morphology characteristics of tree in this area. The loss of pods recorded after maturation in zone II is explained by the exposure of this zone to the prevailing wind. The rate of infected seeds by bruchids is important in all areas of the park and these strong attacks will cause major problems later for natural regeneration of the species.

The year 2007 saw heavy losses in pods per tree (92.71%). This is the result of wind recorded in the region compared with 2006 and 2008 (the annual average is 3 m/s in 2007, 2.3 m/s in 2006 and 2.9 m/s in 2008). The year 2006 saw the highest weight and the average number of seeds (20.50 g / tree; 581 seeds / tree) promoting there after heavy attack by bruchids.

DISCUSSION

Morphological variations

The general linear model revealed significant differences inter integral protection zone and between years for all the examined characters (Pr < 0.0001). Ross (1975) stated that *A. tortilis* is the most widespread Acacia species in southern Africa and displays a remarkable phenotypic plasticity over its geographical range. Our Tunisian populations grow in arid climate conditions: annual rainfall ranges from 150 to 321 mm, mean temperature in the coldest month from 4.1 to 5°C, mean temperature in the hottest month from 36.7 to 38.8°C and altitude from 90 to 165 m (Table 1). The individuals of this species showed higher means of total tree height (3.52 m), diameter at base (13.82 cm), diameter at 1.30 m (7.42 cm), diameter of crown N-S (4.46 m) and diameter of crown E-W (4.15 m). As elevation was the only response variable explain the difference in the morphology of *A. tortilis* in the park. Hultine and Marshall (2000) and Qiang et al. (2003) reported that morphological and physiological properties of most woody plants are affected by different abiotic factors, in particular over altitudinal gradients. The differences detected in growth variables may reflect specific adaptation mechanisms in Tunisian *A. tortilis* (Forsk.) Hayne subsp. *raddiana* (Savi) Brenan also. Thus, Verzino et al. (2003) found that field performance of morphological traits is controlled by the genetic

Table 5. Analysis of variance, comparison of seed production of *Acacia tortilis* for three successive years (2006, 2007 and 2008) in three protected zone at five different altitudes in the Bouhedma national park.

	Source	DF	Sum of squares	Mean square	F value	Pr > F
Number of pods before maturity	Integral protection zone	2	713294.216	356647.104	8.45	0.0002
	Elevation class	2	224325.924	112162.962	2.66	0.0709
	Year	2	440218.954	220109.477	5.21	0.0056
Number of pods after maturity	Integral protection zone	2	440174.094	220087.047	25.23	<0.0001
	Elevation class	2	1005.257	502.628	0.06	0.9440
	Year	2	449519.522	224759.761	25.76	<0.0001
Loss of pods (%)	Integral protection zone	2	18597.487	9298.743	19.84	<0.0001
	Elevation class	2	1211.580	605.790	1.29	0.2752
	Year	2	22051.603	11025.801	23.52	<0.0001
Number of seeds	Integral protection zone	2	29172711.65	14586355.82	25.21	<0.0001
	Elevation class	2	315035.21	157517.61	0.27	0.7618
	Year	2	29406196.34	14703098.17	25.41	<0.0001
Weight of seeds (g)	Integral protection zone	2	49805.251	24902.625	33.16	<0.0001
	Elevation class	2	1353.414	676.707	0.90	0.4066
	Year	2	37485.600	18742.800	24.96	<0.0001
Percentage of seeds infested	Integral protection zone	2	38637.454	19318.727	14.34	<0.0001
	Elevation class	2	15735.951	7867.975	5.84	0.0030
	Year	2	27164.834	13582.417	10.08	<0.0001

characteristics of the tree and the growing conditions under which it has evolved.

Membrives et al. (2003) reported that some morphological characters seem to evolve associated with soil texture. Indeed, Raddad and Luukkanen (2006), noticed the *A. senegal* (L.) Willd. Provenances from the clay soil region in Suddan were distinctly superior to the sand provenances in all traits studied but especially for tree height, basal diameter and crown width, thus, reflecting their adaptation to the environment conditions, since these morphological traits are important yield determinants and interesting for reforestation. Gandiwa et al. (2011) reported that plants damaged by elephants increased with increasing elephant utilization. The study findings suggest that *A. tortilis* woodland is gradually being transformed into an open woodland. Tree cover in savannas is determined as much by disturbances from fire and herbivory as by rainfall and soil resources. Fire especially acts to limit tree cover via a demographic ottleneck, limiting the recruitment of tree saplings to adults (Wakeling et al., 2011). Hean and Ward (2012) showed that Acacia seedlings are tolerant of disturbance events such as herbivory and burning but these effects cannot be assumed to be substitutable.

Importantly, there was a positive response to simulated herbivory and a negative response to fire in most species. We show that fire frequency and fire season influence patterns of vegetation three-dimensional structure, which may have cascading consequences for biodiversity. Managers of savannas can therefore use fire frequency and season in concert to achieve specific vegetation structural objectives (Smit et al., 2010). According to Riginos and Young (2007), savanna tree growth and woody encroachment cannot be predicted by grass cover or herbivore type alone. Rather, tree growth appears to depend on a variety of factors that may be acting together or antagonistically at different stages of the tree's life cycle.

Seed production

Seed production of Acacia can be expressed in many ways, such as number of seeds per pod or per tree or per unit of area. According to our results, the production of an individual seems not to depend on the size of its height and volume of its crown. Indeed, subjects high and especially low volume crowns produce the most seeds. Furthermore, the parameter that crown, when it is important promotes maximal expression of production, against all odds, the final production of seeds seems not to depend on morphology characteristics of individuals

Table 6. Overall comparison of seed production of *Acacia tortilis* for three successive years (2006, 2007 and 2008) in the three integral protection zones (IPZ) in Bouhedma national park using the Newman and Keuls test.

	Integral protected zone	Mean	Statistical similarity	Year	Mean	Statistical similarity
Number of pods before maturity	IPZ 3	240.17	A	2006	220.80	A
	IPZ 2	210.50	A	2008	185.42	AB
	IPZ 1	165.37	B	2007	161.85	B
Number of pods after maturity	IPZ 3	98.927	A	2006	73.664	A
	IPZ 1	39.782	B	2008	61.488	A
	IPZ 2	34.853	B	2007	16.724	B
Loss of pods (%)	IPZ 2	90.410	A	2007	92.713	A
	IPZ 1	86.433	A	2008	81.650	B
	IPZ 3	75.589	B	2006	80.816	B
Number of seeds	IPZ 3	800.55	A	2006	581.67	A
	IPZ 2	310.25	B	2008	507.26	A
	IPZ 1	306.59	B	2007	129.40	B
Weight of seeds (g)	IPZ 3	30.419	A	2006	20.508	A
	IPZ 1	10.080	B	2008	17.588	A
	IPZ 2	9.947	B	2007	4.266	B
Percentage of seeds infested	IPZ 3	85.707	A	2006	38.868	A
	IPZ 1	71.458	B	2008	34.756	A
	IPZ 2	63.547	C	2007	24.552	B

but rather the position of the individual in area and under year. As integral protection zone was the only response variable that moderately explained the difference in the seed production and seed infestation of tree in the park. If seed production appears to vary by individual areas of an individual to another, there is not much for heights. Indeed, it was found that isolated individuals were generally large in size but production is low to medium cloves and this variability is observed along the zone.

Our results are consistent with those of Bation (1994) who after studying the production of seed of *Guiera senegalensis* was led to the conclusion that the low density stands promote maximal expression crown. For fruit production, it is very low for most plots and across years (from 94 to 2285 g); our results are not in agreement with Menwyelet et al. (1994) who obtained for *A. tortilis* subsp. *Spirocarpa*, an average production of 5.3 kg of fruit per tree, or a yield of 75 to 850 kg ha^{-1} in the basis of observed densities. These figures are within the range of values proposed by Ball (1980) for *A. raddiana*: 400 to 600 kg ha^{-1} in areas with 400 mm of annual rainfall. In this sense, Booth et al. (1989) showed that the tree *Acacia colei* (Acacia in Australia) can produce about 2 kg of seeds for at least two to three harvests, from the age of two years, and its flour can be incorporated safe schemes based on millet and sorghum which are eaten by people, this food could be consumed in vast semi-arid areas of Africa and South Asia where climatic conditions are suitable for *A. colei*. According to Cossalter (1987), farmers can obtain at least two crops of about 2 kg each per tree planted seeds of *Acacia elachantha* planted windbreaks in Dandji near Maradi (Niger), provided that annual rainfall average total at least 350 mm throughout the production cycle of trees. Spatial variation in seed weights of *A. tortilis* was primarily determined by rainfall and soil organic carbon (Moleele et al., 2005). However, through years of monitoring, seed yields were hardly inspiring. Many trees have not produced seeds, average yields per tree were low and productivity varies from year to year. In addition, climatic conditions vary considerably from year to year in the region, which suggests that there is a critical relationship between rainfall and seed yield.

The results showed that the number of pods varied significantly in plots of either 38 to 99 pods of 300 to 800 seeds. In this sense, a study was made by FAO (1980) on the number of seeds per pod for various species, showed that *Acacia albida* in South Africa produces 14 to 21 seeds per pod, whereas *Acacia senegal* in Pakistan produces 2 to 5 seeds per pod, *Acacia nilotica* 8 to 16 seeds per pod and *A. tortilis* until 14 seeds. Monk et al. (1981) showed that seed production of *Acacia pulchella* (small Australian shrub) begins at 2 years, attains a maximum of 12,000 seeds per plant per year at 3 to 4 years, and decreases to 2000 seeds per plant at the 13 years. A mature tree of *A. albida* can produce about half a million seeds in the Sudan and South Africa on a large, if the season is favorable, can produce several million (Wickens, 1969). The number of seeds produced per hectare is as a function of density, age and size of trees. Burrows (1973) reported the yield of 2 to 12 kg (about 150000 to 850000 seeds) of seed per hectare for *Acacia aneura*.

Jindal et al. (1990) have shown a non significant relationship between seed weight and pod infestation possibility due to their observations in the month of December when pods are still under maturation. Although, *A. tortilis* seed quality (represented by weight patterns) is a function of both genetic and environmental factors, a study focused on the environmental determinants of seed quality patterns in Botswana (Moleele et al., 2005). The results show that the percentage of seeds infested varied significantly with elevation class (Pr < 0.0030). They indicated that pod infestation causes deterioration in quality of the seed. Singh and Bhandari (1987) reported the seed Bruchids as the most serious pest recorded to date of *A. tortilis* plantations. These observations indicate that the field infestation of fruits of *A. tortilis* with Bruchids if unchecked will provide a potential source for multiplication of this beetle in the Bouhedma National Park. The infestation size of *A. raddiana* seeds by bruchids varies from one year to another according to the humidity, temperature and the rainfall (Halevy, 1974; Ernst et al., 1989). In this current study, Bruchid infestation of seeds varies significantly between *A. raddiana* trees. The high rates of bruchid infestation (from 25.9 to 79.9%), may be attributed to the high density and condensation distribution of this species at the park (Derbel et al., 2007). Seeds collected for further studies were 100% infested with Bruchids, as the insect multiplied at a very fast rate under laboratory conditions.

Very high infestation rates have been found in other Acacia species for seeds, where reinfestation of the seeds occurs, but the rates for seeds from fresh pods are generally lower (Tybirk, 1991; Coe and Coe, 1987). Differences in bruchid infestation between trees have been widely reported (Ernst et al., 1989; Miller, 1996). This may be related to the size of the seed crop and tree density since the proportion of a seed crop is destroyed and its size are often inversely related and infestation may be higher at low tree densities (Mattson, 1971). Seed predation of *A. tortilis raddiana* in the Bouhedma National Park raises a real problem which makes a threat to the presence of this species, not only in Tunisia, but also in Asia and sub-Saharan Africa, as reported by Anton and Delobel (2003). However, in Tunisia, the presence of *Bruchidius raddianae* seems to be very dangerous. These variabilities are related firstly to genotypic characteristics of taxa and partly to the vagaries of environmental conditions (nutrient availability access, climatic variability). Similar correlations have been found between seed weight and rainfall for other species (Vakshasya et al., 1992; Harfouche et al., 2003).

The data obtained in this study has shown the great variability of the morphology traits and fruit characteristics of *A. tortilis* in Bouhedma National Park. These results suggest the importance of preserving the genetic resources of *A. tortilis* and it could be a starting point for further studies, with the aim of the clonal selection with highest yield of seeds. Moreover, the development of trees more adapted to actual and future demands of fodder must take in consideration a strategy that prevents genetic erosion, thus, reduction of the biodiversity of this species in this region is real risk. Thus, evaluation of the biodiversity in *A. tortilis* trees dispersed all over the region is a fundamental step for the implementation of a conservation strategy. Therefore, preventive measures have to be recommended (biological and integrated fight) in order to restrict seed predation and ensuring the germination within the Bouhedma Park, considered by UNESCO, as a biosphere reserve. In these conditions, seed germination increases species density in the park and contributes to the preservation of forest strata in this presaharan ecosystem.

REFERENCES

Abdallah F, Noumi Z, Touzard B, Ouled Belgacem A, Chaieb M (2008). The influence of *Acacia tortilis* (Forssk.) subsp. *raddiana* (Savi) and livestock grazing on grass species composition, yield and soil nutrients in arid environments of south Tunisia. Flora 203:116-125.

Abdelrahman HF, Krzywinski K (2008). Environmental effects on morphology of *Acacia tortilis* group in the Red Sea Hills, North-Eastern Sudan and South-Eastern Egypt. Forest Ecol. Manag. 255:254-263.

Anderson DMW (1978). Chemotaxonomic aspects of the chemistry of *Acacia Gum* exudates. Kew Bull. P. 32.

Anton KW, Delobel A (2003). African species of the Bruchidius centromaculatus group with eyed female pygidium (Coleoptera: Bruchidae: Bruchinae). Genus 14(2):159-190.

Ayoub SM, Yankor LK (1984). Field trials for the evaluation of the molluscidal activity of *Acacia nilotica*. Filoterapia 55:305-307.

Ball JC (1980). Measuring the primary palatable production of browse plants. *In* le Houérou H. N., ed.: Browse in Africa: the current state of knowledge. ILCA, Addis-Abeba. pp. 185-195.

Bation AB (1994). Etude des potentialités agroforestieres, de la multiplication et des usages de Guierra senegalensis JF.GMEL. Mémoire de fin d'étude IDR. Option Eaux et Forêts, Université de Ouaga. P. 156.

Battle I, Tous J (1997). Carob tree. *Ceratonia siliqua* L., Promoting the Conservation and use of Under-utilised and Neglected Crop. Institute of Plant Genetic and Crop Plant Research and Gatersleben/International Plant Genetic Resource Institute, Rome, Italy.

Ben jamaa H, Sliti O, Barbouch N (2008). Les insectes bruchidés de l'*Acacia tortilis* subsp *raddiana* en Tunisie. Annales de l'INRGREF 12 Numéro spéciale. pp. 135-146.ISSN 1737-0515.

Booth TH, Stein JA, Nix HA, Hutchinson MF (1989). Mapping regions climatically suitable for particular species: An example using Africa. For. Ecol. Manage. 28:19-31.

Boulos L (1983). Medicinal Plants of North Africa, References Publications Inc. Algonac, Michigan, USA.

Burrows WH (1973). Regeneration and spatial patterns of Acacia aneura in south west Queensland. Trop. Grassl. 7:57-68.

Coe M, Coe C (1987). Large herbivores, acacias trees and bruchid

beetles. S. Afr. J. Sci. 83:624-635.
Cossalter C (1987). Introduction of Australian acacias into dry, tropical West Africa. For. Ecol. Manage. 16:367-389.
Derbel S, Noumi Z, Anton KW, Chaieb M (2007). Life cycle of the coleopter Bruchidius raddianae and the seed predation of the *Acacia tortilis* Subsp. *raddiana* in Tunisia. C. R. Biologies 330:49-54.
Emberger L (1954). Une classification biologique des climats Recueil des travaux de Laboratoire de Botanique. Série Botanique Fasc. 7:3-43.
Ernst WH, Decelle JE, Tolsma DJ (1989). Predation of seeds of *Acacia tortilis* by insects. Oikos 54:294-301.
Fagg CW, Stewart JL (1994). The value of *Acacia* and *Prosopis* in arid and semi-arid environnements. J. Arid Environ. 27:3-25.
FAO (1980). Ressources Génétiques d'Essences Arborées des Zones Arides et Semi-Arides. Etude visant à améliorer la vie rurale en Amérique latine, Afrique, Indie et Asie du Sud-Ouest. FAO/CIRPG. FAO, Rome.
Ferchichi OH, David JW, Khouja ML, Correal E (2009). Diversity analysis of *Acacia tortilis* (Forsk) Hayne ssp. *raddiana* (Savi) Brenan (Mimosaceae) using phenotypic traits, chromosome counting and DNA content approaches. Genet. Resour. Crop. Evol. 56:1001-1010.
Gandiwa E, Magwati T, Zisadza P, Chinuwo T (2011). The impact of African elephants on Acacia tortilis woodland in northern Gonarezhou National Park, Zimbabwe. J. Environ. 75(2011)9. -ISSN 0140-1963 - pp. 809-814.
Halevy G (1974). Effects of gazelle and seed beetles on germination and establishment of *Acacia* species. Isr. J. Bot. 23:120-126.
Haoua S, Mourier H (1990). Non-Poisonous Methods of Pest Control During Forest Seed Collection, Handling, Storage and Transfer, CNSF Ouagadougou, Burkina Faso.
Harfouche A, Boudjada S, Chettah W, Allam M, Belhoul O, Merazga A (2003). Variation and population structure in aleppo pine (*Pinus halepensis* Mill.) in Algeria. Silvae Genet. 52:244-249.
Hean JW, Ward D (2012). Fire and herbivory are not substitutable: evidence from regrowth patterns and changes in physical and chemical defences in Acacia seedlings. J. Veg. Sci. 23:13-23.
Hocking D (1993). Trees for drylands. International Science Publisher, New York.
Hultine KR, Marshall JD (2000). Altitude trends in conifer leaf morphology and stable carbon isotope composition. Oecologia 123:32- 40. doi:10.1007/s004420050986.
Jindal SK, Kolanki KR, Kachar NL, Sigh P (1990). Variation in seed production and its relationship with morphological traits in *Acacia tortilis*. J. Trop. For. 6(4):350-353.
Kennenni L (2008). Geography and phytosociology of *Acacia tortilis* in the Sudan. Afr. J. Ecol. 29(1):1-10. doi: 10.1111/j.1365-2028.1991.tb00814.x.
Lamprey HF, Harlery HF, Makacha S (1974). Interaction between Acacia bruchid beetles and large herbivores. EA fr. Wild J. 12:81-85.
Mattson MJ (1971). Relationship between cone crop size and cone damage by insects in red seed production areas, Can. Entomol. 103:317-621.
Maydell HJ (1990). Arbres et arbustes du Sahel leurs caractéristiques et leurs utilisations. Josef Margraf Scientific Book, Germany.
Membrives N, Pedrola-Monfort J, Caujapé-Castells J (2003). Correlations between morphological- anatomical leaf characteristics and environmental traits in Southwest African species of *Androcymbium* (Colchicaceae). Bot. Macaronesica 24:73-85.
Menwyelet A, Coppock DL, Detling JK (1994). Fruit production of *Acacia tortilis* and *Acacia nilotica* in semi-arid Ethiopia. Agroforest. Syst. 27:23-30.
Miller MF (1996). Acacia seed predation by bruchids in an African savanna ecosystem. J. Appl. Ecol. 33:1137-1144.
Moleele NM, Reed MS, Motoma L, Seabe O (2005). Seed weight patterns of *Acacia tortilis* from seven seed provenances across Botswana. Afr. J. Ecol. 43:146-149.
Monk D, Pate JS, Loneragan WA (1981). Biology of *Acacia pulchella* R.Br. with special reference to symbiotic nitrogen fixation. Aust. J. Bot. 29:579-92.
Qiang W, Wang XL, Chen T, Feng HY, An LS, He YQ, Wang G (2003). Variation in stomatal density and carbon isotope values in *Picea crassifolia* at different altitudes in Qilian Mountains. Trees (Berl) 17:258-262.
Raddad EY, Luukkanen O (2006). Adaptive genetic variation in water use efficiency and gum yield in *Acacia senegal* provenances grown on clay soil in the Blue Nile region, Sudan. For. Ecol. Manag. 226:219-229. doi:10.1016/ j.foreco.2006.01.036.
Riginos C, Young TP (2007). Positive and negative effects of grass, cattle, and wild herbivores on Acacia saplings in an East African savanna. Oecologia 153:985-995.
Roshetko JM (2001). Agroforestry species and technologies: a compilation of the highlights and factsheets published by NFTA and FACT Net 1895–1999. A Publication of Winrock International, Morrilton.
Ross JH (1975). Notes on African Acacia species. Bothalia 11:443-447.
Ross JH (1979). A Conspectus of the African Acacia Species. Botanical Research Institute, South Africa, pp. 21-58.
Singh P, Bhandari RS (1987). Insect pests of *Acacia tortilis* in India. Indian For. 113:734-743.
Singh P, Bhandari RS (1988). Insect pests of leguminous forest tree seed and their control. Indian For. 114:844-852.
Timberlake J (1980). Handbook of Botswana Acacias, Ministry of Agriculture, Gaborone (Botswana).
Tybirk K (1991). Regeneration of Woody Legumes in Sahel, in: AAU Report, vol. 27, Aarhus Univ. Press Aarhus Denmark 1991. pp. 1-81.
Vakshasya RK, Rajora OP, Rawat MS (1992). Seed and seedling traits of Dalbergia sissoo Roxb: seed source variation studies among 10 sources in India. For. Ecol Man. 48:265-275.
Verzino G, Carranza C, Ledesma M, Joseau J, Di Rienzo J (2003). Adaptive genetic variation of Prosopis chilensis (Molina) Stuntz. Preliminary results from one test-site. For. Ecol. Manage. 175:119-129.
Wakeling JL, Staver AC, Bond WJ (2011). Simply the best: the transition of savanna saplings to trees. Oikos 120(10):1448-1451.
Wickens GE (1969). A study of *Acacia albida* Del. (Mimosoideae). Kew Bull. 23:181-202.