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Modeling of Date Palm (*Phoenix dactylifera* L.) Vegetative Aerial Architecture, Example of Two Tunisian Cultivars

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Abstract: The present study was carried out to verify the statistical relationships between the characteristic parameters in terms of vegetative aerial architecture of the date palms for simulating realistic 3D models. The vegetal material was composed of two Tunisian varieties of *Phoenix dactylifera* L., “Barhi” and “Rochdi”. The observations are taken place in Gabes and on one pair of palms per main stem and offshoot for each cultivar. The analysis of the characteristic dimensions of the pinnae and rachis allowed the determination of a minimum sample. The geometrical analysis confirmed the existence of a strong correlation between rotation angles and radial angles. The architectural analysis of the two Tunisian cultivars revealed that the distribution of characteristic parameter values of pinnae was the outcome of a regionalized variable along the rachis. This statistical study of relationships between the characteristic parameters in terms of vegetative aerial architecture of the two varieties allows executing a new measurement protocol for computing and simulating realistic 3D models.

Key words: *Phoenix dactylifera* L., modeling, architecture, minimum sample, correlation.

1. Introduction

Plant architecture is defined like the whole of the structural forms which the plant presents through its existence; topology is the way in which its organs are laid out the ones linked to the others, while the geometry describes the size and arrangement in the space of these organs [1]. Date palm, *Phoenix dactylifera* L. (*Arecaceae*), is a dioecious monocotyledon; its vegetative propagation through shoot cuttings is widely practiced. Belonging to the *Phoeniceae* tribe [2] classified in the model of *Corner* or the mode of *Tomlinson* for the trees carrying of the rejections according to the botanist [3], the date palm is built with one vegetative axis with apical continues growth and a massive crown of leaves with thorny base; the inflorescence are produced laterally to the palm leaves .

In the context of the present study, we focus on the architectures and the geometry of the palms of this species.

Several studies have dealt with architecture in *Arecaceae*. The first measurement of date palm architecture has been done in 1989 [4] and later in 2002 [5]. MOCAF Phoenix network, which is a Euromediterranean project, carries out studies on date palm but always remaining bounded to the other palm trees researches.

2. Materials and Methods

The vegetal material was composed of two Tunisian cultivars: “Barhi” and “Rochdi”. The measured palms were taken in the palm groves of Gabes in Tunisia. Observations were conducted on one pair of palms per main stem and offshoot for each variety.

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Modeling a palm tree needs the measurements of various metric and geometrical parameters which are necessary to feed the model able to simulate the fronds of the date palm.

Metric measurement related to the rachis characteristics including the rachis length from the insertion on the stem to the extremity, widths and height taken every 10 cm and length of the spiny and pinnate parts measured with one tape meter.

Metric characteristics of the pinnae throughout the rachis counting pinnae length, pinnae opening at the first and second third of their length, pinnae width at the base, the first and the second third of their length, they were measured by means of digital caliper.

Geometrical characteristics of the pinnae, these parameters are three main insertion angles of pinnae relative to the rachis directions: axial angle is the angle between the main directions of the pinnae and the rachis; radial angle is the orthogonal projection of the angle between the main direction of the pinnae and the line joining right and left insertion points on the rachis; rotation angle is the angle between the insertion scare and a perpendicular to the main direction of the rachis.

The sample size of the metric characteristics of the rachis and the pinnae will be estimated using techniques issued from the regionalized variables theory. Considering Da and Db are the random variables recorded on frond A and frond B of the studied palm tree.

According to recent studies [6], respecting the hypothesis of spatially homogeneous variances and covariances [7], the co-variance between Da and Db may be estimated using the following classical estimators:

$$\hat{C}\mathrm{Da(h)} = \frac{1}{\mathrm{N}}\mathrm{(h)} \sum\nolimits_{\mathrm{i,j/hij=h}} \big(\mathrm{Dai} - \mathrm{Mean\ (Da)}\big) * \big(\mathrm{Daj} - \mathrm{Mean\ (Da)}\big)$$

$$\hat{C}\mathrm{Db(h)} = \frac{1}{\mathrm{N}}\mathrm{(h)} * \sum\nolimits_{\mathrm{i;j/hij=h}} \big(\mathrm{Dbi} - \mathrm{Mean(Db)}\big) * \big(\mathrm{Dbj} - \mathrm{Mean(Dd)}\big)$$

The variance of r (r^2) may be the estimated by:

$$\sigma r^2 = \left[\sum \mathrm{N(h)} * \hat{C}\,\mathrm{LDa(h)} * \hat{C}\mathrm{Db(h)}\right] / [\mathrm{n}^{2*}\mathrm{Mean(Da)}^{2*}\mathrm{Mean(Db)}^2]$$

where *n* is the number of paired measurement and N (h) is the number of couple of measurements for given h distance on the non oriented axe.

The minimum useful sample size is defined as to be $m = 1 - \sigma r^2$.

If the two variables are positively auto-correlated, then m < n.

If they are not, m = n.

If they are negatively auto-correlated, it can be expected that m > n.

3. Results

3.1 Width and Height of Rachis Sections

The position on the rachis is normalized relatively to the total length of rachis. Width and height are normalized relatively to their maximum value. For each palm tree separately (Figs. 1 and 2) shows the dot groups for the measurements taken every 10 cm on the rachis of the fronds. The width and height data noted for the two cultivars show that the width and height of the rachis are strongly dependent of their position on the rachis.

The semi-variograms (Fig. 3 and 4) for the two cultivars are of exponential nature showing the significant deviation of the rachis dimension variables along the rachis. The ratio data Height/Width of rachis sections notes for the two cultivars (Fig. 5) varied between 0.5 and 2.5 along the rachis. As the variable width of rachis is strongly regionalized, the regionalized variables theory can be used for estimating a minimum useful sample (Table 1). It gives a sample size of 3 sections along the rachis for the two cultivars.

3.2 Length of Pinnae

The position on the rachis is normalized relatively to the total length of rachis and the pinnae length is

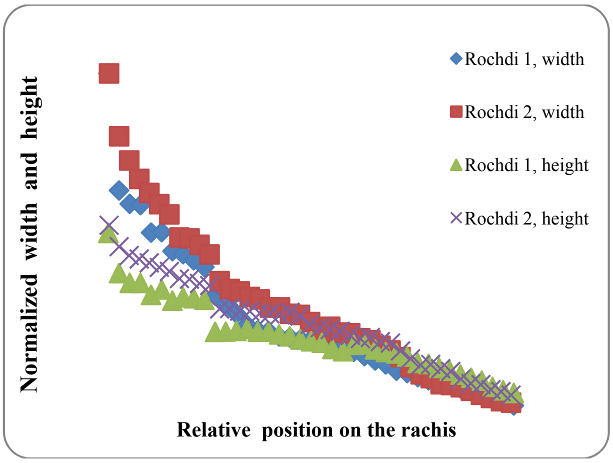


Fig. 1 Width and height – Rochdi.

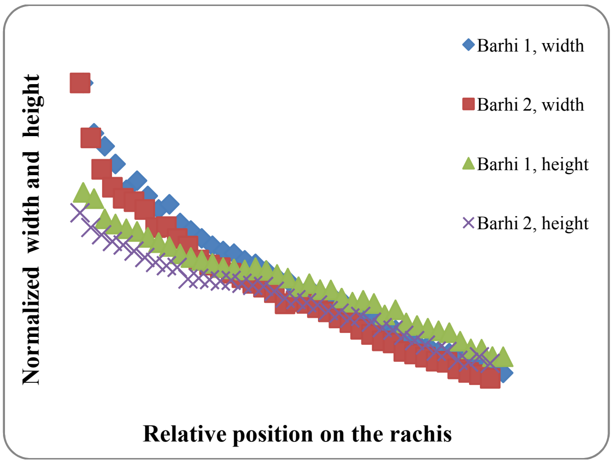


Fig. 2 Width and height – Barhi.

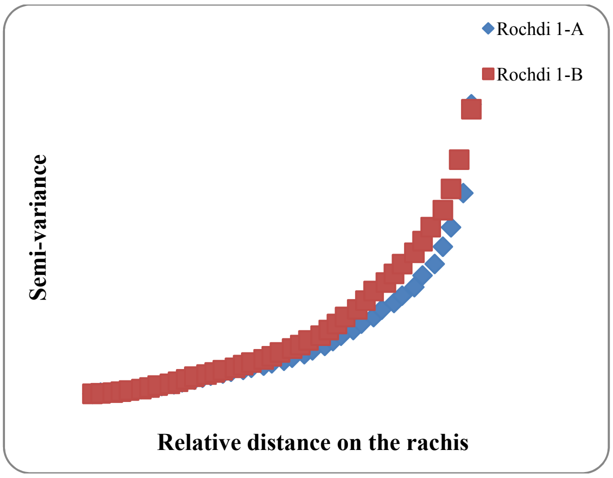


Fig. 3 Semi-variogram of rachis width-Rochdi.

normalized relatively to its maximum value measured on left or right side of the frond. For each studied palm tree (Fig. 6 and 7) shows the evolution of the dot groups for the length measurements of all pinnae

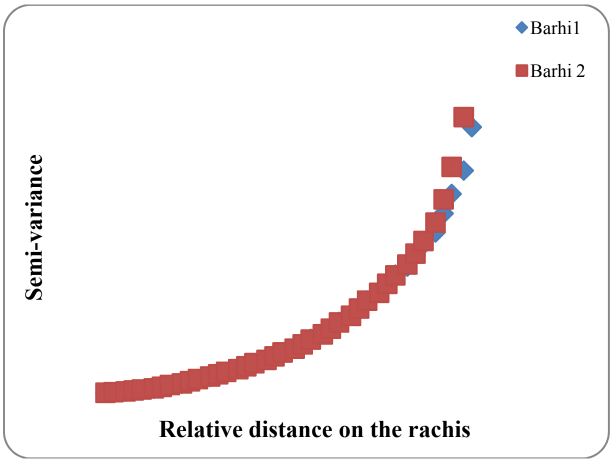


Fig. 4 Semi-variogram of rachis width-Barhi.

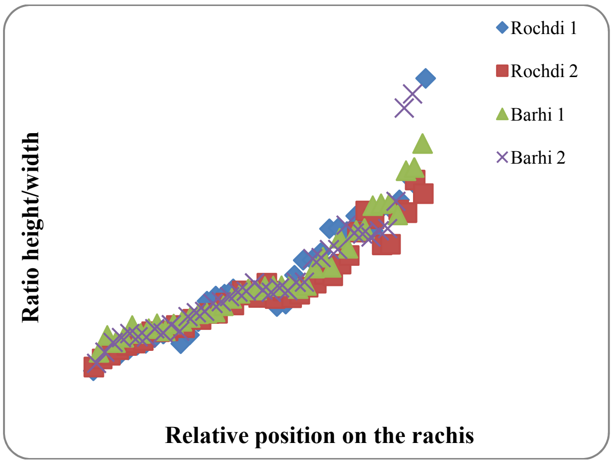


Fig. 5 Ratio height/Width of rachis sections –All palms.

Table 1 Estimation of utile minimum sample size for rachis section width estimations.

	Rochdi	Barhi
Variance of r (x, y)	0.5	0.6
Useful min sample	3	2.7

located on one or the other sides of each frond. It seems that the length of the pinnae is strongly related to its position along the rachis. The two figures show an acceleration of the size difference between the pinnae at the time of transition between spines and leaflets. This phenomenon should not be regarded as discontinuity but as acceleration. The semi-variograms (Figs. 8 and 9) relating to the pinnae lengths may be considered as fitting to a periodic model.

As the variable length of pinnae is strongly regionalized, the regionalized variables theory can be used for estimating a minimum useful sample (Table

2). It gives a sample size ranging between 5 and 6 for the two cultivars.

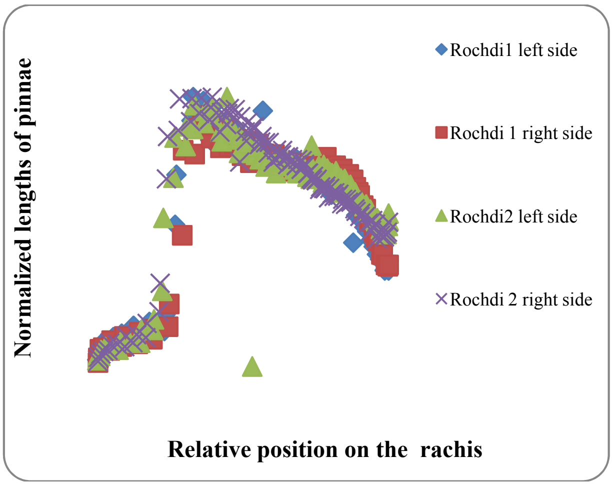


Fig. 6 Length of pinnae- Rochdi.

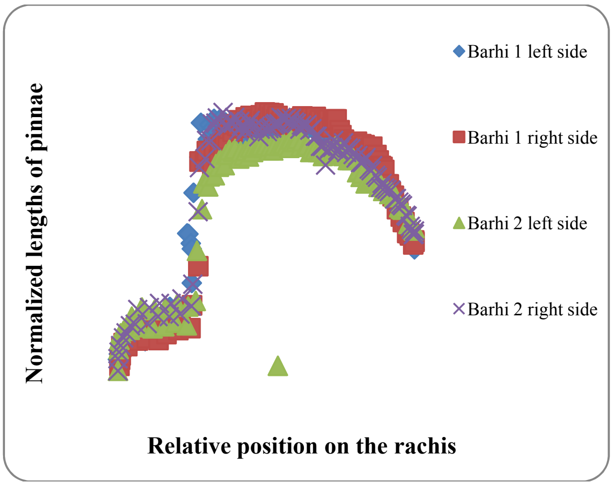


Fig. 7 Length of pinnae- Barhi.

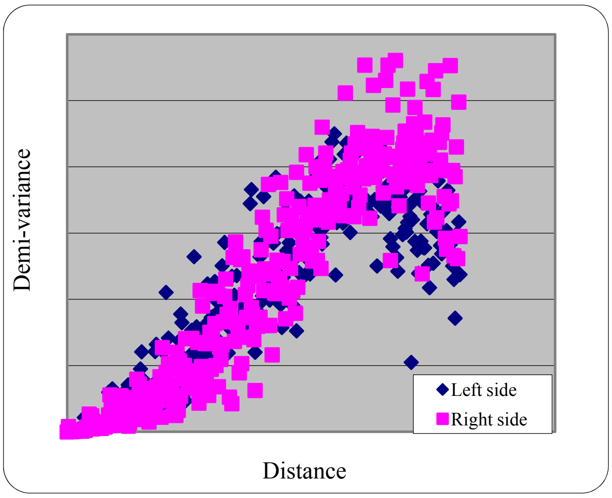


Fig. 8 Semi-variogram of pinnae length Rochdi.

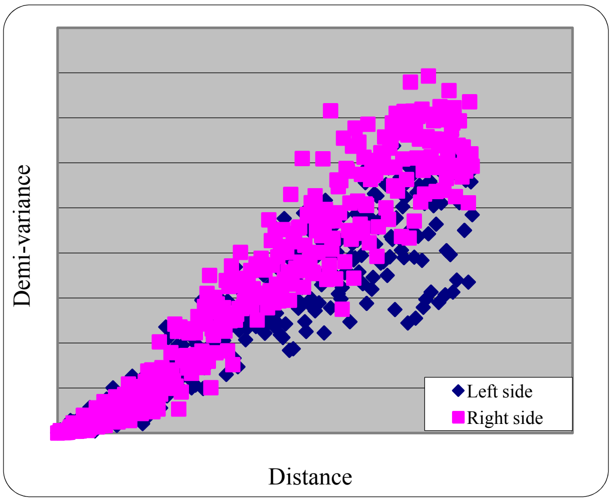


Fig. 9 Semi-variogram of pinnae length Barhi.

Table 2 Details of the estimation of utile minimum sample size for pinnae length estimation.

	Rochdi	Barhi
Variance of r (x, y)	0.21	0.25
Useful min sample	5.7	4.9

3.3 Width of Pinnae at the One Third of Its Length

The position on the rachises is normalized relatively to the total length of rachis and the pinnae width is normalized relatively to its maximum value measured on left or right side of each measured frond of the two cultivars (Figs. 10 and 11) showing that the width of the pinnae is strongly dependent of its position on the rachis. As the variable width of pinnae is strongly regionalized, the regionalized variables theory can be used for estimating a minimum useful sample (Table 3). It gives a sample size ranging between 4 and 7 for the two studied cultivars.

3.4 Relation between Rotation Angle and Radial Angle of Pinnae

For the two cultivars (Figs. 12 and 13) showed the dot groups and the linear regression including its equation and signification coefficient. "Barhi" $y = 1.9711x - 37.816$ with $R^2 = 0.37$ and "Rochdi" $y = 1.8329x - 42.352$ with $R^2 = 0.39$. This result confirms the strong correlation between rotation angle and radial angle of pinnae.

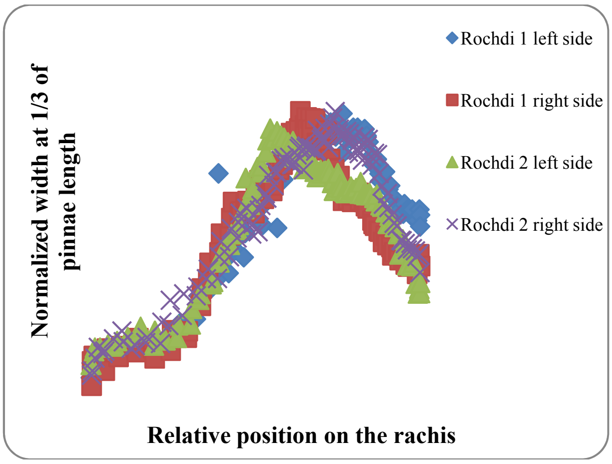


Fig. 10 Width of pinnae at 1/3 of their lengths-Rochdi.

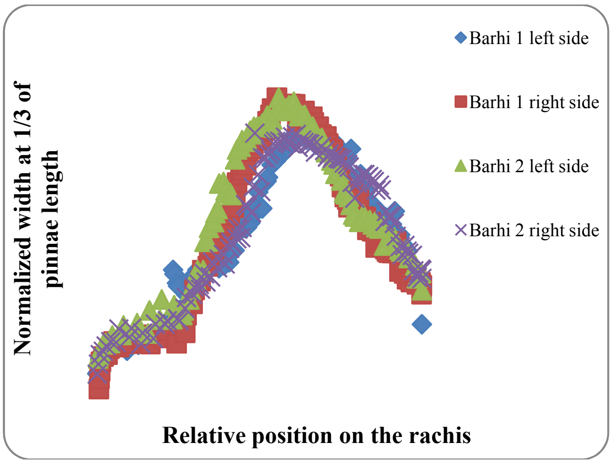


Fig. 11 Width of pinnae at 1/3 of their lengths-Barhi.

Table 3 Details of the estimation of utile minimum sample size for pinnae width estimation.

	Barhi 1	Barhi 2	Rochdi 1	Rochdi 2
Variance of r (x,y)	0.31	0.32	0.3	0.17
Useful min sample	4.2	4.1	4.3	6.6

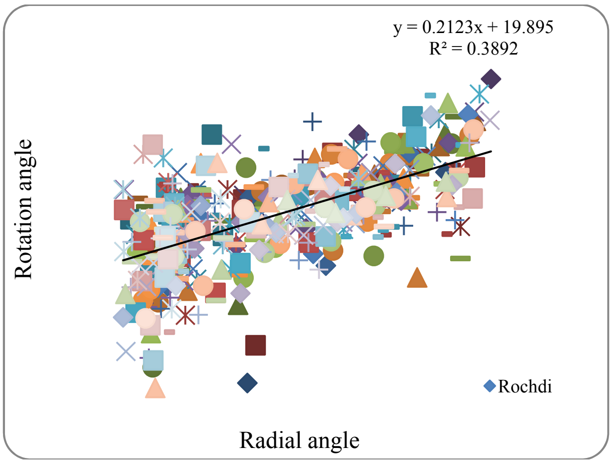


Fig. 12 Radial angle f (Rotation angle) Rochdi.

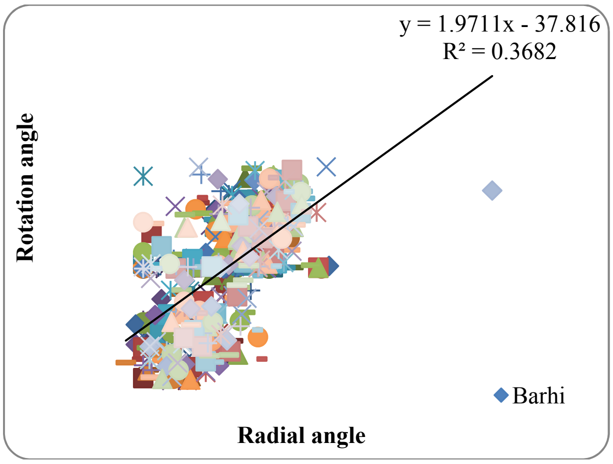
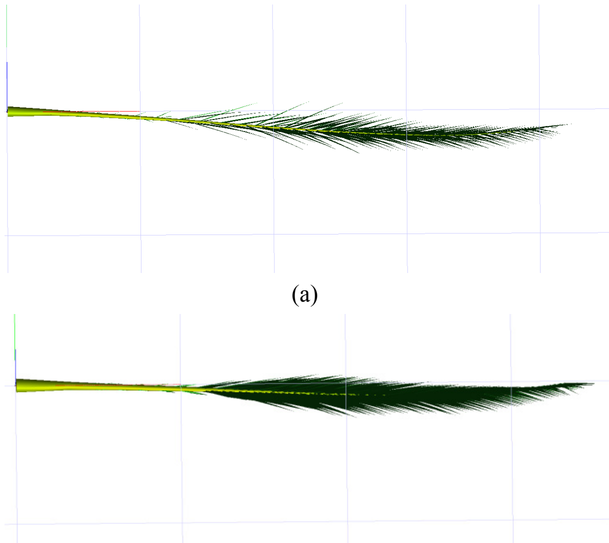


Fig. 13 Radial angle f(Rotation angle) Barhi.



(a)

(b)

Fig. 14 Simulation of fronds. (a)-"Rochdi" fronds. (b)-"Barhi".

3.5 Simulation of Fronds

All these geometrical and morphometric parameters allow the fronds simulation of the two observed cultivars "Barhi" and "Rochdi" (Fig. 14).

4. Discussion

Our results confirm the results obtained in other studies [8], and it shows that the width and the height of rachis section are strongly dependent on their position on the rachis. The ratio height on width for rachis sections throughout the rachis is regular according to previous studies [9]. It appears adjustable to a statistical function curve whose type remains to be discovered according to knowledge in biomechanics. The modeling of the relationship between width and height of the rachis indexed on the position through this rachis may allow us to reduce the observation to only one of the two metric parameters and shorten the observation time. Recent studies have shown that width variation throughout the rachis is adjustable to an exponential function, knowing that the coefficient is strongly dependent of the palm length, and the normalization gives the following equation: $y = 1.2482x - 1.3648$ with $R^2 = 0.9663$. Our results demonstrate that the length of the pinnae is strongly dependent of its position on the rachis and seems to be a pointer of the cultivar. The geometrical measurement confirms the strong correlation between rotation angle and radial angle of pinnae for the two cultivars "Barhi" and "Rochdi". It's the same result obtained with the Italian morphotypes "Romana" and "Ebrea" [8], so we can reduce the observation to only one of the two angles. According to previous researches [9] it exist also a strong correlation between axial and rotation angle and the calculation adjustment obtained by gathering data of the Italian morphotypes and Tunisian cultivars, and linear regression gives the following equation: $y = 0.2642x + 20.627$ with $R^2 = 0.57$. As it is easier to measure the rotation angle we can estimate axial angle from the rotation angle linear regression formula.

5. Conclusions

Our study shows that the metric characteristic of the rachis and the pinnae are strongly dependent of their position on the rachis and can be considered as regionalized variables. This result allows us to estimate a useful sample size for the rachis and pinnae parameters. It can also be used for reducing the number of studied parameters and shortening the observation time and protocol. The strong correlation between radial and rotation angle allows us to reduce the measurement to only one of the two angles. All these characteristics are used as a taxonomical index to differentiate between the two Tunisian varieties. This study allows the frond simulations of the two observed Tunisian cultivars "Barhi" and "Rochdi".

Complementary studies will be undertaken in order to determine the architecture and geometry of the date palm inflorescence.

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References

[1] D. Barthelemy, Y. Caraglio, Plant architecture: A dynamic, multilevel and comprehensive approach to palant form structure and ontogeny, Annals of Botany 99 (0) (2007) 375-407.

[2] N.W. Uhl, J. Dransfield, Genera Palmarum, Allen Press, Lawrence, Kanas, 1987, p. 610.

[3] F. Halle, R.A. Oldeman, Essai Sur L'Architecture et la Dynamique de Croissance des Arbres Tropicaux, Paris, Masson, 1970, p. 178.

[4] V. Dolle, Architecture oasiennes et flux radiatifs. Modélisation architectural de l'oasis: Simulation des transferts radiatifs sur maquettes informatiques tridimensionnelles, Rapport Programme de recherche MRT. Programme national n: 11: Recherche et Développement. 2 GRIDAO. CIRAD6DSA AND CURAD6GERDAT Laboratoire de Modélisation, Montpellier, France, 1989.

[5] M.A. El Houmaizi, Modélisation de L'architecture du Palmier Dattier (*Phoenix dactylifera* L.) et Application à la Simulation du Bilan Radiatif dans les Oasis, 2002, p. 162.

[6] Ph. Aubry, Le Traitement des Variables Régionalisées en écologie, Apports de la Géomatique et de la Géostatistique, Ph.D. Thesis (Speciality Biometrics), 2000, pp. 363.

[7] S. Richardson, D. Hemon, The Variance of the Sample Correlation between two Independent Lattice Processes, Journal of Applied Probability, 1981, pp. 943-948.

[8] S. Memadji-Le-Allah, de la Modélisation de L'architecture des Palmes du Palmier Dattier (*Phoenix dactylifara* L), Relations entre les Paramètres Caractéristiques des Morphotypes Cultivés en Europe, Master BVT1, 2011, p. 51.

[9] S. Memadji-le-Allah, S. Gammoudi, H. Rey, M. Bensalah, R. Lecoustre, Modeling of Arecaceae architecture, example of *Phoenix dactylifera*, descriptions of the characteristics autocorrelation functions of parameters and of the correlations between some of these parameters, in: 1st International Symposium Palmier, Alger: The Date Palm: Review of 50 Years of Work-What Research for Its Preservation and Enhancement?, Nov. 13-14, 2011, Alger, Algeria.