Research Journal of Applied Sciences, Engineering and Technology 6(19): 3547-3558, 2013
DOI:10.19026/rjaset.6.3559
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: December 12, 2012 Accepted: January 01, 2013 Published: October 20, 2013

Research Article

Study of Water Diffusion through Raffia *Vinifera fibres* of the Stem from Bandjoun-Cameroon: Case of Drying Kinetics

[1, 2, 3]N.R. Sikame Tagne, [3]E. Njeugna, [1, 2]M. Fogue, [4]J.Y. Drean and [3]D. Fokwa
[1]Laboratory of Industrial and Systems Engineering Environment (LISIE)-IUT/FV Bandjoun-University of Dschang, Cameroon
[2]Laboratory of Mechanics and Modeling of Physical System (L2MSP)-University of Dschang, Cameroon
[3]Laboratory of Mechanics and Materials Adapted (LAMMA)-ENSET, University of Douala-Cameroon
[4]Laboratory of Physics and Mechanics Textile (LPMT) ENSISA-University of Haute Alsace-France

Abstract: The objective of this study is to determine some physic-chemical properties of raffia *Vinifera fibres* resulting from the stem. The moisture content rate of these fibres was evaluated along the stem and varies in the intervals [12-6] % and [19-107] % for dry and fresh fibres respectively. Thermo gravimetric method using the temperatures 60, 70 and 80°C respectively, enables us, through Fick's 2nd law, to find other parameters. Owing to the data on the moisture content, the different curves were plotted. Fourteen models were tested to predict the drying kinetics of fibres with cylindrical form. It comes out that the models "Diffusion approach" and "Verma *et al*. (1985)" models fitted well with the phenomenon. The effective diffusion coefficient of the initial phase varies in the intervals [6.32×10^{-11}-3.00×10^{-10}] m^2/s and [1.76×10^{-10}-4.47×10^{-10}] m^2/s for dry and fresh fibres respectively. We notice that the moisture content and the effective diffusion coefficient grow from the periphery towards the centre in each cross-section. Owing to the relation of Arrhenius, the activation energy was evaluated only in the initial phase and oscillates respectively in [4.72 – 22.86] KJ/mol.K and [4.65 – 12.13] KJ/mol.K for dry and fresh fibres.

Keywords: Activation energy, diffusion coefficient, mathematical model, moisture content, raffia vinifera

INTRODUCTION

The raffia is a plant which generally grows in the tropical zones of Africa, Asia and South America (Musset, 1933; Obahiagbon, 2009). This plant belongs to the family of palm trees monocotyledons called arecacea. There are about twenty species of raffia in the world among which the raffia vinifera (Sandy and Bacon, 2001). This variety of raffia does not have a trunk (Ndenecho, 2007) and grows essentially in the swamp and at the bottom of the mountainous areas. The raffia vinifera is a plant which has several parts, namely: the stump, the stem, sheets and the fruits (Ndenecho, 2007).

The use of the raffia vinifera as basic materials in the realization of art and craft products such as the baskets, stools, hats, clothing, braces, beds, etc. becomes increasingly intense. In fact, since few years, there is a strong demand by the population. So, the raffia forests are frequently solicited and therefore disappear progressively, since the time of regeneration is long.

In order to understand the physical behaviour of this biodegradable material, the study of dehydration is carried out.

Many researches have been carrying out for an understanding of the behaviour of raphia. We can enumerate the use of the bamboo raffia as reinforcement in the concrete by Kankam (1997), the physicochemical characterization of oils coming from the raffia sese and laurenti by Silou *et al*. (2000), the study of the thermal properties of the trunk of raffia hookeri used like material of ceiling by Etuk *et al*. (2003). For the raffia textilis, reflections were carried out on the microstructure and the physical properties of fibres resulting from the sheets on the one hand and on the other hand on the drying kinetics of these fibres whose sheets are used as materials of roof by villagers (Elenga *et al*., 2009, 2011a, b). In addition, for the raffia viniféra, we can indicate the biochemical characterization of the sap (wine of palm) and its effect on the rats by Tiepma *et al*. (2010). The study on the long-term behaviour of the stem of raffia viniféra in compression or in flexion was approached by Talla *et al*., 2004, 2005, 2007 and 2010). The toxicity of the fruits of raffia viniféra also was the subject of an attention carried out by Fafioye *et al*. (2004) and Fafioye *et al*. (2005). Also on the determination of some mechanical properties of raffia *Vinifera fibres* resulting from the stem, were evaluated like some

Corresponding Author: N.R. Sikame Tagne, Laboratory of Industrial and Systems Engineering Environment (LISIE)– IUT/FV Bandjoun-University of Dschang, Cameroon

parameters related to those as the Young modulus and the density by Njeugna *et al*. (2012).

The knowledge of other parameters related to the raffia *Vinifera fibres* is important for the realization of composite with those fibres as reinforcement. We are proposed to study the drying kinetics of these fibres. The aim of this study is to propose a drying kinetic model, the determination of the moisture content, the effective diffusion coefficient and the activation energy the fibres along the stem of raffia vinifera during drying.

MATERIALS AND METHODS

Materials: The fibres come from raffia vinifera stem of the swamp located around of the University Institute of Technology Fotso Victor of Bandjoun in the west region of Cameroon. We obtained these fibres using the mechanical or direct method as described by Njeugna *et al*. (2012) on the methods of extraction. This study is undertaken on two varieties of stems classified according to the moisture content.

The tools used, are a numerical balance whose precision is about 0.01 g for the weighing of the various samples and a drying oven.

Methods: The fibres used are characterized by a length of 150 mm and the mass ranging between 0.50g and 1g per package. The packages of raffia fibres were taken in the twelve extraction zones along the stem and according to the cross-section as shown in the Fig. 1a and b below. Namely 4 longitudinal positions (PL-1/4; PL-2/4; PL-3/4; PL-4/4) and 3 radial positions (R1; R2; R3).

To choose a mathematical model for the fibres, we carried out the tests of the various existing models in a precise zone of the stem. Thus, the choice of the suitable model to describe this phenomenon with a good accuracy will be the one that presents a higher correlation coefficient (R^2); a lower Root Means Square Error (RMSE) and a chi-square (χ^2). These statistical parameters are defined by the following relations:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(m_{r,i} - m_{p,i}\right)^2}{N}} \quad \text{and} \quad \chi^2 = \frac{\sum_{i=1}^{n}(m_{r,i} - m_{p,i})^2}{N-n} \qquad (1)$$

where, $m_{r,i}, m_{p,i}$, N and n are respectively the ith experimental masses, the ith theoretical masses, the number of observations and the number of constants.

These selection criteria were applied to the drying of the sheets of Mint or waste of Olive by Akgun and Doymaz (2005) and Doymaz (2006, 2005).

We chose three temperatures 60, 70 and 80°C to undertake this study. The air velocity in the laboratory is 1.5 m^2/s and remains constant for the various temperatures (Arumuganathan *et al*., 2009; Kongdej, 2011; Chien *et al*., 2008).

When the drying oven is started, we regulate the temperature that we need. We introduce the prepared package of fibres into the drying oven and after each three minutes, we carry out the various weighing until reaching a noted constant mass m_∞. The interval time between the exit and the introduction of the package of fibres is supposed to be negligible. Because this duration is evaluated approximately at 20s. The studies of the drying kinetics of the fruit of chempedak (Chien *et al*., 2008) and of the effects of the sun on onions (Arlan and Özcan, 2010) were made in the same direction.

Theory on the diffusion of mass through a solid: The equation of mass transfer through solid results in the Fick's 2nd law. This law is given by the Eq. (2):

$$\frac{\partial C}{\partial t} = \mathrm{div}(-\overrightarrow{DgradC}) \qquad (2)$$

with C (mol/m^3) concentration in diffusing molecule and D (m^2/s) the diffusion coefficient.

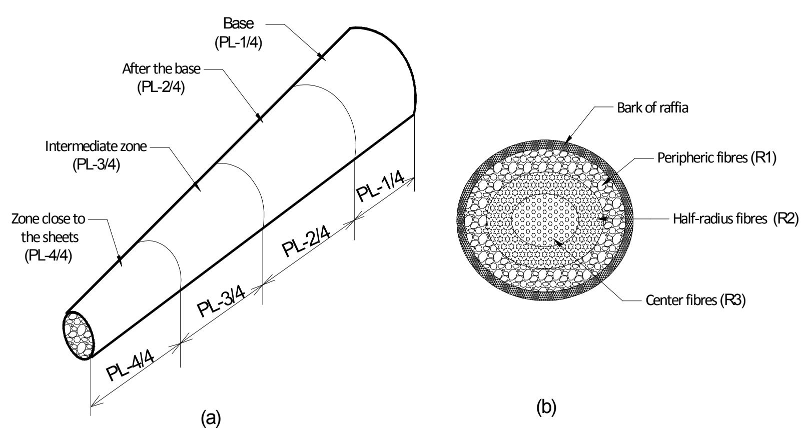

Fig. 1: Localization of the zones of sampling of fibres along the stem of raffia vinifera; (a): longitudinal position, (b): cross-section according to a precise longitudinal position

Taking into consideration the geometry of raffia fibre which has an elliptic cross-section (Njeugna *et al*., 2012), we approximate as a full cylinder.

The Eq. (2) will be written only in cylindrical coordinates. We have:

$$\frac{\partial C}{\partial t} = \frac{1}{r}\left\{\frac{\partial}{\partial r}\left(\mathrm{r}\mathrm{D}\frac{\partial C}{\partial r}\right) + \frac{\partial}{\partial \theta}\left(\frac{D}{r}\frac{\partial C}{\partial \theta}\right) + \frac{\partial}{\partial z}\left(rD\frac{\partial C}{\partial z}\right)\right\} \quad (3)$$

Considering the ratio of length on the diameter which is very high and by neglecting the diffusion along z axis, the Eq. (3) is reduced to:

$$\frac{\partial C}{\partial t} = \frac{1}{r}\left\{\frac{\partial}{\partial r}\left(\mathrm{r}\mathrm{D}\frac{\partial C}{\partial r}\right)\right\} \quad (4)$$

Considering the boundary conditions, we have:

For $t = 0$, $C = C_1$, $0<r<a$
For $t>0$, $C = C_0$ at $r = a$

The solution to the Eq. (4) can be written according to Crank (1975) as follows:

$$\frac{C-C_1}{C_0-C_1} = 1-\frac{2}{a}\sum_{n=1}^{\infty}\frac{\exp(-D\alpha_n^2 t)J_0(r\alpha_n)}{\alpha_n J_1(\alpha\alpha_n)} \quad (5)$$

with J_0 and J_1 being respectively Bessel functions of zero and first order.

Let us note M_t and M_0 moisture content of water diffused through raffia fibre respectively at the moment t and initial time. The Eq. (5) can be rewritten for the water mass rate rejected in terms of effective diffusion coefficient (D_{eff}).

According to Crank (1975), the Eq. (5) becomes:

$$\frac{M_t}{M_0} = 1 - \sum_{n=1}^{\infty}\frac{4}{\alpha^2\alpha_n^2}\exp\left(-D_{eff}\alpha_n^2 t\right) \quad (6)$$

With $a\alpha_n$ being the positive roots of the Bessel function of zero order, a radius of fibres and D_{eff} the effective diffusion coefficient. The Eq. (6) was used by Rastogi *et al*. (1997, 2002) in the study of the phenomenon of dehydration during the mass transfer.

The ratio of the moisture content noted *MR*, is defined by relation:

$$\mathrm{MR} = \frac{M_t}{M_0} = \frac{m_t - m_\infty}{m_0 - m_\infty} \quad (7)$$

with m_0, m_t and m_∞ the mass of fibres samples respectively at the beginning, a time t and the end.

From the Eq. (6), we can say that the Moisture Ratio (MR*)* can take the expression:

$$\mathrm{MR} = \frac{m_t - m_\infty}{m_0 - m_\infty} = \sum_{n=1}^{\infty}\frac{4}{\alpha^2\alpha_n^2}\exp\left(-D_{eff}\alpha_n^2 t\right) \quad (8)$$

This consideration was done for the case of the study on the influence of the shape of the crop products during drying by Senadeera *et al*. (2003) or for the thermo gravimetric analysis of the pasta products by Takenobu *et al*. (2012).

Taking the first term of the series as presented by Senadeera *et al*. (2003), Chien *et al*. (2008) and Schössler *et al*. (2012). The relation (8) becomes:

$$\mathrm{MR} = \frac{m_t - m_\infty}{m_0 - m_\infty} = \frac{4}{\alpha^2\alpha_1^2}\exp\left(-D_{eff}\alpha_1^2 t\right) \quad (9)$$

Posing $b = \frac{4}{a^2\alpha_1^2}$ and $k = D_e\alpha_1^2$, Eq. (9) take the form:

$$\mathrm{MR} = b\exp(-kt) \quad (10)$$

With ($a\alpha_1$) first root of the Bessel function of zero order, a radius of the cross-section of fibre, D_{eff} the effective diffusion coefficient.

Moisture content: The Moisture Content (MC) of raffia *Vinifera fibres* resulting from the various zones of sampling will be given by the formula:

$$\mathrm{MC} = \frac{m_0 - m_\infty}{m_\infty}\times 100 \quad (11)$$

This equation was used for the study of the drying kinetics of pumpkin (Kongdej, 2011) and also during the modelling of drying kinetics of the plates of kiwifruit (Mohammed *et al*., 2009).

Mathematical model: Table 1 gives the different models used during the description of the drying kinetics of some vegetable products.

Evaluation of the effective diffusion coefficient: Applying the logarithmic function to the Eq. (10), we obtain:

$$\mathrm{In\ MR} = \mathrm{In\ b} - kt \quad (12)$$

To determine the effective diffusion coefficient of raffia vinifera fibres, we plot the curve of ln *MR*. according to time t. This curve will be a line referring to the Eq. (12), the slope of this straight line to deduce the effective diffusion coefficient (Senadeera *et al*., 2003; Chien *et al*., 2008; Arumuganathan *et al*., 2009; Kongdej, 2011; Duygu, 2012; Ngankham and Pandey, 2012).

Determination of the activation energy: The equation of Arrehenius is used to describe activation energy in chemical process (Senadeera *et al*., 2003; Arumuganathan *et al*., 2009; Ngankham and Pandey, 2012):

Its general expression is given by:

$$D_{eff} = D_0 \exp\left(\frac{-E_a}{RT}\right) \qquad (13)$$

where D_0 is the constant in the Arrhenius equation expressed in (m^2/s), E_a the activation energy in (KJ/mol), R the constant of perfect gases which is in 8.314 J/mol/K and T the absolute temperature of the air of drying in (°K).

Applying the logarithmic function to the Eq. (13), we have:

$$\text{In}D_{eff} = \text{In}D_0 - \left(\frac{E_a}{R}\right)\left(\frac{1}{T}\right) \qquad (14)$$

The variation of ln D_{eff} with 1/T is plotted using Matlab R2009b and enables us to obtain the slope m = $(\frac{E_a}{R})$ of the straight line and to deduce the activation energy.

RESULTS AND DISCUSSION

Moisture content: According to the use of the raffia vinifera stem by the populations, two varieties were the subject of our study. By using the formula of the Eq. (11), the moisture content of fibres resulting from the stems of raffia was evaluated according to the zones along these.

It comes out that the moisture content rate of one variety is between 12% and 16% as shown in Fig. 2.

We observe that the variation of the moisture content on an unspecified cross-section along the stem is not significant. A similar analysis can be made in the longitudinal direction. The interval of moisture content obtained is comparable with the values found in study on agricultural waste like the bark and the cork of the raffia hookeri which have respectively as water content 10.70% and 14.20% (Israel *et al.*, 2008). It will be called dry raffia vinifera fibre.

Figure 3 shows us a variation of moisture content included between 19% and 107%. We notice that for each cross-section specified along the stem, the moisture content of raffia fibres increases from the periphery towards the center. We also note that the moisture content of fibres located on the cross-section near the sheet at PL-4/4 of the stem is around 20%. It is very low compared to the values located in the interval [65%-107%] obtained in other zones PL-1/4, PL-2/4 and PL-3/4. Such a difference comes from a probable variation of the microstructure of raffia fibres in the cross-section along the stem and also by the feeding system of the sheets in sap. We will name this other fresh raffia vinifera fibre in the following development.

Drying kinetics: Figure 4 illustrates the drying kinetics of raffia *Vinifera fibres* coming from the center located at the bottom (PL-1/4-R3) of the dry stem.

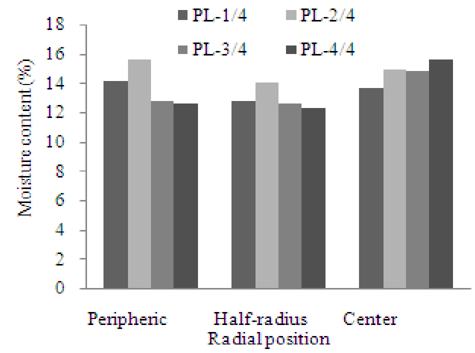

Fig. 2: Evolution of the moisture content of fibres of raffia vinifera along the stem known as dries

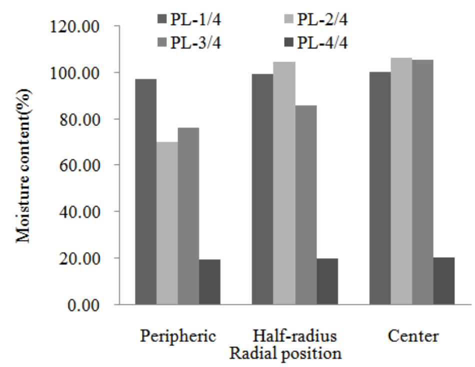

Fig. 3: Evolution of the moisture content of fibres of raffia vinifera along the stem known as fresh

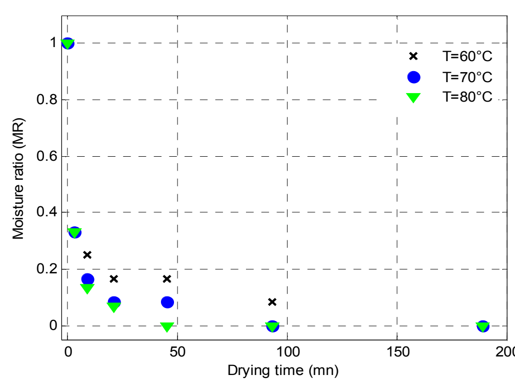

Fig. 4: Drying kinetics of dry raffia vinifera fibres resulting from PL-1/4-R3 of the stem

Similar curves were obtained in the other zones of study presented in figure 1along the stem. It is also the case of raffia vinifera fibres resulting from the fresh stem. The same curves were obtained during the study of the drying of some vegetable products (Taheri-Garavand *et al.*, 2011; Elenga *et al.*, 2011a, b; Ngankham and Pandey, 2012; Duygu, 2012).

Choice of a mathematical model: Table 1 illustrates the different parameters of the proposed models of the

Table 1: Parameters of the mathematical models of fibres located at PL-1/4-R3 of the dry stem of raffia vinifera

Type of model	T (°C)	a	b	c	k	m	n	χ^2	RMSE	R^2
Page	60				0.8103		0.2508	0.004634	0.03044	0.993
	70				0.743		0.378	0.002318	0.02153	0.9969
	80				0.6305		0.5119	0.0005335	0.01033	0.9993
Henderson and Pabis	60	0.9653			0.2593			0.09892	0.1407	0.8512
	70	0.9865			0.3138			0.02819	0.07508	0.9627
	80	0.9912			0.3297			0.01242	0.04984	0.9844
Peleg	60	1.496	1.089					0.01563	0.0559	0.9765
	70	1.542	1.011					0.002979	0.02441	0.9961
	80	1.55	0.9838					0.0005377	0.01037	0.9993
Newton	60				0.2766			0.09998	0.1291	0.8496
	70				0.319			0.02836	0.06875	0.9625
	80				0.333			0.0125	0.04564	0.9843
Modified Page	60				0.4326		0.2507	0.004634	0.03044	0.993
	70				0.4556		0.3779	0.002318	0.02153	0.9969
	80				0.4062		0.5119	0.0005335	0.01033	0.9993
Logarithmic	60	0.8696	0.1264		0.4443			0.03317	0.09107	0.9501
	70	0.9382	0.05647		0.3782			0.01469	0.0606	0.9806
	80	0.966	0.0287		0.3599			0.008913	0.04721	0.9888
Two term	60	0.2643	0.7357		0.01336	0.7397		0.002276	0.02754	0.9966
	70	0.1893	0.8106		0.02651	0.5412		0.001695	0.02377	0.9978
	80	0.2395	0.7605		0.06661	0.5714		0.0002068	0.008302	0.9997
Exponentional two term	60	0.266			0.7067			0.08451	0.13	0.8729
	70	0.2912			0.7809			0.02133	0.06531	0.9718
	80	0.2999			0.8012			0.007802	0.0395	0.9902
Diffusion appraoch	60	0.7358	0.01806		0.7396			0.002276	0.02385	0.9966
	70	0.8107	0.04899		0.5412			0.001695	0.02059	0.9978
	80	0.7605	0.1166		0.5714			0.0002068	0.007191	0.9997
Verma *et al.*	60	0.2643			0.01337	0.7398		0.002276	0.02385	0.9966
	70	0.1893			0.02652	0.5412		0.001695	0.02059	0.9978
	80	0.7611			0.06642	0.5708		0.0002068	0.007191	0.9997
Modified Henderson and Pabis	60	0.9769	-0.241	0.2642	0.7463	0.7675	0.01336	0.002276	0.04771	0.9966
	70	10.5	0.1898	-9.69	0.6467	0.02653	0.657	0.001722	0.0415	0.9977
	80	2.175	0.2669	1.443	0.537	0.0738	0.5069	0.0002331	0.01527	0.9997
Midilli *et al.*	60	1	-0.0004784		0.914		0.1807	0.00155	0.02273	0.9977
	70	1	-2.681×10^{-5}		0.749		0.3728	0.002292	0.02764	0.997
	80	1	-9.797×10^{-6}		0.6315		0.5108	0.0005292	0.01328	0.9993
Wang and Sing	60	-0.02167	8.868e-005					0.9698	0.4404	-0.459
	70	-0.02406	0.0001015					1.09	0.467	-0.4423
	80	-0.02498	0.0001066					1.159	0.4815	-0.4533
Aghbashlo *et al.*	60	28.69			28.97			0.09998	0.1414	0.8496
	70	87.56			87.88			0.02836	0.07532	0.9625
	80	59.16			59.49			0.0125	0.04999	0.9843

Table 2: Different existing models for the study of the drying kinetics of some vegetable products (Mohammed *et al.*, 2009; Duygu, 2012)

N° of the model	Name of the model	Equation of the model	References
1	Page	MR = exp(-ktn)	Page (1949)
2	Henderson and Pabis	MR = aexp(-kt)	Henderson and Pabis (1961)
3	Peleg	MR = 1-t/(a+bt)	Peleg (1988)
4	Newton	MR = exp(-kt)	O'Callaghan *et al.* (1971)
5	Modified Page	MR = exp[(-(kt)n]	Overhults *et al.* (1973)
6	Logarithmic model	MR = aexp(-kt) + b	Karathanos *et al.* (1999)
7	Two term	MR = aexp(-kt) + bexp(-mt)	Sharaf-Eldeen *et al.* (1980)
8	Two term exponential	MR = aexp(-kt) + (1-a)exp(-kat)	Sharaf-Eldeen *et al.* (1980)
9	Diffusion approach	MR = aexp(-kt) + (1-a)exp(-kbt)	Karathanos *et al.* (1999)
10	Verma *et al.*	MR = aexp(-kt) + (1-a)exp(-mt)	Verma *et al.* (1985)
11	Modified Henderson and Pabis	MR = aexp(-kt) + bexp(-mt) + cexp(-nt)	Karathanos *et al.* (1999)
12	Midilli *et al.*	MR = aexp(-ktn) +bt	Midilli *et al.* (2002)
13	Wang et Sing	MR = 1 + at + bt2	Wang and Sing (1978)
14	Aghbashlo *et al.*	MR = exp[-kt/(1+at)]	Aghbashlo *et al.* (2009)

Table 2, the correlation coefficient (R^2), the Root Means Squared Error (RMSE) and the chi-square (χ^2) of the fibres located at the center of base (PL-1/4-R3) of the dry stem of raffia vinifera.

We observe that five models have a correlation coefficient (R^2) which is higher than 0.995 for the three temperatures. There are two term, Diffusion approach, Verma *et al.* (1985) modified Henderson and Pabis (1961) and finally Midilli *et al.* (2002) models. Considering the average of the correlation coefficients of the three temperatures of each of the five models above, only Two term, Diffusion approach and Verma *et al.* (1985) models gives us an identical value of R^2 better whose value is 0.998033 (Simal *et al.*, 2005).

Table 3: Evaluation of the parameters of the two models chosen for dry fibres coming from PL-1/4 of the raffia vinifera stem

Position	Type of model	T (°C)	a	b	k	m	χ^2	RMSE	R^2
Periperic	Diffusion approach	60	0.7332	0.05198	0.8355		0.0002215	0.007441	0.9997
		70	0.9482	0.4051	0.6317		2.04×10^{-6}	0.0007145	1
		80	0.8862	0.05938	1.042		6.09×10^{-5}	0.003901	0.9999
	Verma *et al.*	60	0.2668		0.04341	0.8353	0.0002215	0.007441	0.9997
		70	0.5723		0.7896	0.4431	2.66×10^{-6}	0.000816	1
		80	0.1067		0.05765	0.9999	6.54×10^{-5}	0.004045	0.9999
Half-radius	Diffusion approach	60	0.6545	0.04424	0.5941		0.003128	0.02797	0.9957
		70	0.5752	0.06956	0.7803		0.002444	0.02472	0.9969
		80	0.6373	0.0802	0.6752		0.001815	0.0213	0.9977
	Verma *et al.*	60	0.3455		0.02628	0.5941	0.003128	0.02797	0.9957
		70	0.4247		0.05425	0.7798	0.002444	0.02472	0.9969
		80	0.636		0.6781	0.05443	0.001815	0.0213	0.9977
Center	Diffusion approach	60	0.7358	0.01806	0.7396		0.002276	0.02385	0.9966
		70	0.8107	0.04899	0.5412		0.001695	0.02059	0.9978
		80	0.7605	0.1166	0.5714		0.0002068	0.007191	0.9997
	Verma *et al.*	60	0.2643		0.01337	0.7398	0.002276	0.02385	0.9966
		70	0.1893		0.02652	0.5412	0.001695	0.02059	0.9978
		80	0.7611		0.06642	0.5708	0.0002068	0.007191	0.9997

Proceeding the same way on the values of the chi-square and the relative error of these last three models, we obtain the lowest values of the identical averages which are respectively 0.0013926 and 0.01721033 for Diffusion approach and Verma *et al*. (1985) models. Similar steps were carried out for the drying kinetics of mint (Aghfir *et al*., 2008) and of the sheets of tea (Panchariya *et al*., 2002). Taking into consideration such an analysis, we can say that the mathematical model which best describes the drying kinetics of dry raffia *Vinifera fibres* resulting from the stem of the zone located at PL-1/4-R3 is Diffusion approach or Verma *et al*. (1985) model.

For a better appreciation of the choice carried out, we applied this result to the other zones of sampling of the stem. Thus, Table 3 offers the opportunity to evaluate this choice on the cross-section at the base (PL-1/4) of the stem.

It comes out for the studied sample that the Diffusion approach and Verma *et al*. (1985) models give the same values of correlation coefficient, chi-square and relative error.

It can be deduced that the model which gives a better description of the behaviour of raffia *Vinifera fibres* resulting from the dry stem are the Diffusion approach and Verma *et al*. (1985) models. It is in conformity with the study on the dying of onions (Arslan and Özcan, 2010).

Concerning the raffia *Vinifera fibres* resulting from the fresh stem, methodology in the choice of a mathematical model to describe the drying kinetics remains the same. Initially, we took periphery fibres from the zone close to sheets of the raphia stem (PL-4/4-R1). So, Page, Modified Page, Two term, Diffusion approach, Verma *et al*. (1985) modified Henderson and Pabis (1961) and finally Midilli *et al*. (2002) models gave a correlation coefficient higher than 0.995. Then, the means of the correlation coefficient, root means square error and chi-square of the three temperatures enable to obtain equal

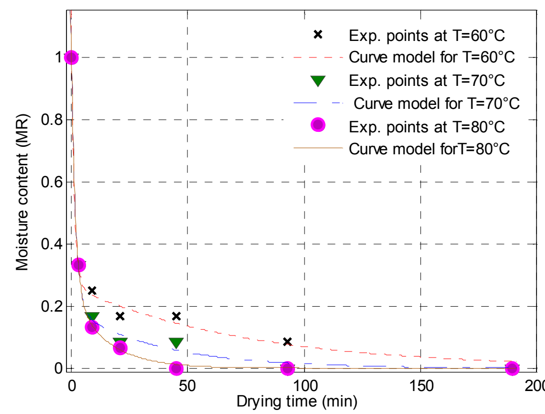

Fig. 5: Representation of Diffusion approach model for raffia fibres vinifera resulting from the dry stem located at PL-1/4-R3 at the temperatures 60°C, 70°C and 80°C

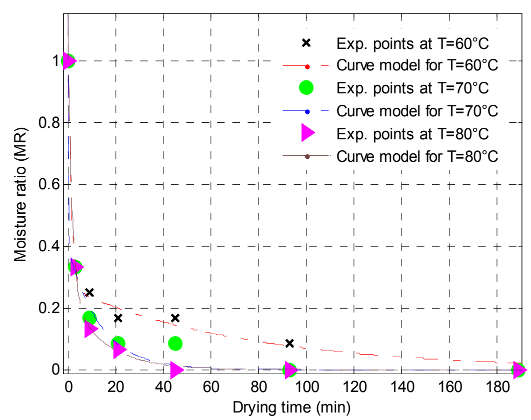

Fig. 6: Representation of Verma *et al*. (1985) model for raffia vinifera fibres exit of the dry stem located at PL- 1/4-R3 at the temperatures 60°C, 70°C and 80°C

optimal values respectively of 0.99967, 0.00021764 and 0.00639933 for Diffusion approach and Verma *et al*. (1985) models. It confirms the result found above.

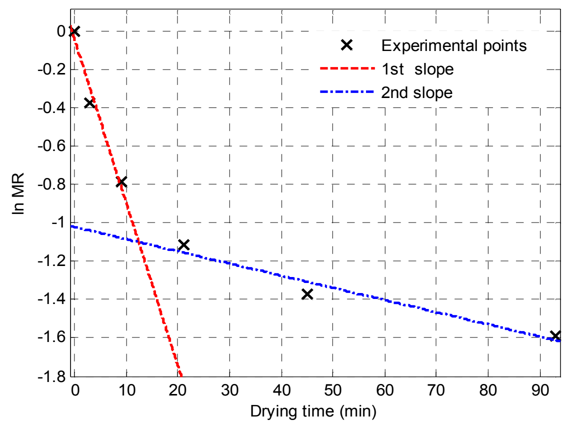

Fig. 7: Representation of the curve of ln MR. according to time t of raffia vinifera fresh fibre (PL-1/4 -R1) at T= 60°C

We can say that Diffusion approach or Verma *et al*. (1985) models give better description of the drying kinetics of fibres along the stem of raffia.

Figure 5 and 6 illustrate respectively the kinetics of Diffusion approach and Verma *et al*. (1985) model presented at various temperatures of the study of fibres of the center coming from base (PL-1/4-R3) of the dry stem. We observe that each curve fit well with the experimental points. The curves of the two suggested models give for different temperatures the same observations as previously for fibres of the fresh stem.

Evaluation of effective diffusion coefficient: Figure 7 represents the variation of the Moisture Ratio (MR) with time t for peripheric fibres resulting from the base of the fresh stem of raffia vinifera at T = 60°C.

We notice that the experimental points of this curve present a bilinear form. We can also say that for the fresh stem as well as for the dry stem and at various zones of sampling, we observe the same behaviour.

Meanwhile, the equation 12 defines that of a line. It means that the curve obtained can be divided into two lines having a slope each. The first slope which defines the initial phase and the 2nd slope which describes the final phase of diffusion during drying. Such an approach was applied during the study of the mathematical modelling of the drying of the mushroom (Arumuganathan *et al*., 2009) and in the same way, during the research of the diffusion coefficient during water absorption of the pasta products (Cunningham *et al*., 2007).

By the help of the software MATLAB R2009b, the slope (k) of the different straight line, the correlation coefficient (R^2) and the effective diffusion coefficient of fibres resulting from the various zones of the dry stem were represented in Table 4.

The analysis of the values contained in Table 4 enables us to note that the slope (k) of regression straight line during the initial phase of drying increases according to the temperature. By deduction, it is the case of the effective diffusion coefficient in each cross-section taken in a zone of sampling along the stem of raffia vinifera during this same phase. Similar results were observed during the studies of drying of the mushroom (Arumuganathan *et al*., 2009), fresh green beans (Souraki and Mowla, 2008; Souraki *et al*., 2012), bel pepper (Taheri-Garavand *et al*., 2011), medicinal plant Gundelia tournefortii (Duygu, 2012) and ripe banana (Rastogi *et al*., 1997). On the other hand, the slope (k) of the regression straight line during the final stage of dehydration does not obey any particular observation.

However, for the fibres from the fresh stem of raffia vinifera, we notice that the correlation coefficient obtained during the two phases is higher than 0.90. In addition, the effective diffusion coefficient in the initial phase increases according to the temperature at any position of the stem. It varies in the interval [1.76×10^{-10}-4.47×10^{-10}] m^2/s in the initial stage and included in the interval [1.03×10^{-11}-1.91×10^{-11}] m^2/s during the final stage.

Figure 8 and 9 illustrate the evolution of the effective diffusion coefficients at the initial phase of drying of raffia *Vinifera fibres* resulting respectively from the cross-sections of the dry (PL-2/4) and fresh (PL-4/4) stems at the different temperatures. In general, we note that the diffusion coefficient in a precise cross-section grows from peripheric towards the center. The same observations have been done for all the other zones along the stem.

Table 5 above illustrates some diffusion coefficients obtained during the study of the drying of certain crop products. We observe that the values of the diffusion coefficient of raffia *Vinifera fibres* at the beginning of drying are higher than those obtained at the end of the process. Meanwhile, we notice that the raffia *Vinifera fibres* resulting from the two varieties of stem during the initial phase of drying have values rather close to those of green beans, bamboo, pumpkin and sheets of olives. However, we note that the respective diffusion coefficient of carrot, Okra, ripe banana, flax fibres and Lippia m. M. leaves seems to be slightly higher than that of raffia *Vinifera fibres* in the two phases. On the contrary, the black tea presents a beach of values comparable to that of raffia *Vinifera fibres* in their final stage. Finally, we note that the diffusion coefficient of raffia textilis fibres resulting from the sheets is in an interval whose values are rather low compared to those obtained during the two phases within the framework of our study.

Activation energy: In this study, we were interested only in the activation energy during the beginning of drying (initial phase). The determination of the

Table 4: Summary of the effective diffusion coefficient D_{eff} according to the slope (k) of the regression straight line and its correlation coefficient (R^2) of dry fibres resulting from the stem of raffia

			Initial stage of diffusion			Final stage of diffusion		
Longitudinal position	Radial position	T(°C)	k (min^{-1})	R^2	D_{eff}(m^2/s)	k (min^{-1})	R^2	D_{eff}(m^2/s)
PL- 1/4 (Base stem)	Peripheric (R1)	60	0.04703	0, 9617	$1.08x10^{-10}$	0, 02296	0.9894	5.27×10^{-11}
		70	0.0529	0.9479	1.21×10^{-10}	0, 02278	0.9005	5.23×10^{-11}
		80	0.05917	0.9215	1.36×10^{-10}	0, 0226	0.9125	5.19×10^{-11}
	Half-radius (R2)	60	0.05601	0.9048	1.44×10^{-10}	0, 01763	0.9055	4.54×10^{-11}
		70	0.06262	0.9083	1.61×10^{-10}	0, 02105	0.9357	5.41×10^{-11}
		80	0.06998	0.9055	1.80×10^{-10}	0, 02302	0.9103	5.92×10^{-11}
	Center (R3)	60	0.06031	0.9067	1.61×10^{-10}	0, 02651	0.9019	7.06×10^{-11}
		70	0.08128	0.901	2.16×10^{-10}	0, 02704	0.9083	7.20×10^{-11}
		80	0.09281	0.9424	2.47×10^{-10}	0, 02887	0.9189	7.69×10^{-11}
PL- 2/4 (Near to the base)	Peripheric (R1)	60	0.06134	0.9351	1.30×10^{-10}	0, 01361	0.9213	2.87×10^{-11}
		70	0.06698	0.9520	1.41×10^{-10}	0.01504	0.9798	3.18×10^{-11}
		80	0.08957	0.9374	1.89×10^{-10}	0.01623	0.9762	3.43×10^{-11}
	Half-radius (R2)	60	0.06325	0.9089	1.45×10^{-10}	0.02068	0.9954	4.75×10^{-11}
		70	0.07189	0.9278	1.65×10^{-10}	0.02129	0.9577	4.89×10^{-11}
		80	0.091	0.9765	2.09×10^{-10}	0.01613	0.9643	3.70×10^{-11}
	Center (R3)	60	0.06722	0.9409	1.61×10^{-10}	0.01434	0.9966	3.42×10^{-11}
		70	0.07395	0.9199	1.77×10^{-10}	0.02211	0.9825	5.28×10^{-11}
		80	0.099	0.901	2.36×10^{-10}	0.01989	0.9115	4.75×10^{-11}
PL- 3/4 (Before the zone close to the sheets)	Peripheric (R1)	60	0.0647	0.9164	1.13×10^{-10}	0.01123	0.9684	1.96×10^{-11}
		70	0.06593	0.9431	1.15×10^{-10}	0.01296	0.9597	2.26×10^{-11}
		80	0.06782	0.9517	1.18×10^{-10}	0.01315	0.9984	2.29×10^{-11}
	Half-radius (R2)	60	0.0659	0.9045	1.24×10^{-10}	0.01177	0.997	2.22×10^{-11}
		70	0.06796	0.9357	1.28×10^{-10}	0.01167	0.9958	2.20×10^{-11}
		80	0.003	0.9786	1.89×10^{-10}	0.01216	0.9633	2.29×10^{-11}
	Center (R3)	60	0.08101	0.9567	1.60×10^{-10}	0.01019	0.9957	2.01×10^{-11}
		70	0.1227	0.9048	2.42×10^{-10}	0.009505	0.9876	1.88×10^{-11}
		80	0.1401	0.9118	2.77×10^{-10}	0.009684	0.9204	1.91×10^{-11}
PL- 4/4 (Near to the sheets)	Peripheric (R1)	60	0.043	0.9051	6.32×10^{-11}	0.0117	0.9209	1.72×10^{-11}
		70	0.07374	0.943	1.08×10^{-10}	0.01398	0.9575	2.05×10^{-11}
		80	0.1263	0.9112	1.86×10^{-10}	0.01283	0.9060	1.89×10^{-11}
	Half-radius (R2)	60	0.05106	0.9514	8.21×10^{-11}	0.01212	0.9618	1.95×10^{-11}
		70	0.09283	0.9014	1.49×10^{-10}	0.010244	0.9512	1.65×10^{-11}
		80	0.1464	0.961	2.35×10^{-10}	0.01201	0.9716	1.93×10^{-11}
	Center (R3)	60	0.07395	0.9520	1.22×10^{-10}	0.01032	0.98	2.75×10^{-11}
		70	0.1103	0.9091	1.82×10^{-10}	0.01021	0.9125	2.72×10^{-11}
		80	0.1817	0.9213	3.00×10^{-10}	0.01102	0.9216	2.94×10^{-11}

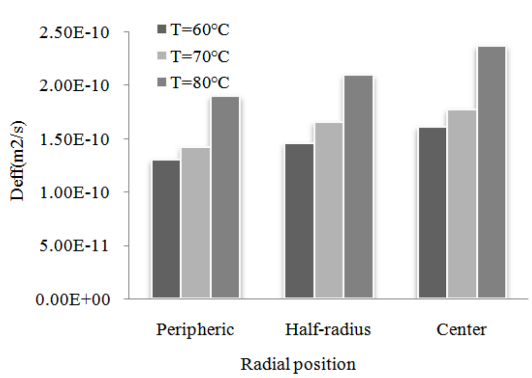

Fig. 8: Variation of the effective diffusion coefficient of raffia vinifera fibres resulting from a cross-section at the zone PL-2/4 for the dry stem at initial phase

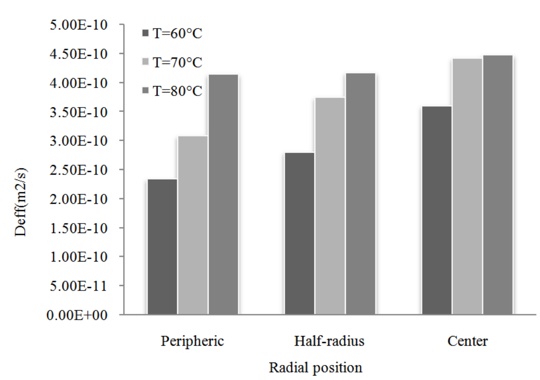

Fig. 9: Variation of the effective diffusion coefficient of raffia vinifera fibres resulting from a cross-section at the zone PL-4/4 of the fresh stem at initial phase

Table 5: Comparison between the diffusion coefficient obtained and those of the existing plants (Chien *et al*., 2008; Elenga *et al*., 2011a, b)

Vegetable plants	D_{eff} (m^2/s) Initial stage	D_{eff} (m^2/s) Final stage	Temperature (°C)	References
Okra	$4.27\times10^{-10} - 1.30\times10^{-9}$	-	50-70	Doymaz (2005)
Olive leaves	$2.95\times10^{-10} - 3.60\times10^{-9}$	-	40-60	Nourhène *et al*. (2008)
Aloe vera	$5.64\times10^{-10} - 18.1\times10^{-10}$	-	30-70	Simal *et al*. (2005)
Black Tea	$1.141\times10^{-11} - 2.985\times10^{-11}$	-	80-120	Panchariya *et al*. (2002)
Lippia m.M. leaves	$7.1\times10^{-10} - 21\times10^{-10}$	-	40-60	Elenga *et al*. (2011a)
Pumpkin	$1.359\times10^{-10} - 5.301\times10^{-10}$	-	55-65	Kongdej (2011)
Fresh green beans	$0.481\times10^{-10} - 2.730\times10^{-10}$	-	30-70	Souraki and Mowla (2008)
Green bean	$1.776\times10^{-10} - 2.707\times10^{-10}$	-	30-50	Souraki *et al*. (2012)
Sweet potato	$1.26\times10^{-9} - 8.80\times10^{-9}$	-	50-90	Ngankham and Pandey (2012)
Ripe banana	$8.5\times10^{-10} - 2.43\times10^{-9}$	-	25-45	Rastogi *et al*. (1997)
Raffia Textilis Fibre	$3.34\times10^{-14} - 2.32\times10^{-13}$	-	30-70	Elenga *et al*. (2011b)
Mushroom	$1.55\times10^{-9} - 4.02\times10^{-9}$	$8.76\times10^{-9} - 16.5\times10^{-9}$	50-60	Arumuganathan *et al*. (2009)
Flax fibre	$5.11\times10^{-9} - 1.92\times10^{-8}$	-	30-100	Ghazanfari *et al*. (2006)
Bamboo	$4.153\times10^{-10} - 22.83\times10^{-10}$	-		Lali *et al*. (2010)
Carrot	$2.74\times10^{-9} - 4.64\times10^{-9}$	-	65-75	Kumar *et al*. (2012)
Dry raffia vinifera fibre	6.32×10^{-11}-3.00×10^{-10}	$1.72\times10^{-11} - 5.92\times10^{-11}$	60-80	Studied case
Fresh raffia vinifera fibre	1.76×10^{-10}-4.47×10^{-10}	$1.03\times10^{-11} - 1.91\times10^{-11}$	60-80	Studied case

Table 6: Summary of the parameters (m) of the straight line, the correlation coefficient (R^2), the activation energy E_a and the constant D_0 of raffia vinifera fibres of the dry stem

Longitudinal position	Radial position	m	R^2	Ea (KJ/mol.K)	D_0(m^2/s) x10^4
PL- 1/4 (Base of the stem)	Peripheric (R1)	586.1	0.905	4.87	2.73
	Half-radius (R2)	568.2	0.9998	4.72	2.93
	Center (R3)	1104	0.9599	9.18	15.5
PL- 2/4 (zone after the base)	Peripheric (R1)	961.1	0.9031	7.99	8.97
	Half-radius (R2)	925.6	0.9658	7.70	8.53
	Center (R3)	983.1	0.9117	8.17	10.5
PL-3/4 (intermediate zone)	Peripheric (R1)	1088	0.9993	9.05	0.685
	Half-radius (R2)	1070	0.9828	8.90	12.3
	Center (R3)	1405	0.9275	11.68	38.6
PL- 4/4 (zone close to the sheets)	Peripheric (R1)	2750	0.9997	22.86	1430
	Half-radius (R2)	2691	0.9963	22.37	1360
	Center (R3)	2292	0.9935	19.06	478

Table 7: Comparative study of the activation energy of the different vegetable products (Aghfir *et al*., 2008; Elenga *et al*., 2011a, b)

Nature of the product	Ea (KJ/mol.K)	References
Pumpkin	27.8361-37.8437	Kongdej (2011)
Vegetation wastes	19.800	Lopez *et al*. (2000)
Black Tea	406.028	Panchariya *et al*. (2002)
Carrot	22.430	Togrul (2006)
Pear	26.460-31.210	Park *et al*. (2002)
Lippia m.M. leaves	46.3-47.8	Elenga *et al*. (2011a)
Aleo vera	24.4	Simal *et al*.(2005)
Olive leaves	52.15-83.6	Nourhène *et al*. (2008)
Cabbage	36.115	Mwithiga and Olwal (2005)
Okra	51.26	Doymaz (2005)
Bel pepper	44.49	Taheri-Garavand *et al*. (2011)
Green bean	23.97-47.26	Souraki and Mowla (2008)
Raffia Textilis Fibre	49-71	Elenga *et al*. (2011b)
Potato	12.87-14.35	Senadeera *et al*. (2003)
Groundnut shell	21.2	Dengyu *et al*. (2012)
Dry raffia viniféra fibre	4.72-22.86	Studied case
Fresh raffia viniféra fibre	4.65-12.13	Studied case

activation energy was carried out according to the extraction zone of fibres for each stem of raffia vinifera.

Figure 10 illustrates the representation of the curve of ln (D_{eff}) according to 1/T of peripheric fibres resulting from the zone close to sheets (PL-4/4-R1) of fresh stem.

We observe that this curve has the form of a line as initially mentioned in the theoretical study. The different curves done in other zones of sampling of the stem present similar plotting. Looking at the fibres resulting from the dry stem, we notice that the curves of ln D_{eff} according to 1/T have the same graph as the previous one. Similar curves were also obtained for the study of the drying kinetics of the (Panchariya *et al*., 2002), fruits of chempedak (Chien *et al*., 2008), pumpkin (Kongdej, 2011) and sweet potato (Ngankham and Pandey, 2012).

The parameters of the relation 14 and the correlation coefficient (R^2) are represented in Table 6 for the case of fibres coming from the dry stem.

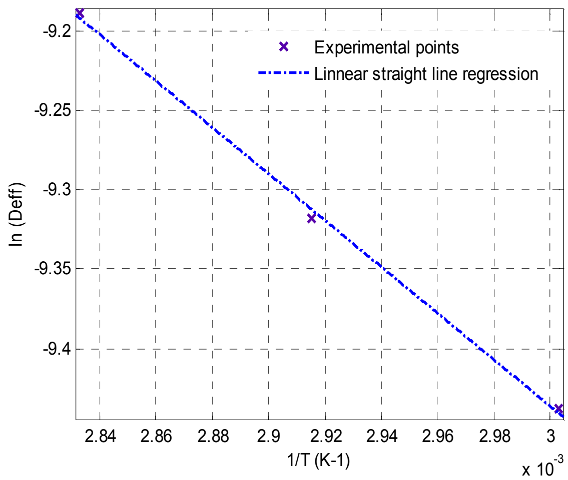

Fig. 10: Curve of ln (D_{eff}) according to time 1/T- fresh raffia vinifera fibres resulting from PL-4/4-R1

A comparative study of the various values of the activation energy in this table shows that the activation energy vary in the interval [4.72-22.86] KJ/mol/K. In addition, we note that this energy is maximum in the zones close to the sheets on the dry stem of raffia vinifera.

The activation energy of fibres resulting from the fresh stem belongs to the interval [4.65 - 12.13] KJ/mol/K. The maximum energy in this case is located once more in the zones close to the sheets.

Finally, we note that the maximum value of the activation energy of fibres of raffia resulting from the dry stem is twice the one coming from the fresh stem.

In general, we can say that the activation energy of raffia fibres during drying is very small compared to the others vegetable products presented in Table 7. Nevertheless the products such as carrot, groundnut shell, potato and certain vegetable wastes give values comparable to those obtained in certain zones of the stem of raffia vinifera. This low activation energy for the raffia fibres is due probably to their microstructure.

CONCLUSION

The water dehydration of raffia *Vinifera fibres* was explored. The fibres were classified in two varieties. The fibres whose evaluated moisture content vary in the interval [12-16] % called dry fibres and those whose values are included in the interval [19-107] % named fresh fibres. Then, the drying kinetics was approached through the drawing of the different curves according to the type of fibres and the three temperatures 60, 70 and 80°C, respectively. All the curves present two phases. One called initial phase describing the beginning of drying and the other named final stage marking the end of the process characterized by a constant mass. From 14 investigated models, it comes out that only "Diffusion approach" and "Verma *et al*. (1985)" models give correlation coefficients (R^2) identical and higher than 0,999. This permits to conclude that these two models describe the behaviour of dry fibres as well as that of fresh one also during drying. In addition, we continued with the determination of the diffusion coefficient of raffia *Vinifera fibres* according to their nature. For dry raffia fibres, the diffusion coefficients are included in the intervals [6.32×10^{-11}-3.00×10^{-10}] m^2/s and [1.72×10^{-11}- 5.92×10^{-11}] m^2/s respectively for the initial phase and final phase along the stem. For these fibres, we noted a growth of the effective diffusion coefficient from the periphery towards the center in any cross-section located along a stem. As for fresh raffia fibres, the effective diffusion coefficients are located in the intervals [1.76×10^{-10}-4.47×10^{-10}] m^2/s and [1.03×10^{-11}-1.91×10^{-11}] m^2/s respectively during the initial and final phases. The values of these various coefficients are comparable to those of some vegetable fibres. Finally, a reflection was carried out on the determination of the activation energy of raffia fibres. The study was carried out only in the initial phase of drying. Consequently, the activation energy of dry and fresh raffia fibres is included respectively in the intervals [4.72 - 22.86] KJ/mol/K and [4.65-12.13] KJ/mol/K. These values are low compared to those of other fibres and vegetable products.

REFERENCES

Aghbashlo, M., M.H. Kianmehr, S. Khani and M. Ghasemi, 2009. Mathematical modeling of carrot thin-layer drying using new model. Int. Agrophysic., 23: 313-317.

Aghfir, A., S. Akkad, M. Rhazi, C.S.E. Kane and M. Kouhila, 2008. Determination of the diffusion coefficient of the activation energy of mint upon drying in continuous conduction. J. Renew. Energ., 11(3): 385-394.

Akgun, N.A. and I. Doymaz, 2005. Modelling of olive cake thin-layer drying process. J. Food Engine, 68: 455-461.

Arslan, D. and M.M. Özcan, 2010. Study the effect of sun, oven and microwave drying on quality of onion slices. LWT- Food Sci. Technol., 43: 1121-1127.

Arumuganathan, T., M.R. Manikantan, R.D. Rai, S. Anandakumar and V. Khare. 2009. Mathematical modeling of drying kinetics of milky mushroom in a fluidized bed dryer. Int. Agrophys., 23: 1-7.

Chien, H.C, L.L. Chung, C. Michael, L.H. Ching, C.A. Luqman and W.D. Wan Ramli, 2008. Drying kinetics and product quality of dried chempedak. J. Food Engine, 88: 522-527.

Crank, J., 1975. The Mathematics of Diffusion. Oxford University Press, Ely House, London W.I., pp: 69-79.

Cunningham, S.E., W.A.M. McMinn, T.R.A. Magee and P.S. Richardson, 2007. Modeling water absorption of pasta during soaking. J. Food Eng., 82: 600-607.

Dengyu, C., L. Kai and Z. Xifeng, 2012. Determination of effective moisture diffusivity and activation energy for drying of powdered peanut shell under isothermal conditions. BioResources, 7(3): 3670-3678.

Doymaz, I., 2005. Drying characteristics and kinetics of Okra. J. Food Eng., 69(3): 275-279.

Doymaz, I., 2006. Thin-layer drying behavior of *mint* leaves. J. Food Eng., 74: 370-375.

Duygu, E., 2012. Thin layer drying kinetics of *Gundelia tournefortii L*. Food Bioprod. Process., 90: 323-323.

Elenga, R.G., G.F. Dirras, J. Goma Maniongui, P. Djemia and M.P. Biget. 2009. On the microstructure and physical properties of untreated *Raffia textilis* fiber. Compos Part A-Appl. S., 40(4): 418-422.

Elenga, R.G., T. Gouollaly and J. Goma Maniongui, 2011a. Effects of drying methods on the drying kinetics and the essential oil of *Lippia multiflora moldenke* leaves. Res. J. Appl. Sci. Eng. Technol., 3(10): 1135-1141.

Elenga, R.G., F.D. Guy, G.M. Jean and M. Bernard, 2011b. Thin-layer drying of *Raffia textilis* fiber. BioResources, 6(4): 4135-4144.

Etuk, S.E., L.E. Akpabio and K.E Akpabio, 2003. Investigation of *Raphia hookeri* trunk as a potential ceiling material for passively cooled building design. Ghana J. Sci., 43: 3-7.

Fafioye, O.O., A.A. Adebisi and S.O. Fagade, 2004. Toxicity of *Parkia biglobosa* and *Raphia vinifer*a extracts on *Clarias gariepinus juveniles*. Afr. J. Biotechnol., 3(11): 627-630.

Fafioye, O.O., S.O. Fagade and A.A. Adebisi, 2005. Toxicity of *Raphia Vinifera P. beauv* fruit extracts on biochemical composition of Nile Tilapia (*Oreochromis niloticus, Trewavas*). Niger. Soc. Exp. Biol., 17(2): 137-142.

Ghazanfari, A., S. Emami, L.G. Tabil and S. Panigrahi, 2006. Thin-layer drying of flax fiber: II. Analysis of modeling using Fick's second law of diffusion. Dry. Technol., 24: 1637-1642.

Henderson, S.M. and S. Pabis, 1961. Grain drying theory I: Temperature effect on drying coefficient. J. Agric. Res. Eng., 6: 169-174.

Israel, A.U., I.B. Obot, S.A. Umoren, V. Mkpenie and J.E. Asuquo, 2008. Production of cellulosic polymer from agricultural wastes. E-J. Chemist., 5(1): 81-85.

Kankam, C.K., 1997. Rafiia palm-reinforced concrete beams. Mater. Struct., 30: 313-316.

Karathanos, V.T. and V.G. Belessiotis, 1999. Application of a thin layer equation to drying data fresh and semi-dried fruits. J. Agric. Eng. Res., 74: 355-361.

Kongdej, L., 2011. Effects of temperature and slice thickness on drying kinetics of pumpkin slices. Walailak J. Sci. Tech., 8(2): 159-166.

Kumar, N., B.C. Sarkar and H.K. Shama, 2012. Mathematical modeling of thin layer hot air drying of carrot pomace. J. Food Sci. Technol., 49(1): 33-41.

Lali, M.B., Abhijit, K., Santosh, S. and Satya, N.N., 2010. Drying kinetics and effective moisture diffusivity of bamboo shoot slices undergoing microwave drying. Int. J. Food Sci. and Techn., 45: 2321-2328.

Lopez, A., Iguaz, A., Esnoz, A., Virsedia, P., 2000. Thin-layer drying behavior of vegetable waste from wholesale market. Drying technology, 18: 995-1006.

Mwithiga, G. and Olwal, J.O., 2005. The drying kinetics of (Brassica oleracea) in a convective hot air dryer. J. Food Engine., 71 (4):373-378.

Midilli, A., H. Kucuk and Z. Yapar, 2002. A new model for single-layer drying. Dry. Technol., 20(7): 1503-1513.

Mohammed, A., R. Shahin, K. Alireza and E.D. Zahra, 2009. Moisture content modeling of sliced kiwifruit during drying. Pak. J. Nutr., 8(1): 78-82.

Musset, R. 1933. Raffia. Annal. Geogr., 42(236): 190-193.

Ndenecho, E.N., 2007. Biogeographically and Ethno botanical analysis of the raphia palm in the west Cameroon highlands. J. Cameroon Acad. Sci., 7(N°1): 21-32.

Ngankham, J.S. and R.K. Pandey, 2012. Convective air drying characteristics of sweet potato cube (*Ipomoea batatas*). Food Bioprod. Process., 90: 317-322.

Njeugna, E., N.R. Sikame Tagne, J.Y. Drean, D. Fokwa and O. Harzallah, 2012. Mechanical characterization of raffia fibres from raphia *vinifera*. Int. J. Mech. Struct., 3(1): 1-17.

Nourhène, B., K. Mohammed and K. Nabil, 2008. Experimental and mathematical investigations of convective solar drying of four varieties of olive leaves. Food and Bioproducts Process., 86: 176-184.

Obahiagbon, F.I., 2009. A review of the origin, morphology, cultivation, economic products, health and physiological implications of Raphia palm. Afr. J. Food Sci., 3(13): 447-453.

O'Callaghan, J.R., D.J. Menzies and P.H. Bailey, 1971. Digital simulation of agricultural dryer performance. J. Agri. Eng. Res., 6(3): 223-244.

Overhults, D.D., G.M. White, M.E. Hamilton and I.J. Ross, 1973. Drying soybeans with heated air. Trans. ASAE, 16: 195-200.

Park, K.J., Vohnikova,Z. and Brod, F.P.R, 2002. Evaluation of drying parameters and desorption isotherms of garden mint leaves (Mentha Crispa. L.). J. Food Engine., 51: 193-199.

Page, C., 1949. Factors infl uencing the maximum rate of drying shelled corn in layers. M.S. Thesis, Purdue University, West Lafayette, Indiana.

Panchariya, P.C., D. Popovic and A.L. Sharma. 2002. Thin-layer modeling of black tea drying process. J. Food Eng., 52: 349-357.

Peleg, M., 1988. An empirical model for the description of moisture sorption curves. J. Food Sci., 53: 1249-1251.

Rastogi, N.K., K.S.M.S. Raghavarao and K. Niranjan, 1997. Mass transfer during osmotic dehydration of banana: Fickian diffusion in cylindrical configuration. J. Food Eng., 31: 423-432.

Rastogi, N.K., K.S.M.S. Raghavarao, K. Niranjan and D. Knorr, 2002. Recent developments in osmotic dehydration: Methods to enhance mass transfer. Trend. Food Sci. Technol., 13: 48-59.

Sandy, M. and L. Bacon, 2001. Tensile testing of raffia. J. Mat. Sci. Lett., 20: 529-530.

Schössler, K., J. Henry and K. Dietrich, 2012. Effect of continuous and intermittent ultrasound on drying time and effective diffusivity during convective drying of apple and red bell pepper. J. Food Eng., 108: 103-110.

Senadeera, W., R.B. Bhesh, Y. Gordon and W. Bandu, 2003. Influence of shapes of selected vegetable materials on drying kinetics during fluidized bed drying. J. Food Eng., 58: 277-283.

Sharaf-Eldeen, Y.I., J.L. Blaisdell and M.Y. Hamdy, 1980. A model for ear corn drying. Trans. ASAE, 23: 1261-1271.

Silou, T., C. Makonzo-Mokando, J.P. Profizi, A. Boussoukou and G. Maloumbi, 2000. Physico-chemical characteristics and fatty acid composition of oils Raphia sese and Raphia laurenti (French). Tropicultura, 18(1): 26-31.

Simal, S., A. Femenia, M.C. Garau and C. Rossello, 2005. Use of exponential, Page's and diffusional models to simulate the drying kinetics of kiwi fruit. J. Food Eng., 66: 323-328.

Souraki, B.A. and D. Mowla, 2008. Axial and radial moisture diffusivity in cylindrical fresh green beans in a fluidized bed dryer with energy carrier: Modeling with and without shrinkage. J. Food Eng., 88: 9-19.

Souraki, B.A., A. Ghaffari and Y. Bayat, 2012. Mathematical modeling of moisture and solute diffusion in the cylindrical green bean during osmotic dehydration in salt solution. Food Bioprod. Process., 90: 64-71.

Togrul Hasan, 2006. Suitable drying model for infrared drying of carrot. J. Food Engine., 77: 610-619.

Taheri-Garavand, A., R. Shahin and K. Alireza, 2011. Study on effective moisture, activation energy and mathematical modeling of thin layer drying kinetics of bell pepper. Australian J. Crop Sci., 5(2): 128-131.

Takenobu, O., K. Takashi and A. Shuji, 2012. Prediction of pasta drying process based on a thermogravimetric analysis. J. Food Eng., 111: 129-134.

Talla, P.K., A. Foudjet and M. Fogue, 2005. Statistical model of strength in flexion and effect on the failure of Raphia *vinifera* L. (*Arecacea*). J. Bamboo Rattan, 4(4): 335-342.

Talla, P.K., A. Fomethe, M. Fogue, A. Foudjet and G.N. Bawe, 2010. Time-temperature equivalency of Raphia *vinifera* L. (*Arecaceae*) under compression. Int. J. Mech. Solid, 5(1): 27-33.

Talla, P.K., F.B. Pelap, M. Fogue, A. Fomethe, G.N. Bawe, E. Foadieng and A. Foudjet, 2007. Nonlinear creep behavior of Raphia *vinifera* L. (*Arecacea*). Int. J. Mech. Solid, 2(1): 1-11.

Talla, P.K., J.R. Tekougnening, E. Tangka and A. Foudjet, 2004. Statistical model of strength in compression of Raphia vinifera L. (*Arecacea*). J. Bamboo Rattan, 3(3): 229-235.

Tiepma, N.E.F., N.F. Zambou and M.F. Tchouanguep, 2010. Immune system stimulation in rats by *Lactobacillus sp* isolates from raffia wine (*Raphia vinifera*). Cell. Immun., 260(2): 63-65.

Wang, C.Y. and R.P. Singh, 1978. A Thin Layer Drying Equation for Rough Rice. ASAE Paper No. 78-3001, St. Joseph, MI, USA.

Verma, L.R., R.A. Bucklin, J.B. Endan and F.T. Wratten, 1985. Effects of drying air parameters on rice drying models. Trans. ASAE, 28: 296-301.