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Morphological and Shape Pods Variability of *Acacia tortilis* ssp. *raddiana* (Savi) Brenan in South of Morocco

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ABSTRACT

Acacia raddiana (L.) Willd. is an African leguminous multipurpose tree species belonging to subfamily Mimosoideae, subgenus *Acacia*, highly valued for pods, leaves and gum production. This study estimated the genetic diversity within and among Moroccan populations of the species in the Agdz, N'Koub, Tazarine, Mceissi, Tata, Tissint, Fom Zguid, Gluemim, Msceid and Assa provenances based on 9 quantitative traits which included; Pod Length (LP) (cm), Pod Width (WP) (mm), Pod Weight (WtP) (g), Seed Weight per Pod (WtS P⁻¹) (g), Empty Pod Weight (WtEpP) (g), Seed Number per Pod (SN P⁻¹), Infected Seed Number per Pod (InSN P⁻¹) and 100-seed weight (100-Wt) (g) and shapes of pods throughout two seasons. In the both seasons provenances N'Koub, Tazarine and Tissint present the best means for the majority of traits studied, indicating geographical structuring of the genetic variability but it remained much reduced. Analysis of traits in various forms has shown that purely morphological criteria are inadequate for the selection of the *Acacia raddiana* trees which had a range of quantitative characters. The various traits are not regularly correlated with pods quality; they appear strictly in a variety of combinations and relations with environmental conditions. In view of this, any attempt for selection based on morpho-metrics traits of the polymorphic species must fail.

Key words: *Acacia raddiana*, pods, population structure, morphological variability, shapes of pods, selection

INTRODUCTION

The genus *Acacia* (Leguminosae, Mimosoideae) includes over 1350 species (Maslin, 2003). It is distributed in tropical and subtropical regions of the Americas, Australia, Africa and southern Asia (Guinet and Vassal, 1978; Ross, 1981; Luckow, 2005). The current classification of *Acacia* differentiates three subgenera (Ross, 1979): *Acacia*, *Heterophyllum* and *Aculeiferum*. Actually, with the progress of molecular analysis, the analyses of chloroplast genes have been informative in developing a better understanding of phylogenetic relationships of the group. The new data clearly show that the genus as presently defined (i.e., *Acacia sens. lat.*) is not monophyletic. Furthermore, five separate monophyletic groups can be recognised within *Acacia sens. lat.* and it is recommended that these each be recognised as a distinct genus. The five genera (Maslin *et al.*, 2003), *Acacia*,

Senegalia, *Racosperma*, *Acaciella* and a genus yet to be named, comprising species related to *A. coulteri*. Following the decision of the Nomenclature Session of the 17th International Botanical Congress (IBC) (Moore *et al.*, 2010) in Vienna decision the type of *Acacia* changes from the African/Asian species, nomenclaturally, the most significant changes apply to “*Acacia*” that occur in Africa, Asia and the Americas where less than half will become known as *Vachellia* (corresponding to the former *Acacia* subgenus *Acacia*) (Maslin, 2006) In Morocco, three species of *Acacia* exist in a wild state: *Acacia gummifera*, *Acacia ehrenbergiana* and *Acacia raddiana* (McDonald and Maslin, 2000). The base chromosome number in the genus *Acacia* is $x = 13$ with polyploidy occurring in several species, such as *Acacia nilotica*, *Acacia seyal* and *A. tortilis* (Forsk.) Hayne and *A. raddiana* (Savi) Brenan (Bennett *et al.*, 2000; Bukhari, 1997). Vegetation dominated by *Acacia raddiana* was founded in arid and Saharan areas. It exists in the main channels of the rivers and in rivers terraces with deep sediments where the stones and gravels cover a considerable part of the ground surface. In this very fragile environment, human pressure, altering climatic conditions and the use of wrong technology have provoked a long and dangerous process leading to the manifestation of desert biotopes, even in prior non-desert areas. Increasing populations and socioeconomic changes are responsible for overuse of this environment (Benmohammadi *et al.*, 2000), the destruction of vegetation has been encouraged by drought, especially since 1960. The most dramatic effect is the disappearance of *Acacia raddiana*. Currently, it only exists as a small stand scattered in the beds of rivers (Benmohammadi *et al.*, 2000). The trees of this species are generally very sparse and overused by local people, who have no other fuelwood (Khbaya *et al.*, 1998; Romdhane *et al.*, 2006). When the herbs have disappeared from the areas, local people turn to the foliage of the tress, to make fruits and foliage more accessible they delimb trees or even cut the tree down completely. Generally, in the more open conditions created, species have difficulty regenerating because soils become drier and more barren and seedling are subjects to water stress, which lowers their survival rate. One of the most crucial results of cutting tree, deforestation is the increase of opportunity of erosion and landslides which reduce soil fertility and water retention quality (Duponnois and Plenchette, 2003). Combination between desertification and ecosystem degradation problems in Mediterranean regions *Acacia tortilis* (Forsk.) Hayne ssp. *raddiana* (Savi) Brenan (Family Fabaceae; subfamily Mimosoideae) (Brenan, 1957), remains one of the only wild *Acacia* which grow spontaneously in arid and Saharan areas which makes it an important reforestation species. It has highly durable seeds, capable of endure fire and remain viable during medium to long-term storage in the soil. Namely, trees growing at low density in arid and semi-arid pastoral ecosystems have often been found to improve their understory environments, compared to neighboring grasslands, soils under tree crowns (canopies) (Belsky *et al.*, 1993), *Acacia raddiana* it shows remarkable climatic tolerance and ecological adaptability. It is characterized by a large ecological plasticity, colonizing regions receiving between 50 and 1,000 mm of annual precipitation (Ouarda *et al.*, 2009). *Acacia raddiana* forms a natural symbiosis with rhizobium and fix atmospheric nitrogen, it is the best in total N fixed, fixing 1.05 g N plant⁻¹ compared to an average of 0.48 g N plant⁻¹ for the other *Acacia* (Ndoye *et al.*, 1995), it is therefore often survive on land which is low in nitrogen and organic mater where other species fail, these characters allows its to be highly valued for soil fertility and improvement. Similar to other legumes, *Acacia raddiana* plays an significant role for fertility of poor and eroded soils, it form symbiotic associations with soil bacteria to fix atmospheric nitrogen, making them suitable for poor quality soils, this is proved by studies on the effect of *Acacia* trees on their physical, chemical and biological environments in different ecosystems (Belsky *et al.*, 1993; Hagos and Smit, 2005;

Abule *et al.*, 2005; Burke, 2006). The positive influence of *Acacia tortilis* subsp. *raddiana* in terms of soil enrichment in arid ecosystems is conformed especially for to soil organic matter, total N, P and Ca²⁺. Additionally, *Acacia raddiana* provides a staple browse especially the leaves and pods who serve as feed for sheep goats cattle and camels. Forage is accessible during most of the dry season when other sources are insufficient. Regrettably, populations of *Acacia raddiana* are under two compulsions: tree mortality (Ward and Rohner, 1997; Shrestha *et al.*, 2003) and infestation of seeds. Rate of infestation of the seeds varies greatly between years and trees (Ernst *et al.*, 1989; Derbel *et al.*, 2007). Restoration of stands of *Acacia raddiana* is made difficult due to overgrazing which adds its restrictive effects to those of aridity (Bijaber and Ahlafi, 2005) and infestation rate. Not much effect has been made in Morocco to develop management strategies for plantation and genetic conservation of *Acacia raddiana* despite the fact that it is a source of livelihood for many people in areas where it grows naturally. A coordinated effort to conserve stands of *Acacia raddiana* would be valuable to restore its ecosystems which would lead to effective utilization of the resources to improve productivity and quality of this tree. This would make a contribution to sustainable development in the south of morocco; there is urgent need to conduct genetic diversity assessment of the species throughout its natural habitats in the country. The knowledge of genetic diversity is a prerequisite for development of any strategy for germplasm collection, management and conservation, domestication and improvement of the species genetic resources (Chiveu *et al.*, 2009). Consequently, there is a need for provenance selection to offer indispensable information on the diversity and heritability of important traits (Dangasuk *et al.*, 1997). The morphological variability signifies the adaptation of the species to the environment and it may be genetically determined or environmentally induced. The objective of this study was to evaluate the genetic diversity among and within the Moroccan provenances of *Acacia raddiana* based on morphological differences in pod traits that are related to the success of species establishment and evaluation of stability of pod forms within provenances.

MATERIALS AND METHODS

A field study was carried out during July 2009 (season 1) and July 2010 (season 2) to study quantitative variation in ten provenances of *A. raddiana* in morocco.

Provenances sampled: Ten isolated natural provenances: Agdz, N'Koub, Tazarine, Mceissi, Tata, Tissint, Fom Zguid, Gluemim, Msceid and Assa were collected. They were chosen to represent a range of different geographical locations between latitude 28°02' N to 31°13' N and longitude between 4°48' W to 10°50' W in south of Morocco. Three hundred pods were collected from ten mother trees that were separated from each other by more than 100 m to minimize the risk of sampling closely related individuals.

Location and climate of site under study: Sites under study are situated in one of the driest river basins of the world (Revengea *et al.*, 1998), Drâa valley, where water is a rare and precious resource. The Drâa basin can be roughly divided into three main units, the High Atlas Mountains, the basin of Ouarzazate and the Anti-Atlas (De Jong *et al.*, 2008). The Drâa river basin is characterized by arid climatic conditions (Hubener *et al.*, 2005). It is dominated by a bimodal distribution of annual precipitation and high rainfall variability (Klose *et al.*, 2008). Precipitation decreases generally from North to South. Annual precipitation north of the Anti-Atlas Mountains is around 200-300 mm. South of the Anti-Atlas annual precipitation rates decline to 100-200 mm

(Schulz *et al.*, 2008), in province of Zagora the average annual rainfall is about 60 mm. Rainfall varies during the year with less rain in the summer months and more rainy days in the winter period. Generally, two precipitation maxima can be distinguished within one year, the first around October to December and the second around February and March. The temperature variations are large and the evaporation rates (2000-3000 mm year⁻¹ on average) regularly exceed rainfall rates.

Quantitative trait measurement in the laboratory: Thirty pods were selected randomly from the one hundred pods collected per tree for measurement of pod length (cm) and width (mm), by use of a vernier caliper and thread. Number of seeds in each pod measured was counted and weighed (g); also, the weight of empty pod was taken (g). Weight of 300 randomly selected seeds per tree for the ten populations was also determined using a weighing balance to the nearest 0.001 g.

Six hundred trees were identified based on the eight morpho-metric traits of mature pods: pod length (LP) (cm), pod width (WP) (mm), pod weight (WtP) (g), seed weight per pod (WtS P⁻¹) (g), empty pod weight (WtEpP) (g), seed number per pod (SN P⁻¹), Infected seed number per pod (InSN P⁻¹) and 100-seed weight (100-Wt) (g). Each provenance consisted of ten mother-tree and thirty pods per tree with three replications to provide genetic variation.

The observation of pods allows as detecting a high level of morphological polymorphism within provenances. Characteristics of *Acacia* pods varied considerably. It possessed highly coiled pods flat and an uncoiled pod (Lakshmi and Gopakumar, 2009). To be sure, a representative sample of ten pods each of the six provenances studied, illustrates the existence of various shapes of the pods. In this study we did not give importance to the color of the pod since it is generally comparable. In addition, morphological traits related to the shape of the pods were observed. Thus it was determined by six basic shapes: elongated, spiral, wavy, round, arched (Fig. 1). Traditionally, production and fruit quality, including its shape, have been widely exploited as basic criteria for selection in some species such as carob. For experts, these trait help to differentiate the wild-type and Caroubier type cultivar.

Statistical analysis: All statistical analyses were performed with STATISTICA software. Analyses of variance were carried out on data using the GLM procedure. The broad sens heritability (h^2_b) was assigned for the data of each season according to Nanson (1970) and Jacques *et al.* (2004). The Phenotypic Coefficient of Variance (PCV%) and genotypic coefficient of variance were computed according to (Baye and Becker, 2005; Diaz *et al.*, 2007). Conventional genotypic gain was estimated (Nanson, 2004; Jacques *et al.*, 2004).

The portion of variance attributed to each factor was estimated from expected mean squares in the analysis of variance (Table 1).

Table 1: Expected mean squares for analysis of variance of *Acacia raddiana* pod

Source of variation	Degrees of freedom	Mean squares	Expected mean squares
Season	1	MS _s	$\sigma^2 + 30 \sigma_{s \cdot tP-1}^2 + 3000 \sigma_s^2$
Provenance	9	MS _p	$\sigma^2 + 60 \sigma_{tP-1}^2 + 3000 \sigma_p^2$
Season * Provenance	9	MS _{s*p}	$\sigma^2 + 30 \sigma_{s \cdot tP-1}^2 + 300 \sigma_{s \cdot p}^2$
Tree Provenance ⁻¹	90	MS _{tP-1}	$\sigma^2 + 60 \sigma_{tP-1}^2$
Season*Tree/ Provenance	90	MS _{s \cdot tP-1}	$\sigma^2 + 30 \sigma_{s \cdot tP-1}^2$
Season*Tree/ Provenance*	5800	MS _e	σ^2

σ^2 : Error variance, σ_{tP-1}^2 : Variance of genotype within provenance, σ_p^2 : Variance of provenance, σ_s^2 : Variance of season, *Sampled trees

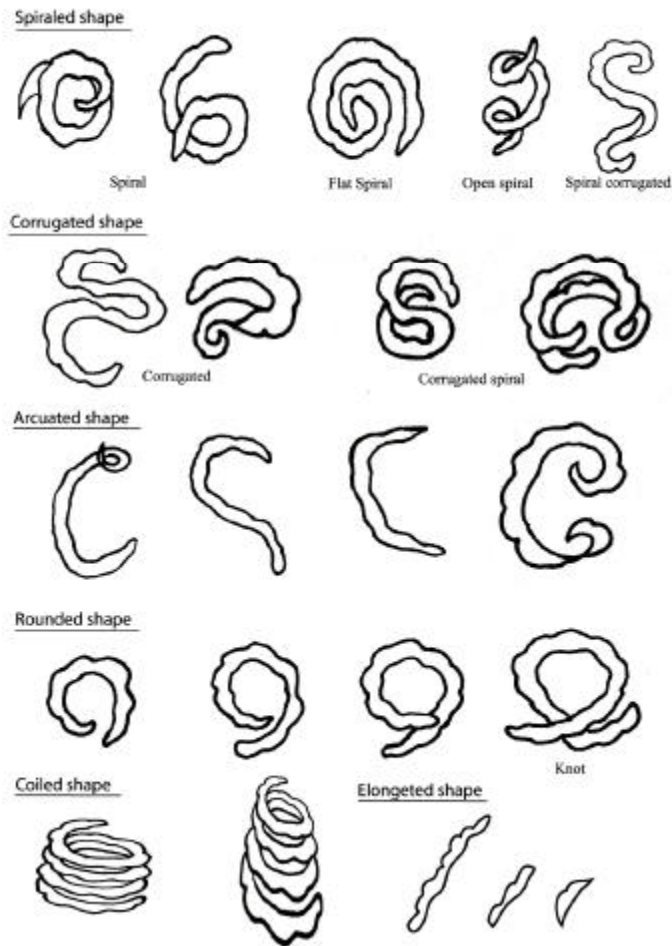


Fig. 1: Typical pod shape of Moroccan *Acacia raddiana*

RESULTS

Descriptive statistics for 9 traits in ten *Acacia raddiana* provenances including the minimum, maximum, mean and their standard deviations for data averaged over the two seasons are summarized in Table 2. In general, all the traits exhibited wide range of variation.

Descriptive statistics of quantitative variables: The mean and coefficient of variation of the various traits observed in the two years of study are presented in Table 2. Large variations appeared for all traits considered, between the provenance and the seasons. Morphological traits of the pod width and weight of 100 seeds were regularly less variable in succession they did not exceed 12 and 20%. The coefficients of variation of number of infected seeds were above 70% for two seasons with values of 87.16 and 73.53% sequentially for the first and the second season, while the width of the pods were lower to 15%. Other morphological traits of the pod studied showed intermediate levels of variability, between 18 and 37%.

Levels of variation are very similar between the two years, the values of means, minimum and maximum show that the conditions of two years were similar, with the exception of the length of

Table 2: Descriptive statistics of characters measured in 100 genotypes within 10 provenances of *Acacia tortilis* (Forsk.) Hayne ssp. *raddiana* (Savi) Brenan

Variables	Season	Mean	Min.	Max.
(a) The values of means, minimum and maximum				
Pod length	1	13.14	1.36	28.20
	2	13.12	3.60	27.00
Pod width	1	7.40	3.97	11.08
	2	7.33	3.97	11.08
Pod weight	1	1.10	0.14	2.97
	2	1.08	0.25	2.97
Seed weight pod ⁻¹	1	0.44	0.03	1.29
	2	0.42	0.03	1.16
Empty pod weight	1	0.65	0.06	2.26
	2	0.66	0.06	2.04
Seed number pod ⁻¹	1	7.59	1.00	15.00
	2	7.50	1.00	15.00
Infected seed number pod ⁻¹	1	3.78	0.00	13.00
	2	3.85	0.00	13.00
100-seed weight	1	6.56	3.16	11.00
	2	6.68	3.40	11.00

Variables	Mean	Provenances					Genotype/Provenance				
		df	(SD)	CV %	F	R ²	df	(SD)	CV %	F	R ²
(b) Intensity of effects (R²)											
Season 1											
Pod length	13.16	9	3.54	26.88	3.27**	24.64	90	3.54	26.88	22.37***	75.36
Pod width	7.47	9	0.91	12.17	0.47ns	4.54	90	0.91	12.17	62.38***	95.46
Pod weight	1.11	9	0.39	34.7	1.08ns	9.77	90	0.39	34.7	27.02***	90.23
Seed weight Pod ⁻¹	0.47	9	0.18	37.91	2.31ns	18.77	90	0.18	37.91	18.58***	81.23
Empty pod weight	0.65	9	0.25	39.12	0.75ns	7.01	90	0.25	39.12	35.76***	92.99
Seed No. Pod ⁻¹	7.68	9	2.14	27.87	3.98***	28.5	90	2.14	27.87	8.58***	71.50
Infected seed No. Pod ⁻¹	3.71	9	3.23	87.16	31.68***	76.01	90	3.23	87.16	12.45***	23.99
100-seed weight	6.44	9	1.18	18.39	0.90ns	8.3	90	1.18	18.39	385.06***	91.70
Season 2											
Pod length	13.12	9	3.44	26.21	3.48***	25.82	90	3.44	26.21	14.05***	74.18
Pod width	7.33	9	0.94	12.84	1.10ns	9.94	90	0.94	12.84	39.97***	90.06
Pod weight	1.08	9	0.37	34.18	2.87***	22.32	90	0.37	34.18	16.13***	77.68
Seed weight Pod ⁻¹	0.42	9	0.16	39.44	2.94**	22.73	90	0.16	39.44	13.94***	77.27
Empty pod weight	0.66	9	0.25	38.12	3.27***	24.68	90	0.25	38.12	17.49***	75.32
Seed No. Pod ⁻¹	7.5	9	2.08	27.7	4.90***	32.89	90	2.08	27.7	5.69***	67.11
Infected seed No. Pod ⁻¹	3.85	9	2.83	73.53	15.46***	60.73	90	2.83	73.53	7.969***	39.27
100-seed weight	6.68	9	1.36	20.37	2.55ns	20.34	90	1.36	20.37	378.16***	79.66

*** Significant at $\alpha = 0.001$, ** Significant at $\alpha = 0.01$, * Significant at $\alpha = 0.05$, ns: Non-significant

the pod where the minimum was 1.36 cm in the first season and 3.60 cm in the second (Table 2a). This discard of nearly 50% was not accompanied by significant differences in other morphological characters studied. This means identifying values, maximum and minimum between the two years could be due to the similarity of the conditions of rainfall in the two years.

The interaction of two years showed the same trends of variance that every year presented independently. We demonstrated by the calculation of the index of the intensity of effects (R²) (Table 2b; Fig. 3) that the genotype had exercised more than 30% effect on all of the variance

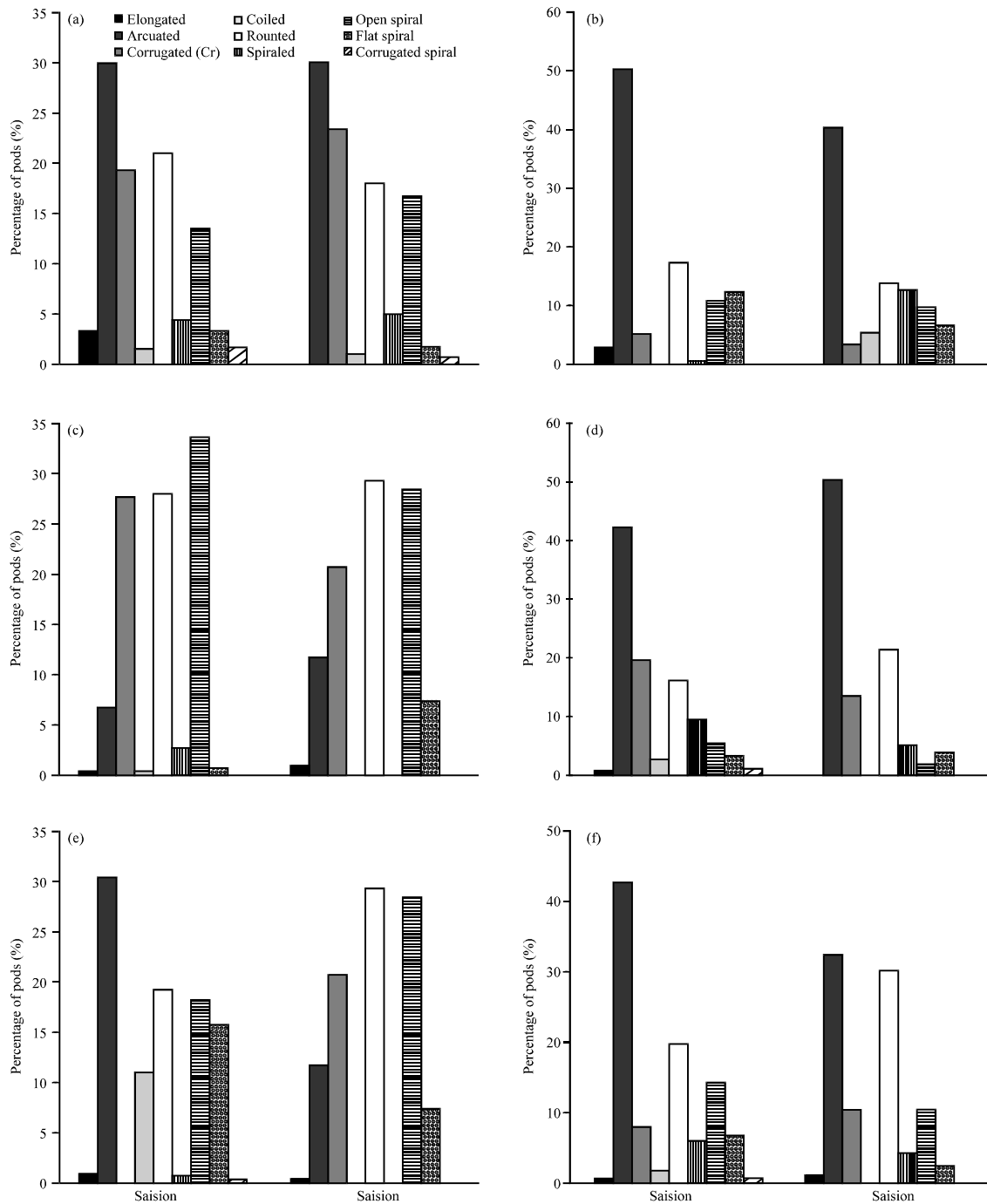


Fig. 2(a-f): Percentage of Pod shapes in provenances, (a) Foug Zgud, (b) Assa, (c) Tissint, (d) Mceissi, (e) Msceid, (f) Gluemim

observed in the provenance, this intensity increases to over than 40% in its combination with the factor of season for most characters studied. The trait number of seeds infected per pod escapes of this effect; we observed that the effect of the provenance factor on the variance exceeds 39 and

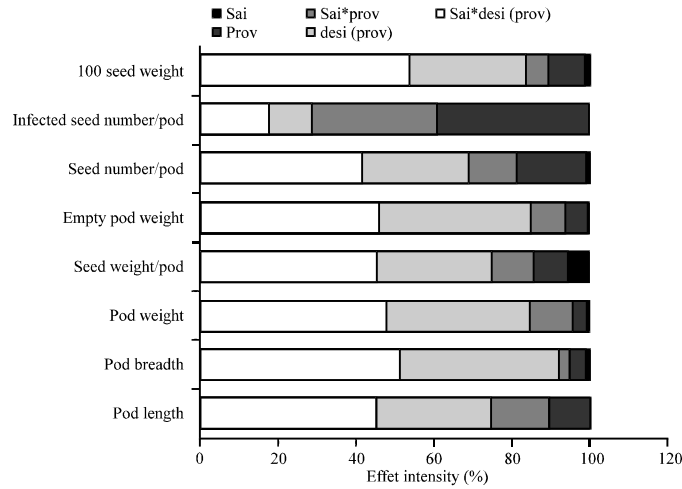


Fig. 3: Effect of factor on variation expression

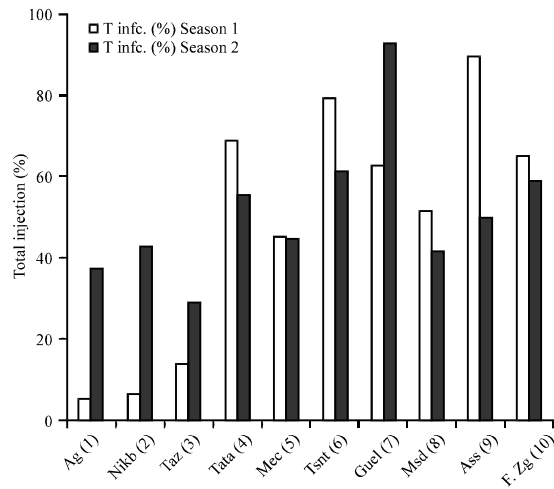


Fig. 4: Infection rate of seeds between the provenances

30% for the effect of the season factor. It should be explained by the rate of infestation of the seeds that varied greatly between genotypes from the same provenance and same genotype between two different years (Fig. 4).

Structure of the phenotypic variation: The relative importance of inter-component provenances, inter and intra-genotype of the phenotypic variance was different depending on the trait in question and showed a similar pattern between the two seasons (Fig. 5).

The variation of morphological traits (LP, WP, WtP, WtS P^{-1} and WtEpP) was dominated by components: inter and intra-genotype, the rest of their variation was represented by the component inter-provenances (except for WP for which the variation between provenances was almost zero).

The variance in number of infected seed per pods was signed by the inter-provenance and intra-genotype components. The weight of 100 seeds per pod was the trait most strongly marked at the level of genotypes.

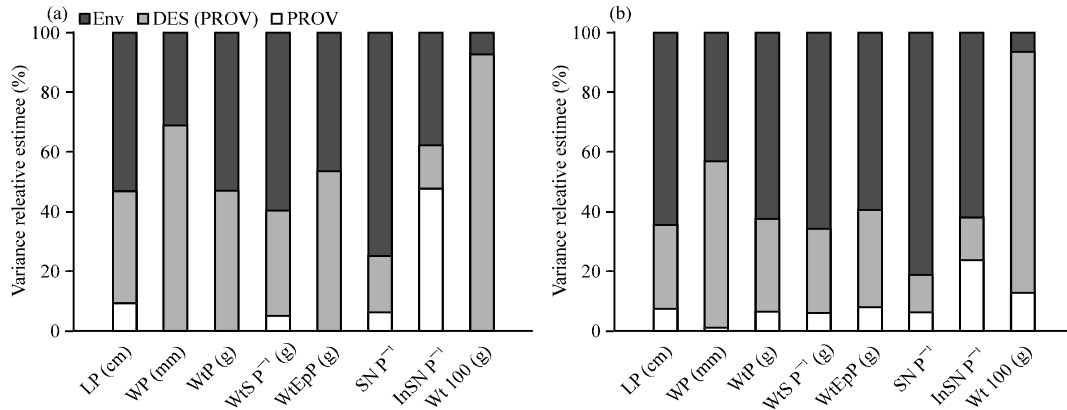


Fig. 5(a-b): Distribution of the phenotypic variance within ten provenances of *Acacia* in (a) season 1 and (b) season 2

The intra-genotype variance (inter-pod) was more important than the other for most traits studied except for the characters WP, InSN P⁻¹ and weight of 100 seeds. It has even become dominant in season 2 for the trait SN P⁻¹, with development of its contribution for the remaining traits. This reflects the importance of intra-genotype variance under the same environmental and microclimatic conditions.

Two groups of traits seem to be distinguished:

- Those closely related to the genotypes (mother tree) (weight of 100 seeds, the width of the pod): they are primarily characteristics of the genotypes themselves
- Those related to the quality of the pod (pod weight, weight of seeds per pod, empty pod weight and number of infected seeds per pod): they were more dependent on the level of the pod and related to the particular conditions of fertilization and infestation that takes place during the phenology, where both phenomena occur with different probabilities within the same genotype. This pattern also seems to relate well illustrated for the number of infected seeds per pod as suggested by the increase in intra-genotype variance in season 2

It is therefore not strictly morpho-metric traits of pods that were related but rather a result of two independent phenomena acting strongly on the quality of the pod.

Inter-provenance variation: Statistically significant differences existed between the ten provenances of *Acacia raddiana* for both seasons (Table 2b). Traits LP, SN P⁻¹ and InSN P⁻¹ were showed significant differences inter provenance and stable between the two years of study: Agdz N’Koub, followed by Tazarine Mecissi, Foum Zguid and Tissint with the most highly means for these traits, except Tissint who presented for the two seasons of high infestation rate compared to other sites.

The characters WtP and WtEpP have changed the status of non-significant difference in the season 1 with a significant difference in season 2, the traits WP and weight of 100 seeds kept a non-significant difference between the provenances consistently for the two years.

Stability of inter-season traits: pod length, number of seeds per pod and seed number of infected pods reflects the relationship between the size of the pod and seed production, despite some

fluctuations in production due to infestations but overall it remains stable within the same provenance. These traits may be characteristics of provenance, but only tests the behavior of genotypes respond to environmental stresses lead to the conclusion marked.

Variation inter-genotype: The *Acacia raddiana* is specie with an allogamy and entomophily reproduction recognized for its polyploidy and our measurements have been performed on non-protected sites, wild, where the maternal effects were strong and was contributed to a significantly inter-genotype variance, hence its importance in relation to the inter-provenance variance. It depended on: the year, the population and the traits considered.

In general, the intra-genotype variability exceeded the inter-genotype for almost all provenances, suggesting that heritability of morphological traits of the pod would be less for most traits involved except 100-seed weight and width of the pod.

For provenance, the variability inter-provenance depended largely on the trait considered, for some it retains the same pattern of variation between the two seasons for other provenances it fluctuates widely, reflecting the contribution of environmental conditions, climate interaction with polyploidy of the specie.

However, two groups of variables can be distinguished:

- LP, WtP, WtS P^{-1} and WtEpP, WS and InSN P^{-1} , where the proportion of inter-genotype variance varied considerably between provenances and years. For example Tissint, the proportion for trait LP passes from 70% in season 1 to 18% for year 2 and for the WtEpP 58% in season 1 to 31% in season 2
- The characteristic 100-seed weight generally had an inter-genotype variation greater than 80% and WP exceeded 45%

Estimation of the genetic parameters: To compare the variation among various traits, estimates of variance components (σ^2_p , σ^2_g , $\sigma^2_g P^{-1}$), phenotypic (PCV) and Genotypic Coefficient of Variability (GCV), broad sense heritability (h^2_b) and Genetic Advance (GA) as a percentage of mean are given in (Table 3). For most traits the genotype-environment interactions ($\sigma^2_g P^{-1}$) are larger than the genetic variance (σ^2_g).

In the first and second season, lowest value of Phenotypic Coefficient of Variability (PCV) was noted for the character pod width, with successively 12.42-12.84% and it decreased to 10.62 in the interaction of the both years. While, highest value was noted for infected seed number per pod with successively 64.48, 65.02, for the first and second season and it decreased to 61.32 in the interaction of the both. For both traits the value decreases in the interaction of two seasons.

The Genotypic Coefficient of Variation (GCV) showed similar trends as (PCV) and ranged between 10.65, 9.18% for pod width and 33.89, 28.23% for infected seed number per pod simultaneously for the first and second seasons. Heritability (h^2) estimates range from 20.19, 13.53% for seed number per pod to 92.75, 92.63% for 100 seed weight. High heritability does not necessarily mean high genetic gain. The utility of heritability estimates is, therefore, increased when they are used to estimate genetic advance (GA) (Johnson *et al.*, 1955) which indicates the degree of gain in a character obtained under a particular selection pressure.

Coefficients of correlation: The coefficients of correlation between traits observed each year are presented in Table 5. Most of the traits related to the size of the pod (pod weight, seed weight of the pod, the weight of empty pod and number of seeds per pod) were positively correlated with the

Table 3: Estimation of genetic parameters for pods traits in *Acacia tortilis* (Forsk.) Hayne ssp. *raddiana* (Savi) Brenan

Variables	Season	PCV (%)	GCV (%)	h ² %	GA%	R ²
Pod length	1	25.81	16.65	41.61	10.74	
	2	25.34	13.95	30.32	7.68	
	1*2	23.22	11.01	22.49	5.22	11.42
Pod width	1	12.42	10.18	67.17	8.34	
	2	12.84	9.65	56.51	7.26	
	1*2	10.62	7.33	47.63	5.06	20.37
Pod weight	1	34.71	23.66	46.45	16.13	
	2	33.24	19.25	33.53	11.15	
	1*2	30.53	15.61	26.15	7.98	14.03
Seed weight pod ⁻¹	1	37.13	22.57	36.96	13.72	
	2	38.42	21.09	30.14	11.58	
	1*2	34.75	16.24	21.84	7.59	10.88
Empty pod weight	1	39.47	28.91	53.68	21.18	
	2	36.79	21.92	35.48	13.05	
	1*2	33.79	18.50	29.98	10.13	16.54
Seed No. pod ⁻¹	1	27.07	12.17	20.19	5.47	
	2	26.96	9.92	13.53	3.65	
	1*2	25.60	7.02	7.51	1.92	5.82
Infected seed No. pod ⁻¹	1	64.48	33.89	27.63	17.81	
	2	65.02	28.23	18.85	12.26	
	1*2	61.32	23.03	14.11	8.65	7.43
100-seed weight	1	18.55	17.86	92.75	17.2	
	2	19.24	18.52	92.63	17.82	
	1*2	14.30	13.36	87.22	12.48	20.82

Table 4: Mean performance for the both season of ten provenances of *Acacia tortilis* (Forsk.) Hayne ssp. *raddiana* (Savi) Brenan (test Duncan $\alpha = 0.001$)

Variables	Agdz	N'Koub	Tazarine	F. Zguid	Mecissi	Tissint	Tata	Gluemim	Msceid	Assa
Season 1										
LNGS (mm)	13.07 ^{cd}	13.80 ^{bc}	13.91 ^{bc}	11.92 ^d	12.16 ^d	15.68 ^a	14.52 ^{ab}	12.18 ^d	11.91 ^d	12.42 ^d
LRGS (mm)	7.49 ^a	7.35 ^a	7.32 ^a	7.77 ^a	7.68 ^a	7.38 ^a	7.53 ^a	7.27 ^a	7.31 ^a	7.51 ^a
PGSp (g)	1.01 ^a	1.23 ^a	1.20 ^a	0.97 ^a	1.13 ^a	1.22 ^a	1.14 ^a	1.06 ^a	1.09 ^a	1.06 ^a
PGR/GS (g)	0.46 ^a	0.53 ^a	0.51 ^a	0.37 ^a	0.51 ^a	0.50 ^a	0.49 ^a	0.41 ^a	0.42 ^a	0.43 ^a
PGS - PGR	0.54 ^a	0.69 ^a	0.68 ^a	0.59 ^a	0.61 ^a	0.71 ^a	0.64 ^a	0.64 ^a	0.66 ^a	0.63 ^a
NGR/GS	7.07 ^{cd}	8.41 ^a	8.01 ^{ab}	6.41 ^d	7.99 ^{ab}	8.43 ^a	7.64 ^{abc}	7.30 ^{abc}	7.96 ^{ab}	7.52 ^{abc}
NGRI/GS	0.37 ^a	0.56 ^a	1.11 ^a	4.15 ^{bc}	3.61 ^b	6.67 ^d	5.25 ^c	4.56 ^{bc}	4.09 ^{bc}	6.70 ^d
P100 Gr	6.93 ^a	6.55 ^a	6.69 ^a	6.23 ^a	6.75 ^a	6.27 ^a	6.66 ^a	6.15 ^a	5.76 ^a	6.38 ^a
Season 2										
LNGS (mm)	13.93 ^{ab}	13.27 ^{abc}	13.47 ^{abc}	13.94 ^{ab}	14.96 ^a	12.88 ^{abc}	13.63 ^{abc}	11.64 ^f	11.55 ^f	11.90 ^{bc}
LRGS (mm)	7.28 ^a	7.44 ^a	7.26 ^a	7.78 ^a	7.15 ^a	7.43 ^a	7.62 ^a	7.23 ^a	6.98 ^a	7.14 ^a
PGSp (g)	1.06 ^{ab}	1.17 ^{ab}	1.09 ^{ab}	1.24 ^a	1.20 ^{ab}	1.00 ^{ab}	1.15 ^{ab}	0.99 ^{ab}	0.93 ^a	0.90 ^a
PGR/GS (g)	0.38 ^a	0.50 ^a	0.45 ^a	0.44 ^a	0.42 ^a	0.34 ^a	0.46 ^a	0.38 ^a	0.38 ^a	0.37 ^a
PGS-PGR	0.67 ^{ab}	0.66 ^{ab}	0.64 ^{ab}	0.79 ^a	0.78 ^a	0.66 ^{ab}	0.68 ^{ab}	0.61 ^{ab}	0.55 ^b	0.53 ^b
NGR/GS	7.52 ^{ab}	7.99 ^a	8.24 ^a	7.08 ^{ab}	7.97 ^a	7.98 ^a	7.59 ^{ab}	6.64 ^b	6.63 ^b	7.33 ^{ab}
NGRI/GS	3.22 ^{abc}	2.98 ^{ab}	2.39 ^a	3.93 ^{bcd}	4.88 ^d	7.39 ^e	3.39 ^{abc}	2.75 ^a	3.29 ^{abc}	4.30 ^d
P100 Gr	3.22 ^a	2.98 ^a	2.39 ^a	3.93 ^a	4.88 ^a	7.39 ^a	3.39 ^a	2.75 ^a	3.29 ^a	4.30 ^a

Table 5: Spearman correlation among different morph-metrics traits of *Acacia tortilis* (Forsk.) Hayne ssp. *raddiana* (Savi) Brenan

	LP (cm)	WP (mm)	WtP (g)	WtS P ⁻¹ (g)	WtEpP (g)	SN P ⁻¹	InSN P ⁻¹
WP (mm)	0.214***						
WtP (g)	0.765***	0.484***					
WtS P ⁻¹ (g)	0.607***	0.383***	0.834***				
WtEpP (g)	0.730***	0.462***	0.926***	0.563***			
SN P ⁻¹	0.640***	0.022ns	0.649***	0.672***	0.511***		
InSN P ⁻¹	0.240***	0.005ns	0.159***	0.026**	0.220***	0.329***	
Wt100 _{unfs} (g)	0.198***	0.444***	0.386***	0.447***	0.272***	-0.034**	-0.149***

*** Significant at $\alpha = 0.001$; ** Significant at $\alpha = 0.01$; * Significant at $\alpha = 0.05$; ns non-significant

length of the pod. However, it remains independent of the index of the quality of seed production in our study represented by the weight of 100 seeds uninfected. In both seasons, seed production was also positively related to moderately correlated with the width of the pod, weight of the pod and seed weight of the pod with a value of $r = 35$.

The coefficients of correlation were the lowest recorded for the number of infected seed pod which underlines the non-existence of any link between the quality features of the pod and the seeds of infection. Although, the infestation of the pods of *Acacia raddiana* occurs in a very early period of flowering, this does not alter the development of the pod (length, width, weight of the pod) and hence it has no effect on the quality of the pod except for the number of seeds per pod, but it remains very low with an average value of $r = 0.31$.

Shape of pods: In the both seasons and for all the provenances the most abundant shape of pods was, arcuated and round. Maximum of arcuated shape was noted in Tissint and Assa provenances 50.33% and for round shape in Gluemim 30% in the first season and in Tissint 28% in the second season. Tissint make the exception, where we were noted coexistence of the form corrugated, round and spiral corrugated. Complicated shape such as spiral corrugated, corrugated spiral and coiled remained in very low percentages in the both seasons.

Discussion: Many parameters affect growth and health condition of *A. raddiana*. These are physical factors (climate, soils, water balance and topography), biological factors (diseases and pests, especially insect) and traditional constraints (human land use systems). The study of pods morpho-metrics traits of the natural populations is often considered to be useful step in the study of the genetic variability (Kaushik *et al.*, 2007). This would involve identifying different provenances representing homogenous environmental zones within which selections are deployed and used in further breeding. Phenotypic variation is determined by genotype and environment interactions and is assumed to be the expression of genotypic variation when environmental conditions are controlled (Dangasuk *et al.*, 1997; Cony and Trione, 1998; Westoby *et al.*, 2002; Moles and Westoby, 2004).

In this study, pod characteristics in *A. raddiana* indicated variation within and among provenances in which the soil and geographic position was clearly different. The large variance of the population for the characters implied that the selection for these traits can be successful (Alake *et al.*, 2012). Variation of traits in *Acacia raddiana* pods could be due to the fact that the species grow over a wide range of rainfall, temperature and soil type. Membrives *et al.* (2003) reported that some morphological characteristics associated with soil texture. This can be assumed to reflect true genetic variation and adaptation to different edaphic conditions. Raddad (2007)

noticed that in Sudan, clay plain provenances showed considerable variation in seed weight and seed number of pods of *Acacia senegal*. They had the smallest seed weight but the highest seed number, while the sand provenances had the largest seed weight but lowest seed number. The morphological variation found in pods of *Acacia raddiana* (El-Ayadi *et al.*, 2011) also tended to follow this variation, with the altitude, distance from the water source and soil quality. For this, in the both seasons provenances N'Koub, Tazarine and Tissint present the best means for the majority of traits studied (Table 4). Although, the provenance of Msceid is close to the sea, but the quality of the pods was minimal, it was explained by the fact that this source is isolated in the desert, without any protection from strong and hot winds of South and South East of Morocco. Studies have showed good tolerance of the species to salinity, since it is able to germinate in high concentrations of salt (Jaouadi *et al.*, 2010), it was widely grown where drainage was adequate but it does not tolerate poorly drained soils whether they were saline or otherwise.

Variability of a character is measured by range and Genotypic Coefficient of Variation (GCV). Genotypic variation is useful when selecting genotypes to improve particular traits (Okeno, 2002). In most of the cases large difference between genotypic and phenotypic coefficient of variations was observed indicating that environment had great influence on the expression of most of the characters, except for pod width and 100-seed weight. For all the characters studied, the factors genotype (Des) and season (Sat) had a great effect on the variation, with the exception of character pod width where the factor provenance (prov) and season play an important role in the variations detected (Fig. 3). Best values of heritability for the both season were noted for 100-seed weight (92.75-92.93%) and pod width (67.17-56.51%). The height value of heritability noted for pod width and weight of empty pod reflected the predominance of heritable variation for this trait. High heritability does not necessarily mean high genetic gain. The utility of heritability estimates is, therefore, increased when they are used to estimate genetic advance (Johnson *et al.*, 1955) which indicates the degree of gain in a character obtained under a particular selection pressure. Low heritability for weight, seed number and infected seed number per pod can be explained by the loss of weight and seed by abortion and hard infestation of seed. Johnson *et al.* (1955) found that heritability value along with estimates of genotypic gain were more useful than heritability alone in predicting the effect of selection. High heritability estimates associated with high genotypic conventional gain were obtained for the traits: 100-seed weight and pod weight for the both season.

Repeatability parameters of yield represented by number of seeds per pod and weight of 100 seeds were estimated (Table 3). It was observed that the response of yield and its basic components were dependent of environmental variation. The height value was noted for 100-seed weight and pod width successively (20.822-20.371%) but the values remain low and could not be useful in the selection of cultivars stable for grain yield.

Each tree develops more than two types of pods. Usually around 30 pods were collected per tree; most of pods (9-15) possess arquated shape with the exception of Tissint provenance with value of 3 arquated pods per tree. Less than 0.3% of pod was smaller (1.36-3.6 cm). Different shapes of pods were collected at the end of the mature tree period. Number of seeds per pod varied in the wide range (1-15 per pod), with a seed-coat color range from various shades of brown. These colors are further varied within pods of the same tree and within provenance. It has to be noted that because *Acacia raddiana* is predominantly open-pollinated tree and are usually non uniform, were one for the reasons for the observed morphological difference in pods shape. But also we found an average of two to three trees with regular shape of pods in each provenance for the both seasons with the exception of the provenance Foum Zguid devoid of regular shape of tree. In the both season the

arquated pods were dominated in the provenance of Assa, Mceissi Gluemim, followed by Msceid and Foum Zguid (Fig. 2). Most identical shape of pods was focused in the center of the crown. While around peripheral, the shape of pods was much more varied. It may be due to easy access by insects to peripheral flowers, they were pollinated by the first flowers found in their way. The flowers in the center had tendency of self-pollination the percentage of diversity of form was due to polyploidy, who compensated the diversity of this specie.

CONCLUSION

In this study, morpho-metric traits were used for characterization of genetic diversity within and among natural populations of *Acacia raddiana* in Morocco. Secondly, all the morpho-metric traits were correlated to pod shape in order to establish any relationship which might exist between them. The information obtained would be used for germplasm conservation, management and selection for domestication and improved tree regeneration. Our study on provenances showed that all morpho-metric characters are influenced by environment (soil quality, temperature and annual rainfall) and genetic factors. We have observed significant variations within tree in provenance, provenances and season in all traits. Intra and inter-provenance variability were of the same order; therefore, it was very difficult to characterize provenances according to their geographic origin. This diversity is explained by the type of pollination and polyploidy in this species which makes very difficult a breeding program based on morphological markers. A detailed morphological analysis of a number of characters in the various forms has shown that purely morphological criteria are inadequate for the selection of the trees which had a range of better trait morpho-metrics. The various traits are not regularly correlated with pods quality; they appear strictly in a variety of combinations and relations with environmental conditions. In view of this, any attempt for selection based on morpho-metrics traits of the polymorphic species must fail.

In order to make *Acacia raddiana* rural in Morocco a commercially practicable business, there is urgent need to accomplish molecular genetic diversity assessment of the species throughout its natural habitats in the country. The hyper-variability of molecular markers constitutes great advantages for these types of studies. Further research including available ISSR (inter simple sequence repeats) and microsatellites marker would hopefully provide additional information.

ABBREVIATION

LP (cm)	=	Pod length
WP (mm)	=	Pod width
WtP (g)	=	Pod weight
WtS P ⁻¹ (g)	=	Seeds weight per pod
WtEpP (g)	=	Empty pod weight
SN P ⁻¹	=	Seed number per pod
InSN P ⁻¹	=	Infected seed number per pod
Wt100 (g)	=	100-seed weight
Des	=	Genotype
Sat	=	Season
Pro	=	Provenance

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