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Development of a mathematical model by multivariate linear regression of prediction of the time of radiative drying to the electromagnetic radiation of microwaves of the starch products usually consumed in Africa

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ABSTRACT : *The objective of this work is to develop a mathematical model of prediction of time of radiative drying with the electromagnetic radiation of the microwaves of Dioscorea cayenensis, Colocasia esculenta and Ipomoea batatas by the multivariate analysis. The radiative drying of the starch products of forms parallelepipedic and cylindrical were dried with the microwawe oven GEEPAS Industriel (140, 280 and 420 W).The simulation of the kinetics of drying was carried out thanks to the existing semi-empirical models in the literature. Times of drying of the starch products were determined by interpolation starting from semi-empirical model adapted best. They were then modelled starting from the experimental designs. Simulations of the kinetics of drying revealed that the model of Page* ($0.97244 \leq R^2 \leq 0.99957$, *of* $0.0000538 \leq \chi^2 \leq 0.00233$ *and of* $0.00322 \leq RMSE \leq 0.06682$) *is adapted to predict time of radiative drying of each product. The analysis of the instantaneous residues of the water content reduced presents the averages of distribution close to the normal law centered reduced with densities of probability which vary from 38. 5 to 55 %. the prediction of the time of drying by multivariate linear regression showed the satisfactory results.The test of ANOVA approved the possibility of developing a single model of the time of drying of the starch products with the threshold of significativity of* $p \leq 5\ \%$.

KEYWORDS *starch products, kinetics of drying, radiative drying, simulation, linear regression multi varied*

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I. INTRODUCTION

In sub-Saharan Africa, the roots and tubers constitute the most significant food cultures. These local roots and tubers are the manioc (*Manihot esculenta*), the potato (*Solanumn tuberosum*), the sweet potato (*Ipomoea batatas*) the yam (*Dioscorea*) and the taro (*Colocasia esculenta*). The world production of sweet potato, the yam and the taro was respectively 106, 68 and 10 million tons in 2014, behind manioc and potato (385 million tons) (270 million tons). The content of glucides compared to the matter dries are of approximately of 90 % for the yam, 60 to 90 % for the taro and of 80 % for sweet potato [Nepa, 2006;Jane *et al.*, 1992; Payne *et al.*., 1941]. Because of their content of high (50 80 % of water), the losses post-harvest are considerable and rise few thousands of tons each year [Nepa, 2006]. Drying thus constitutes a suitable means to slow down these losses and to extend their consumption to the periods of nonproduction, while creating added value.The recent studies showed that the flours and the starches of these products in particular of *Manihot esculenta*, *Ipomoea batatas*, *Dioscorea cayenensis-rotundata*, of *Xanthosoma sagittifolium* and of *Colocasia esculenta*) can be used in the formulation of products in agricultural processing industry and industry pharmaceutical [Ganongo-Po *et al.*, 2018; Ndangui., 2015; Ndangui *et al.*., 2014; Ahmed *et al.*, 2010;.Kouassi, 2009]. Conventional drying is largely used in the literature.Today, among the innovating processes of drying, radiative drying with the electromagnetic radiation of microwaves proved to be effective for a certain number of agricultural produce such as cocoa broad beans [Nogbou *et a.l*, 2015], the tomato [Koné, 2011], dates [

Chekroune, 2009] and corn [Walde *et al.*, 2002]. Drying with the microwaves reduces the time of drying to more than 99 % when it is compared with drying with the sun and the drying oven [Arslan and Muza Ozcan, 2007]. The course of drying can be influenced by several independent factors, in fact the conditions of drying such as the temperature or the power of heating, the speed and the relative humidity of the air, as well as properties of the solid such as the density, porosity and hygroscopicity [Mendez Lagunas, 2007]. Kimbonguila *et al.*(2018) showed that the thickness or the diameter of the samples on the one hand and the temperature or the power of heating of drying on the other hand, showed significant effects over time of drying of *Dioscorea cayenensis, Colocasia esculenta* and *Ipomoea batatas.* Elongo *et al.*(2019*)* showed that the energy and the entropy of activation (agitation molecule) of *Dioscorea* cayenensis, of *Colocasia esculenta* and of *Ipomoea batatas* during convectif drying are not significant between these three starch products, which constitutes an asset to develop a single model of prediction of times of drying of the latter.

A great number of mechanisms were proposed to explain the movement of water inside food during drying (Prati, 1990).Models of various complexities were developed to describe the phenomenon of drying.They are the ideal models, the semi models empirical or phenomenologic and the models empirical (Midilli *et al.*, 2002;.Panchariya *et al.*, 2002). The ideal models according to their complexity, detail the mechanisms of transfer finely. Unfortunately, the difficulty of obtaining certain parameters limits sometimes their use.In the current state of knowledge, the establishment of the majority of the models of kinetics of drying of the various products comes under the field semi-empirical (Guimaraes *et al.*, 2018;Nasfi and Bagane, 2017;Nogbou *et al.*, 2015;Thu ha Nguyen., 2015;Messaoudi *et al.*, 2015; Jannot *et al.*, 2006). However, the establishment of the semi-empirical models does not take account of the effects of the factors implied in the model.The objective of this work is to develop a mathematical model of prediction of time of radiative drying of the starch products by multivariate linear regression while taking of account the effects of the implied factors.

II. MATERIEL AND METHODS

II.1. VEGETABLE MATERIAL

The tubers of *Dioscorea cayenensis, Colocasia esculenta* and *Ipomoea batatas* (Fig.1) were bought at the Total market and the market Texaco de Brazzaville.

a) Tubers of *Ipomoea batatas* b) Tubers of *Colocasia esculenta* c) Tubers of *Dioscorea cayenensis*

Fig. 1(a,b,c): Tubers of the three starch products

They were stored at the laboratory at the ambient temperature for all the experimental period.

II.2. MATERIAL OF LABORATORY AND EQUIPMENT OF DRYING

The material used consists of a Balance with precision**,** of an electric slicer, cylindrical Moulds, the Slide caliper and the microwawe oven GEEPAS (Fig.2)**.**

a)Balance with precision Explore-pro (0-210g, with E = 0.0001g) b) Cylindrical mould of Diameter = 15 mm; Height = 40 mm c) Slide caliper

d) Electric slicer RCL1

e) Microwawe oven of GEEPAS

Fig. 2 (a, b, c, d, e) : Material of the laboratory

II.3. SAMPLING

The tubers of *Dioscorea cayenensis* (yellow yam), of *Colocasia esculenta* (taro) and *Ipomoea batatas* (sweet potato) were dimensioned in the parallelepipedic form (L×l×E = 40 mm× 30 mm × (4 or 14 mm)) and cylindrical (height = 40 mm and of diameter D = 15 mm and D=20 mm) (Fig.3).

Fig.3 (a, b): Cylindrical and parallelepipedic samples of the starch products

Dimensioning was carried out using an electric Slicer of mark RCL1 and moulds of cylindrical form. Exact dimensions of each sample were checked using a slide caliper.

The samples were coded in the following way: X-F/QJ/Z

With:

X: Code starch product: (DC.:*Dioscorea cayenensis;* CE: *Colocasia esculenta* and IB: *Ipomoea batatas);*

F:Form sample (P: parallelepipedic form; C:cylindrical form;

Q: Thickness or of the diameter;

J:Dimension thickness or the diameter (mm);

Z:Temperature (C) or power of drying (W).

II.4. RADIATIVE DRYING WITH THE MICROWAWE OVEN

The samples of the starch products were weighed beforehand to record the initial mass.Then, they were placed on the rotary table of the microwawe oven (GEEPAS) with powers of heating and the time of intermittency respectively of 140, 280 and 420W and of 60, 30 and 10 S. the follow-up of the mass was carried out until the stabilization of this one.

II.5. PARAMETERS OF KINETICS OF DRYING

II.5.1. *Water content and water content reduced*

The determination of the water content was carried out according to method AOAC (1990) based to the measure of the loss in mass of the samples after stoving with 105 ± 2°C until complete elimination of interstitial water and the volatile matters.

$$X= [(m_h-m_s) / m_h] \times 100 \qquad (1)$$

X: water content;

M_h: mass wet sample (g);

M_s: mass dry sample (g);

$$X^* = (X_{(t)} - X_{eq}) / (X_o - X_{eq}) \qquad (2)$$

X*: reduced tenor in water

$X_{(t)}$: instantaneous tenor in water ($g_{H2O}.g^{-1}._{MS}$)

X_0 : initial tenor in water ($g_{H2O}. g^{-1}._{MS}$)

X_{eq} : balanced tenor in water ($g_{H2O}.g^{-1}._{MS}$)

The water content reduced was simplified by the equation (Eq. 3) because Xéq is relatively negligible compared to $X_{(t)}$ and X_0 (Akmel *et al.*, 2009;Haoua, 2007).

$$X^* = X_{(t)} / X_o \qquad (3)$$

II.5.2. *Time of drying*

The time of drying is defined theoretically like time necessary to the evaporation of the water totality contained in the product.However, it is difficult to evaporate the water totality contained in the product. This time of drying corresponds then to the moment when one observes a stability of the mass of the product during drying. For this work, the time of drying was defined as being time necessary to reach a water content reduced final of 10 %. It was determined by simulation and interpolation of the $X^*=f(t)$ function using the OriginPro2016 software.

II.6. SEMI-EMPIRICAL SIMULATION OF THE KINETICS OF DRYING

The semi-empirical simulation of kinetics of drying of *Dioscorea cayenensis, Colocasia esculenta* and *Ipomoea batatas* was carried out starting from four (04) models (table 1).

Table 1. Mathematical models used in this study

N°	**Name of the model**	**Equation of the model**	**References**
1	Newton	$Xr= \exp(-kt)$	Dadali *et al.*,2007
2	Henderson & Pabis	$Xr= a.\exp(-kt)$	Akmel *et al.*,2009
3	Page	$Xr= \exp(-k\, t^n)$	Sharma and Prasad ,2001
4	Midilli	$Xr= a \exp(-kt)+ bt$	Midilli *et al*.,2002

The numerical analysis of curve of kinetics of drying was carried out using the Software OriginPro version 2016. The choice of the best model was based on the values of the coefficient of determination (R^2) high and reduced ki-square (χ^2) and of the square root of the average quadratic error (RMSE) lowest (Doymaz., 2004)

These parameters were calculated as follows:

$$R^2=1-[\Sigma^N_{i=1} (X^*_{ei} - X^*_{pi})^2]/ \Sigma^N_{i=1} (X^*_{m} - X^*_{pi})^2] \qquad (5)$$

$$RMSE= [(1/N)\times\Sigma^N_{i=1} (X^*_{ei} - X^*_{pi})^2]^{½} \qquad (6)$$

$$\chi^2= 1/(N-n)\times\Sigma^N_{i=1} (X^*_{ei} - X^*_{pi})^2 \qquad (7)$$

With

X^*ei, $i^{ème}$ experimental value,
X^*pi $i^{ème}$ predicted value by the model,
X^*me, average experimental values
N, number of observations,
n, number of model constants

II.7. MATHEMATICAL MODELING BY MULTIVARIATE LINEAR REGRESSION OF THE TIME OF DRYING

II.7. 1. *Experimentation and construction of the experimental design*

The samples of *Dioscorea cayenensis*, *Colocasia esculenta* and *Ipomoea batatas* of parallelepipedic and cylindrical form were used. The complete factorial design with two factors and two levels each one was selected like the experimental design in this study (number of test: $N = 2^k$; $K = 2$; $N = 4$).

The outline levels of experiment are as follows:

- Power: 140 and 280 W;
- Thickness: 4 and 14 mm;
- Diameter: 15 and 20 mm

The matrix of the experimental designs is presented in table 2.

Table 2. Stamp experimental design of radiative drying

N° test	**Facteurs**			
	Power	**Thickness**	**Power**	**Diameter**
1	-1	-1	-1	-1
2	-1	+1	-1	+1
3	+1	-1	+1	-1

4	+1	+1	+1	+1
Bottom grade (-1)	140 W	4 mm	140 W	15 mm
High level (+1)	280 W	14 mm	280 W	20 mm

Each experiment was carried out with three (03) counterparts.

II.7. 2. *Equation of modeling*

The function connecting the response y (time of drying) to the independent variables (power of drying, thickness or diameter of the samples) is given by the equation (8).It is about a polynomial model of degree 1 compared to each variable.

$$Y= f(x_1,x_2) = y_0 + a_1x_1 + a_2x_2 + a_{12}x_1x_2 \qquad (8)$$

The terms, a_1,a_2 , a_{12} are average effects of the factors (power, thickness or diameter) and their interaction on the answer considered (time of drying).

Where :

xi : the level allotted to factor *i* represents.

y_0 : is the value of the response to the center of the field of study.

a_1: is the effect of factor 1 (power).

a_2: is the effect of factor 2 (thickness or diameter).

a_{12}:is the effect of the interaction between factors 1 and 2.

x_1 x_2:correspond to the interactions between the factors x1 and x2 [Goupy, 2006]

The multivariate analysis was used to describe association between the two (02) variables.

- ***Calculation of the parameters of the model***

The parameters of the model were calculated by using the software Minitab version 2017 and while regarding as answer the time of drying and the above mentioned variables of entry.

- ***Studied answer***

The complete factorial design with two (02) factors and two (02) levels was selected to model the time of drying necessary to reach a water content reduced X*=10 % during the radiative drying of these three (03) starch products.

- ***Analyze statistical and validation of the models***

The statistical analysis of the data was carried out using the software OriginPro 2016 and Minitab 2017.The test of ANOVA was applied to determine the factors having significant effects on the answer (IC = 95 %).

The test of validation was carried out thanks to the test of residues by comparing the values predicted with those obtained in experiments.The equations of residue and the sum of the squares of the residues are presented on the relations (9) and (10).

$$\textbf{\textit{Residue}} = [y_{exp} - (y_0 + a_1x_1 + a_2x_2 + a_{12}x_1x_2)] \qquad (9)$$

$$\textbf{\textit{Summon squares of the residues:}}\ S = \sum_{i=1}^{n}[\,y_{exp} - (\,y_0 + a_1x_1 + a_2x_2 + a_{12}x_1x_2\,)]^2 \qquad (10)$$

y_{exp}:experimental value (actual value (time of drying (s) t=f(X*=10))

III. RESULTS AND DISCUSSION

III.1 *EFFECT OF THE POWER OF HEATING ON THE KINETICS OF DRYING OF THE STARCH PRODUCTS*

The effect of the power of heating on the kinetics of radiative drying of Dioscorea *cayenensis* (cd.) *Colocasia esculenta* (EC) and *Ipomoea batatas* (IB) is represented on Fig.4 and Fig.5 respectively for the parallelepipedic and cylindrical form, has show below.

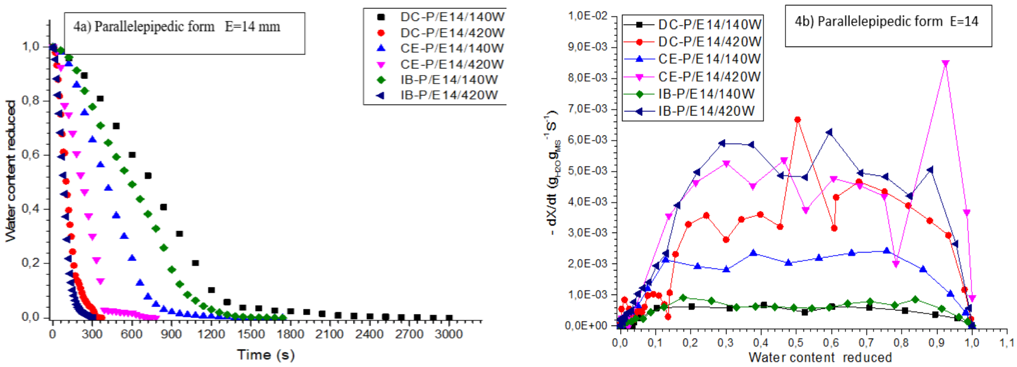

Fig. 4. Influence power of heating of microwaves on the kinetics of radiative drying of three starch products (Parallelepipedic form)(X-DC: 66,32 ± 5 % ; X-CE : 60,08 ± 6 % et X-IB : 63,25 ± 0,3 %)

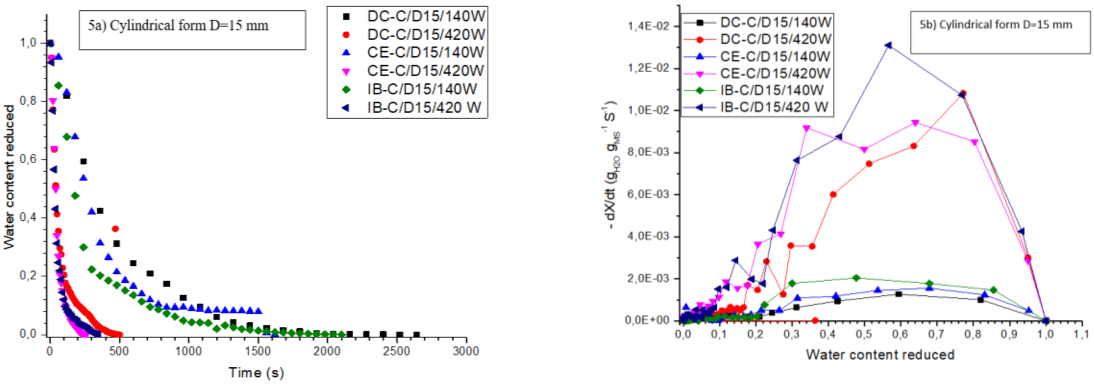

Fig. 5. Influence power of heating of microwaves on the kinetics of radiative drying of three starch-based (Cylindrical form)(X-DC.:66,32 ± 5 %;X-CE:60,08 ± 6 % and X-IB:63,25 ± 0,3 %)

The analysis of these figures shows that the rise in the power of heating has an influence on the reduction of time of drying.
The time of drying decreases significantly with the increase in the power of heating.For the samples of parallelepipedic form thickness E=14 mm (Fig.4), one notes a reduction in the time of drying of about 77. 27, 42.36 and of 86.11 % respectively for drying DC., from CE and IB, when the power of heating passes from 140 to 420 W (X*=5 %).

This time of drying decreases by 75.00, 84.09 and 78.94 % respectively for the samples of DC., CE and cylindrical IB of form of diameter D = 15 mm (Fig.5) when the power increases by 140 to 420 W.
The shape of curves speed presents three (03) phases each one for the two shapes of dried samples.It is about the phase of temperature setting, the phase at constant speed and the phase at decreasing speed.
The three phases of the curves speed are observed for the dried samples of parallelepipedic form with low power (Fig.4b) compared to those of form cylindrical (Fig.5b).

The results obtained reflect those of the literature.Indeed, Alibas (2007) and Al-Harahsheh, Al-Muhtaseb & Magee (2009) respectively announced it for drying by the microwaves of sections of pumpkin and tomato pulp. The disappearance of the phase at constant speed for the high powers (420 W) can be explained by the fact that on these levels of power, flows of the water of the interior towards surface of the product are faster, outcome with a phase at shorter constant speed.Indeed, more the heat generated within the product is significant, the difference in water vapor pressure is larger between the center and the surface of the product.It is this gradient of pressure which would be at the base of the fast elimination of water for the high powers [Al-Harahsheh, Al-Muhtaseb, & Magee, 2009].

Mudgett (1986) showed that the food being insulators, they generally absorb a great fraction of the electromagnetic waves, from where them very high heating instantaneous, which has as a consequence the reduction of time of drying.
The effect of the power of drying was made by several authors, while working on products [Nogbou *et al.*, 2015;Darvishi *et al.*, 2013; Bal *et al.*, 2010;McMinn, 2006].
Darvishi *et al.,* 2013 showed that the time of radiative drying (microwave) of sardine, is reduced by 51 %. Nogbou *et al.(*2015) and Bal *et al.*.(2010) observed respectively in the case of the broad bean drying of cocoa and bamboo shoots, a reduction of time of drying of 46.66 and 56.66 %, when the power passed respectively from 450 to 600 W and 450 to 700 W and one 70 %, when the power passed from 140 W with 350 W.

III.2 *EFFECTS THE THICKNESS AND OF THE DIAMETER OF THE SAMPLES ON THE KINETICS OF DRYING OF THE STARCH PRODUCTS.*

The effect of the diameter and the thickness and during radiative drying of three starch products is presented respectively on Fig.6 and Fig.7., has show below.

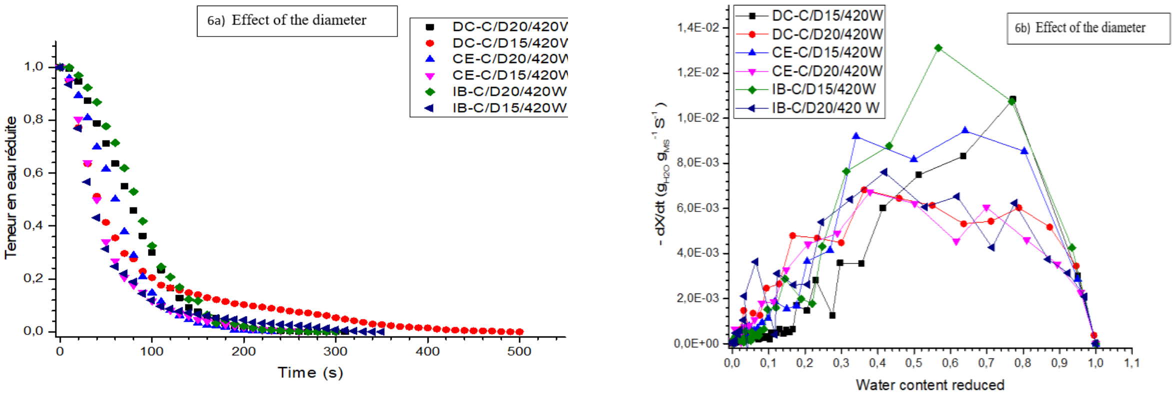

Fig. 6.Effect of the diameter on the kinetics of radiative drying of three starch products (X-DC: 66,32 ± 5 % ; X-CE : 60,08 ± 6 % et X-IB : 63,25 ± 0,3 %

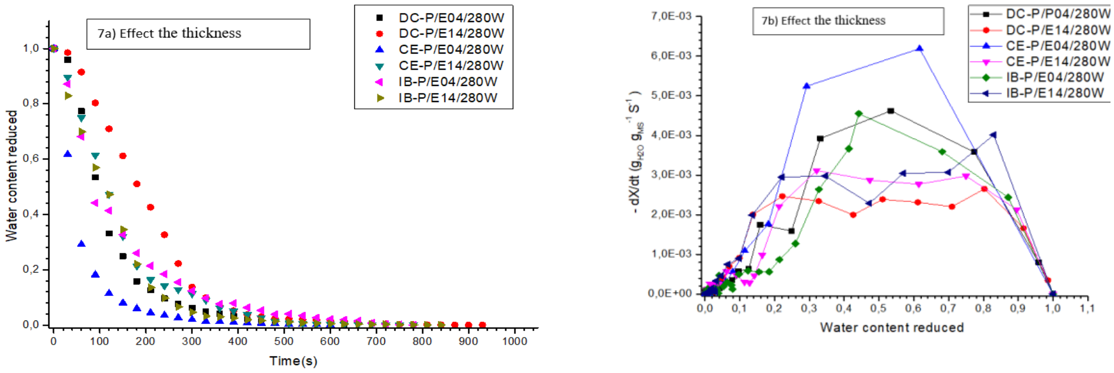

Fig. 7.Effect the thickness on the kinetics of radiative drying of three starch products (X-DC: 66,32 ± 5 % ; X-CE : 60,08 ± 6 % et X-IB : 63,25 ± 0,3 %

The analysis of the figures shows that the variation of the diameter or thickness of the samples of each starch product has an influence on the kinetics of radiative drying. The reduction in the diameter or thickness of the samples is proportionally in the the time of drying.

Indeed, the reduction in diameter from 20 to 15 mm during radiative drying with 420 W makes it possible to reduce the time of drying from 118 to 105 s (DC.), from 95 to 75 s (CE) and from 120 to 75 s (IB) (for a final moisture of 10 % (Fig.ã)). That is to say a temporary reduction ratio of 11.02, 21.05 and 37. 5 % respectively for the drying of DC, CE and IB. Radiative drying with 280 W of the samples of 14 and 4 mm makes it possible to reduce this time of drying of 56.53 % (DC), 53.85 % (CE) and 48.89 % (IB) (Fig.7a).

The reduction in the diameter or thickness makes it possible to accelerate the phenomenon of transfer of heat and matter and consequently, it entraine the reduction of the time of drying.Several researchers showed that the increase in the time of drying for the samples of large diameter is due by the distance which moisture must traverse to reach the surface of the product [Bennamounv and Belhamri, 200 and Akpinar *et al.*,2000].

The analysis of curve of kinetics of radiative drying (Fig.6b and Fig.7b) makes it possible to distinguish the three (03) following phases:the phase of temperature setting, the phase at constant speed and the phase with decreasing pace. These results enable us to cancel the assumption according to which drying in thin layer in general does not present only one phase at decreasing pace.

The existence of three phases of drying could be due to the mode of transfer of heat.Indeed, the starch products being rich in water (polar molecules), during the heating microwaves, absorptive energy is degraded in heat by dielectric relieving [Coffey *et al.*, 1988].The intermolecular shocks generated by the rotation of these molecules (molecular agitation) generate a great quantity of heat (appearance of the phase at constant speed) [Kozempel *et al.*, 1998].

III.3 *SEMI-EMPIRICAL SIMULATION OF THE KINETICS OF DRYING*

The results of simulation of the kinetics of radiative drying of *Dioscorea cayenensis* (DC) *Colocasia esculenta* (CE) and *Ipomoea batatas* (IB) with the model of Newton, of Henderson and Pabis, Page and Midilli are presented table 3.

Table 3. Results of the modeling of the kinetics of radiative drying

Produits	**Echantillons**	**Page**			**Midilli**		
		R^2	**χ^2**	**RMSE**	**R^2**	**χ^2**	**RMSE**
Dioscorea cayenensis	**DC-C/D15/140W**	0.99688	0.000253	0.01592	0.99694	0.000261	0.01617
	DC-C/D20/140W	0.99932	0.0000553	0.00743	0.96703	0.00277	0.0526
	DC-P/E04/140W	0.99101	0.000561	0.02367	0.95962	0.00539	0.07345
	DC-P/E14/140W	0.99715	0.000366	0.01948	0.99245	0.000496	0.02227
	DC-C/D15/280W	0.9915	0.000575	0.02398	0.99142	0.0006	0.02449
	DC-C/D20/280W	0.99848	0.00017	0.01395	0.96818	0.00257	0.05066
	DC-P/E04/280W	0.99857	0.0001587	0.0126	0.97777	0.00182	0.04267
	DC-P/E14/280W	0.99855	0.000164	0.01281	0.96696	0.00388	0.06228
	DC-C/D15/420W	0.98105	0.00104	0.0323	0.99078	0.000655	0.0256
	DC-C/D20/420W	**0.99957**	**0.0000538**	**0.00733**	0.96947	0.00396	0.06291
	DC-P/E04/420W	0.991	0.000584	0.02416	0.99329	0.000484	0.00256
	DC-P/E14/420W	0.99771	0.000276	0.01661	0.97939	0.022	0.05056
Colocasia esculenta	**CE-C/D15/140W**	0.97244	0.00233	0.04832	0.98298	0.0015	0.03872
	CE-C/D20/140W	0.99845	0.000174	0.01318	0.97867	0.00252	0.05015
	CE-P/E04/140W	0.99396	0.000385	0.01962	0.99393	0.000404	0.02011
	CE-P/E14/140W	0.99896	0.000132	0.0115	0.96076	0.00518	0.07198
	CE-C/D15/280W	0.97244	0.00233	0.04832	0.98298	0.0015	0.03872
	CE-C/D20/280W	0.99743	0.000311	0.01763	0.97822	0.00281	0.05303
	CE-P/E04/280W	0.99491	0.000327	0.01807	0.99566	0.000294	0.01715
	CE-P/E14/280W	0.9948	0.000465	0.02157	0.98806	0.03336	0.00111
	CE-C/D15/420W	0.99239	0.000697	0.02641	0.98704	0.00124	0.03515
	CE-C/D20/420W	0.99912	**0.000113**	**0.01062**	0.97144	0.00383	0.06188
	CE-P/E04/420W	0.98046	0.00216	0.04652	0.95491	0.04957	0.03922
	CE-P/E14/420W	0.99113	0.00119	0.03455	0.96437	0.00501	0.07078
Ipomoea batatas	**IB-C/D15/140W**	0.98178	0.00108	0.03676	0.98313	0.00103	0.03211
	IB-C/D20/140W	0.99766	0.000227	0.06682	0.97141	0.00287	0.05361
	IB-P/E04/140W	0.99421	0.0003462	0.010004	0.9947	0.0003039	0.01743
	IB-P/E14/140W	0.9949	0.0006904	0.01933	0.97424	0.00362	0.06016
	IB-C/D15/280W	0.99019	0.000625	0.01752	0.99093	0.0005995	0.02449
	IB-C/D20/280W	0.9977	0.001714	0.00669	0.90453	0.008	0.08944
	IB-P/E04/280W	0.99246	0.0005712	0.01428	0.99321	0.000537	0.02317
	IB-P/E14/280W	0.99657	0.000276	0.00747	0.98667	0.00112	0.03343
	IB-C/D15/420W	0.98629	0.0009495	0.03186	0.98896	0.0007878	0.02807
	IB-C/D20/420W	0.99888	0.000159	0.00449	0.96042	0.00568	0.07534
	IB-P/E04/420W	0.98743	0.0011	0.03186	0.98291	0.00155	0.03932
	IB-P/E14/420W	**0.99917**	**0.000107**	**0.00322**	0.96911	0.00411	0.00411
	Min	**0.97244**	**0.0000538**	**0.00322**	**0.90453**	**0.000261**	**0.00111**
	MAX	**0.99957**	**0.00233**	**0.06682**	**0.99694**	**0.04957**	**0.08944**

The criteria of modeling vary from one starch product to another according to various models. The criteria of modeling vary from one starch product to another according to various models.The values of the coefficient of determination (R^2), reduced ki-square (χ^2) and of the square root of the average quadratic error (RMSE) vary from $0.91165 \leq R^2 \leq 0.99638$, of $0.000281 \leq \chi^2 \leq 0.0391$ and of $0.00153 \leq$ RMSE ≤ 0.1075 for the model Newton; from $0.97244 \leq R^2 \leq 0.99957$, de $0.0000538 \leq \chi^2 \leq 0.00233$ and of $0.00322 \leq$ RMSE ≤ 0.06682 if the kinetics are simulated with the Page model; from $0.90453 \leq R^2 \leq 0.99694$, of $0.000261 \leq \chi^2 \leq 0.04957$ and of $0.00111 \leq$ RMSE ≤ 0.08944 for the Midilli model and of $0.9266 \leq R^2 \leq 0.9968$, of $0.00026 \leq \chi^2 \leq 0.08792$ and of $0.00692 \leq$ RMSE ≤ 0.08891 for the simulation carried out with the model Henderson and Pabis.

Among the four (04) models tested, best simulations are obtained starting from the model of Page some is the product starch dried with the electromagnetic radiation of microwaves. The model of Page remains adapted best respectively to predict kinetics of dryings radiative of *Dioscorea cayenensis* and *Colocasia esculenta* of diameter D = 20 mm and *Ipomoea batatas* (IB) thickness E = 14 mm.

The adjustment of the kinetics of drying of the agro-alimentary products by the model of Page was underlined by several authors [Chen, 2007;Nogbou et al.., 2015].Meziane (2013) showed that the model of Page remains most suitable in the prediction of the instantaneous reduction of the water content during the radiative drying of cocoa broad beans (0,9967 $\leq R^2 \leq$ 0,9993) with powers ranging between 400 and 700 W). Nogbou et al.(2015) showed that the model of Page is best the model semi-empirical one to describe the behavior of cocoa broad beans during drying microwave intermittently with powers (700 W, 600 W, 450 W) with R^2 which vary respectively from 0,9967, 0,9971 and 0,9993.The results obtained are also close to those obtained by Chen (2007).

III.4 *BETTER SIMULATIONS OF THE KINETICS OF RADIATIVE DRYING OBTAINED STARTING FROM THE MODEL OF PAGE*

Simulations of the kinetics of drying of *Dioscorea cayenensis*, *Colocasia esculenta* and *Ipomoea batatas* and the evolution of their parameters with the power of heating are presented on Fig.8 and Fig.9, has show below.

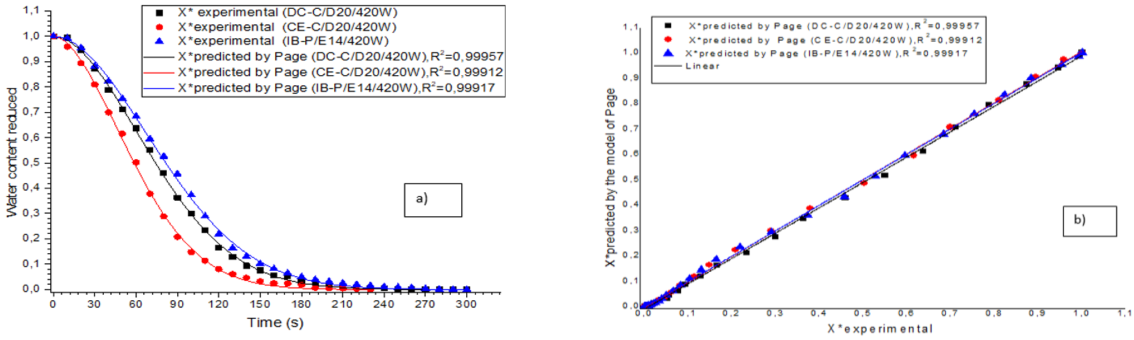

Fig.8. Better simulations of the kinetics of radiative drying of three starch products by the model of Pag

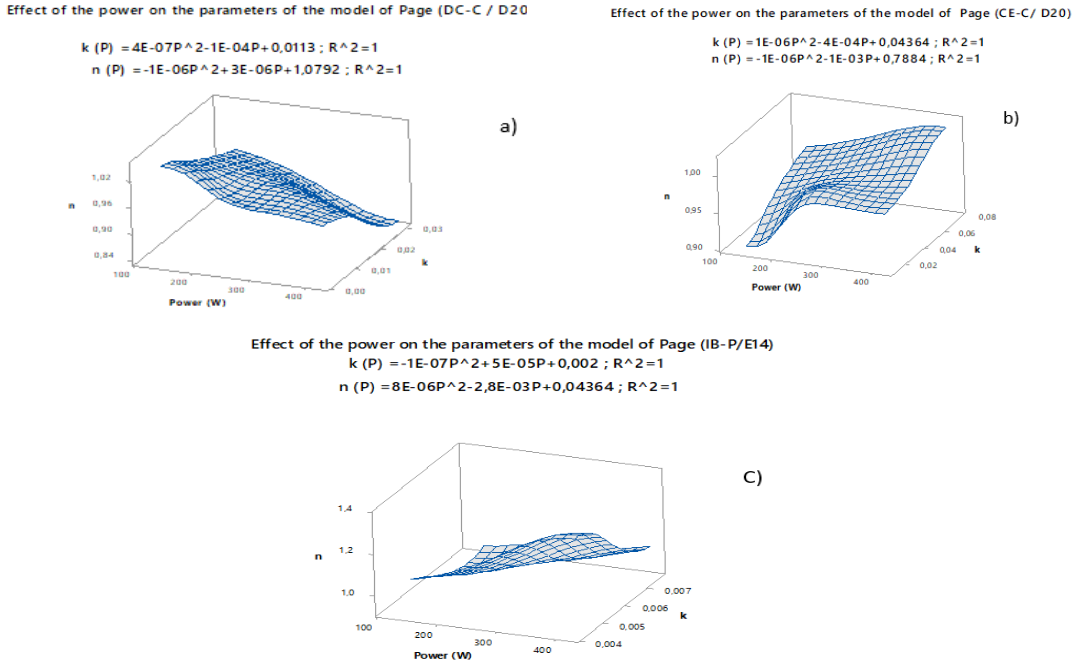

Fig.9 Diagram of surface effects of the radiative power drying on the parameters of the Page model

The effect of the heating of microwaves on the evolution of the parameters of the model of Page of *Dioscorea cayenensis*, *Colocasia esculenta* and *Ipomoea batatas* differs from one product to another.This difference of the kinetic behavior can be explained by their dielectric properties. Indeed, Sosa-Morals *et al.*, 2010 showed that the factor of loss of a material varies with its temperature, its water content and the frequency of the electric field which is subjected to him.The dielectric properties such as the permittivity (which express the ability of the product to store the electric power) and the factor of loss (which indicates the capacity of material to dissipate the electric power in heat) play a significant role for the dissipation of the electric power in heat during the heating to the microwaves [Nelson *et al.*.(1973)].

III.5 *LAW OF PROBALITY OF THE INSTANTANEOUS RESIDUES OF BEST SIMULATIONS*

Graphics of the law of probability of instantaneous residues of the water content reduced are presented on Fig.10., below.

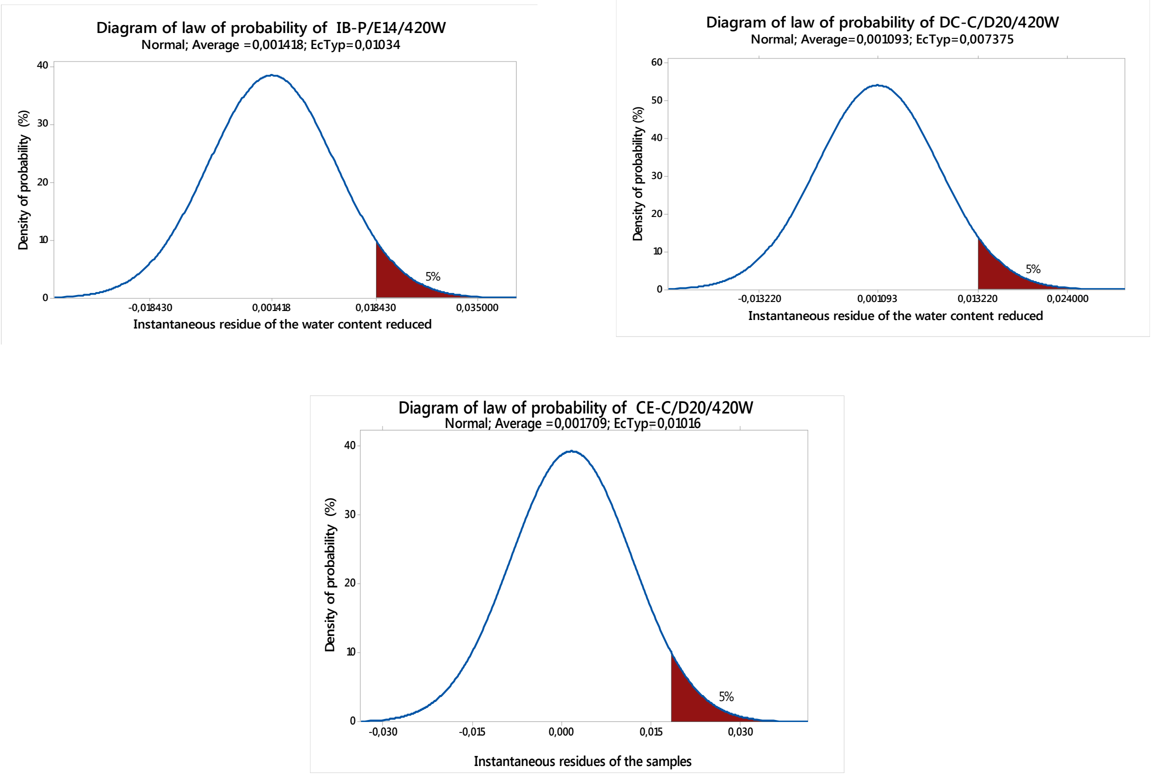

Fig.10 Law of probability of the residues of simulation of the drying and radiative of the starch products

The results show that the generalized normal law presents the averages of distribution close to the reduced centered normal law.The normal curves show a symmetrical distribution centered on the average, characteristic of a normal law. Moreover, the instantaneous residues of the water content reduced in the zone of interest (with IC = 95 %) represent the average values of residues almost null with densities of probability ranging between 38,5 and 55 %**.**These results prove that the instantaneous residues of the water content reduced of prediction of kinetics of drying of the starch products follow the normal law well to the threshold of confidence of 95 %.

III.6 *DIAGRAM OF PROBALITY OF THE INSTANTANEOUS RESIDUES OF BEST SIMULATIONS*

The graph of the diagram of probability of instantaneous residues of the water content reduced is presented on Fig.11, below.

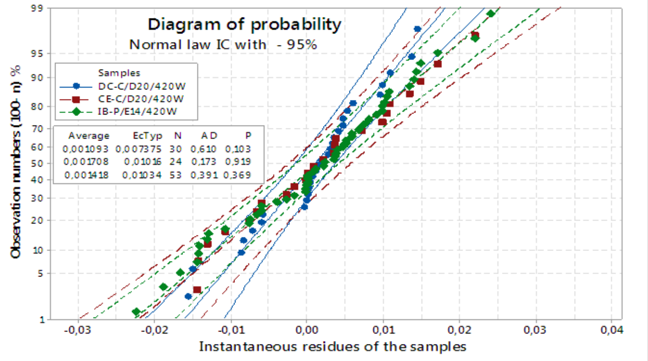

Fig.11. Digraph of probability of better simulations of the kinetics of radiative drying of the starch products

The results of diagram of probability show that the three (03) distributions are close to the line of average relationship of Henry during drying case of radiative drying.The values of the test of Anderson-Darling (AD) and of the p-value of residues are respectively of AD = 0.610 and p = 0.103 for *Dioscorea cayenensis*, of AD = 0.173 and p = 0.919 for *Colocasia esculenta* and of AD = 0.391 and p = 0.369 for *Ipomoea batatas.*

It should be noted that all the p-values are higher than the threshold of significativity ($p \geq 0,05$). Thus, the distribution of the residues is not significant during radiative drying ($p \geq 0,05$) for the whole of starch products, which for consequence the non-linearity of the right-hand side of Henry.

The principal interest of modeling is to obtain the instantaneous residues of the water content reduced null.The distributions show that these zero values of residues are obtained with probabilities around 40 % for the three (03) starch products.

III.7 *DEVELOPMENT OF THE MODELS OF TIME OF DRYING BY MULTIVARIATE LINEAR REGRESSION*

The effect of the power of heating, the thickness or the diameter of the product on the multivariate linear regression of the time of radiative drying of *Dioscorea cayenensis* (DC), *Colocasia esculenta* (CE) and *Ipomoea batatas* (IB) is presented on table 4, below.

Tab 4. Parameters of the model of linear regression multiple of the time of drying of the starch products

Parammters		**Parallelepipedic form**				**Cylindrical form**			
		DC	CE	IB	PA	DC	CE	IB	PA
	Y°	295.6	18397	414.3	6368.97	597.6	536.7	1024	719.43
	a_1	- 0.4888	- 262.10	- 0.6996	-87.76	-1.861	- 1.674	- 4.931	-1.861
	a_2	140.9	- 193.30	98.55	119.725	51.82	44.91	- 9.697	48.365
	a_{12}	- 0.4574	11.94	- 0.3273	11.94	-0.1381	- 0.1074	0.1697	0.0158
(1) power; (2) thickness ou diameter ; **DC :** *Dioscorea cayenensis ;* **CE** : *Colocasia esculenta*; **IB** : *Ipomoea batatas* ; **PA :** starch product									

The results show that the parameters of the multiple model of regression of the time of radiative drying of the samples of *Dioscorea cayenensis* of form of cylindrical are close to those of *Colocasia esculenta.* In the same way, the radiative drying of parallelepipedic *Dioscorea cayenensis of* form presents the same behavior as that of *Ipomoea batatas.* In parallel, the samples of parallelepipedic form of *Colocasia esculenta* behave same manner as those of cylindrical *Ipomoea batatas* of form. The development of a single model of time of drying of starch products (Pa) starting from the results of *Dioscorea cayenensis, Colocasia esculenta* and *Ipomoea batatas* is possible.

The multivariate analyses are largely used seeks development of it, in particular to describe association between the variables by controlling the effect of other variables [Gillaizeau and Grabar, 2011]. The behavior of the

model of linear regression multiple to predict the variables was also used in the literature [Ndoki *et al*.., 2018 and Tetang *et al.*, 2013].

III.8 *VALIDATION OF VARIOUS MODELS OF TIME OF DRYING OF STARCH PRODUCTS*

The results of modeling of the time of drying and validation of the models of multiple linear regression of the starch products are presented in tables 5 and 6 and on Fig.12, has show below.

Table 5. Validation of the models of time of radiative drying of the starch products

Samples	*Dioscorea cayenensis* X* = 0,1032 ± 0009					*Colocasia esculenta* X* =0,1014 ± 0,0016					*Ipomoea batatas* X* =0,1054 ± 0,0035				
	Y_{exp} (s)	Y_{pre} (s)	Residue	σ	S	Y_{exp} (s)	Y_{pre} (s)	Residue	σ	S	Y_{exp} (s)	Y_{pre} (s)	Residue	σ	S
P/E04/140W	534.54545	534.62	-0.07	0.05	0.0828	421.818	421.84	-0.02	0.02	0.007	527.2727	527.27	0	0	0.0029
P/E14/140W	1303.0303	1303.26	-0.23	0.16		720.606	720.58	0.03	0.02		1054.545	1054.55	0	0	
P/E04/280W	210	210.05	-0.05	0.04		127.273	127.33	-0.06	0.04		246.0606	246.04	0.02	0.01	
P/E14/280W	338.18182	338.33	-0.15	0.1		275.757	275.71	0.05	0.03		315.1515	315.1	0.05	0.04	
C/D15/140W	824.242	824.35	-0.11	0.08	0.0828	453.333	453.31	0.02	0.02	0.07	544.8484	544.58	0.27	0.19	0.3258
C/D20/140W	986.667	986.78	-0.11	0.08		878.788	878.84	-0.05	0.04		615.1515	614.88	0.27	0.19	
C/D15/280W	273.6363	273.8	-0.16	0.12		200.001	200.12	-0.12	0.08		210.9091	210.61	0.3	0.21	
C/D20/280W	339.3939	339.56	-0.17	0.12		235.454	235.68	-0.23	0.16		400	399.7	0.3	0.21	

Table 6. Models obtained from the time of radiative drying of the starch products

	Form sample	**Equation of the model of time of drying of starch products (s) (X*=10%)**
Radiative drying	Parallelepipedic form	Time (s)= 6368,97 – 87,76 Power + 119,73 Thickness + 11,94 Power * Thickness
	Cylindrical form	Time (s) = 719,43 – 1,861 Power + 48,365 Diameter + 0,01158 Power*Diameter
140W ≤ Power ≤ 280W ; 4 mm ≤ Thickness ≤ 14 mm ; 15 mm ≤ Diameter ≤ 20 mm ; Length =40 mm ; width =30 mm ; height =40 mm ; 60,08 % ≤ Water content initial ≤ 66,32 % ; Water content reduced final = 10 %		

The criteria of validation of various models are the sum least squares of the residues of the time of drying and the significativity of the test of ANOVA with $p \leq 0{,}05$.

The evolution of the time of radiative drying is well represented by the combination of the selected descriptors (power of drying and the thickness or the diameter of the product).The models obtained are adapted to adjust the real data.Indeed, the values predicted by the model of linear regression multiple are relatively close to those obtained in experiments (table 5).

The values of residues for the whole of the experiments prove that the model set up is adapted to explain the relation between the variables [Mendenhall, 1975;Little and Hills 1978].

The adjustment of variables of drying by the model of linear regression multiple was also proven by Benseddik *et al.(*2016).

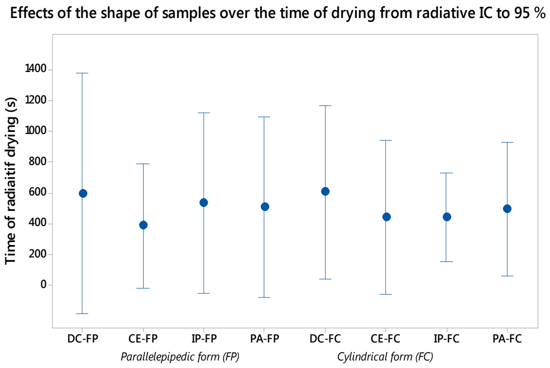

Fig.12. Diagram of ANOVA of the effects of the shape of samples over the time of drying of three starch products

By comparing the various models of prediction, the test of ANOVA (Fig.12) shows that the various models obtained can be employed for the prediction of the time of drying from one product to another with the intervals of well defined times.

The reduction of time of drying with the rise in the power of heating was meant in the literature.The effectiveness of radiative drying to the electromagnetic radiation of microwaves can be explained by a high pressure interns and the gradients of concentration which increase the evaporation of liquid through the product until stability **[** Chemat, *et al.*, 2008;Ghanem, *et al.*, *2012*].

IV. CONCLUSION

Drying remains one of the unit operations which I necessarily intervenes in the transformation of the roots and tubers into flour.It makes it possible to preserve them by the water elimination (by evaporation) by using thermal energy or electromagnetic energy. The reduction in the water content of the product during drying makes it possible to reduce the growth potential of the micro-organisms and to minimize undesirable biochemical reactions during the storage of this one while increasing its lifespan.

The development of the mathematical models of prediction of the parameters of drying of the starch products and the maitrise their processes of transformation into sight industrialization remain a delicate problem in the research and development.

Simulations of the kinetics of drying revealed that the model of Page ($0.97244 \le R^2 \le 0.99957$, and $0.0000538 \le \chi^2 \le 0.00233$ and of $0.00322 \le RMSE \le 0.06682$) is adapted to predict electromagnetic times of radiative drying to the radiation of each product.

The distribution of the instantaneous residues of the water content reduced follows the normal law centered reduced with densities of probability which vary from 38.5 to 55 %.

The modeling of the time of drying by multivariate linear regression showed the satisfactory results for each product.The evolution of the time of radiative drying is well represented by the combination of the selected descriptors.The models obtained are adapted to adjust the real data.The values predicted by the model of linear regression multiple are relatively close to those obtained in experiments.The test of ANOVA approved the possibility of developing a single model of the time of drying of the starch products with the threshold of significativity of $p \le 5\ \%$.

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