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Characterization of the cinetique of drying of *Ipomoea batatas* Lam at the drying oven and with microwawe oven

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Key words: *Ipomoea batatas*, Drying with the drying oven, Oven drying microwave, Kinetics of drying, Effective diffusivity, Activation energy

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Abstract

The objective of this work is to contribute to the valorization of *Ipomoea batatas* Lam by the characterization of drying kinetics, drying with the drying oven and to the Microwawe oven. The drying of the samples of *Ipomoea batatas* Lam of cylindrical form (diameter 15 and 20mm) and parallelepipedic (thickness 4 and 14mm) was carried out at temperatures of 50, 60 and 70 °C and powers of 140, 280 and 420 W. The results obtained show on the one hand that the temperature or the power, the thickness and diameter is parameters which influence the duration of drying and effective diffusivity, and on the other hand that there is not phase of drying at constant speed. The oven drying with microwaves made it possible to only reduce significantly the time of drying a few hours to a few minutes. On a purely illustrative basis, for samples with a diameter 20mm, the time of drying are reduced of 99.16% when one passes from drying to the drying oven (t = 5.19 h with 70°C) to the oven drying to microwaves (t = 2.60 min with 420 W). The activation energy of sweet potato varies from 0.931 to 5.537 kJ.mol^{-1} under various explored conditions.

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Introduction

In sub-Saharan Africa, the roots and tubers constitute the most significant food cultures. These local roots and tubers are mainly the manioc (*Manihot esculenta)*, the potato (*Solanum tuberosum)*, the sweet potato (*Ipomea batatas* Lam) the yam (*Dioscorea*) and the taro (*Colocasia esculenta*). These roots and tubers are the subject of the particular studies for a valorization and diversification of the economies, moreover share of the tropical and subtropical countries (Kouassi, 2009).

The sweet potato is produced cultivated in more than 114 countries of the world for its wealth in energy (80% of glucides in base dry mainly in the form of starch), out of beta-carotene and minerals (Nepa, 2006). With a world production of 123 tons million in 2006 the needs for the market of sweet potato (starch-based) and the detection of its new functionalities caused, on the level of under area a particular interest in scientific and technical research. In Congo, the sweet potato is generally marketed in rough form, and does not profit from a very significant added value. The research orientations developed within this framework relate to in particular the characterization of the produced flours, the definition of their qualities and their functionality. Ahmed *et al.* (2010) studied the effects of pretreatment and temperature of drying on the sweet potato flour. Moreover, these results made it possible to say that the flour of sweet potato is promising ingredient in many traditional food preparations and in industry. NDangui (2015) showed that it is possible to use the flour of sweet potato in panification with a rate of incorporation of 25%.

Drying is an operation having for goal water elimination impregnating the solid by evaporation. Durant drying, water is eliminated from the solid, reducing the growth potential of the micro-organisms and the undesirable chemical reactions, therefore increase in the lifespan of product (Gowen *et al.*, 2008). The maitrise of the drying of sweet potato becomes paramount for the development and of the industrialization of its production process. For Bonazzi and Bimbenet (2003), the variability and the diversity of the foodstuffs and biological, the best means of characterizing behaviour with the drying of a product consists in measuring its kinetics of drying in experiments. Thus, the purpose of this study is to characterize the kinetics of drying of *Ipomoea batatas* Lam to the drying oven and the microwawe oven under various operating conditions.

Material and methods

Vegetable material and sampling

The sweet potatos (*Ipomoea batatas* Lam) were bought at the Total market of Brazzaville. They were stored at the laboratory at the ambient temperature for all the period the experiment. The tubers were dimensioned in the parallelepipedic form (L×l×E = 40mm× 30mm × (4 or 14mm)) and cylindrical height 40mm for the diameters of 15 and 20mm. Dimensioning was carried out using an electric Slicer of mark RCL1 and Moulds of cylindrical form exact dimensions were checked using a slide caliper and /or scale.

The samples were coded in the following way: X/Y/Z

With:

X: form sample (P: parallelepipedic; C: cylindrical)

Y: Thickness (mm) or diameter (mm)

Z: temperature (°C) or power (w) of drying

Drying with the drying oven

The drying of the plates was carried out at temperatures of 50, 60 and 70°C. The sample of *Ipomoea batatas* Lam was placed at drying oven (INDELAB; 0-250°C), then weighed after each five minutes (5 min). Using a balance with precision of mark EXPLORER-PRO (0-210g, with E = 0.0001g), the mass of the sample was followed in the course of time until this one does not vary any more between 3 successive measurements.

Oven drying with microwaves

The samples of *Ipomoea batatas* Lam weighed beforehand to record the initial mass. Then, they were placed on the rotary table of the microwawe oven (GEEPAS, for the powers and times of intermittency respectively of 140, 280 and 420 W and of 60, 30 and 10 s. The follow-up of the mass was carried out until the stabilization of this one.

Determination of the parameters of kinetics of drying

Water content

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.

$X= [(m_d-m_w) / m_d] \times 100$ (1)

X = tenor in water reported to wet mass

M_w= mass of the wet sample

M_d = mass of the dry sample

Kinetic of drying

The instantaneous speed of drying at time t is determined by the formula hereafter:

$dX/dt = -[(X_{(t+\Delta t)} - X_{(t)}) / \Delta t]\times 100$ (2)

With:

dX/dt: speed of drying in g of eau/g of MS/sec.

X: water content in base dries (g of eau/g of MS).

Δt: variation of time in seconds (or in min)

Effective Diffusivity (D_{eff})

The transfer of matter during drying is controlled by internal diffusion. The second law of Fick of diffusion indicated in the equation (2), was largely used to describe the process of drying for the majority of the biological products (Srikiatden *et al.*, 2008).

The diffusion coefficient of the plates of yam was given starting from the analytical equation of the second law of Fick, developed by Crank (1975). By supposing that the transfers are unidimensional, water content initially uniform in the product, without contraction of the solid matter and a long time of diffusion.

The analytical solution of the equation of Fick, according to the geometrical shape of the sample is given by the following equations:

Parallelepipedic form

$X^* = (X_{(t)}-X_{eq}) / (X_o-X_{eq}) = 8/(\pi)^2 \exp [(\pi^2 \times D_{eff} / 4L^2) \times t]$ (3).

With:

X *: water content reduced

$X_{(t)}$ (g.g⁻¹.MS): water content instantaneous;

X_O (g.g⁻¹.MS): water content initial;

$X_{éq}$ (g.g⁻¹.MS): water content with balance

D_{eff} (m^2s^{-1}) : coefficient of effective diffusion;

L (m): Half-thickness of the sample;

t (s): time of drying.

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

Where : $\ln (X^*) = \ln (8/\pi^2) - [(\pi^2 \times D_{eff} \times t) /4L^2]$ (3)

The coefficient of effective diffusion is thus calculated starting from the bearing graph in X-coordinate the time of drying and in ordinate Ln (X*). The slope of the straight regression line giving Ln(X*) according to time makes it possible to calculate the coefficient of effective diffusion of moisture according to the following relation:

$(\pi^2 \times D_{eff})/4L^2 = K$ $D_{eff} = (4L^2 \times K)/\pi^2$ (4)⟶with K: slope

Cylindrical form

$X^* = (X_{(t)}-X_{eq}) / (X_o-X_{eq}) = 4/(\beta)^2 \exp[(\beta^2 \times D_{eff} / r^2) \times t]$ (5a).

Ou $\ln (X^*) = \ln (4/\beta^2) - [(\beta^2 \times D_{eff} \times t) / r^2]$ (5b).

The coefficient of diffusion is given by tracing the experimental data of drying starting from the curve giving the logarithm of X* according to time; giving an equation of the form:

$Y= K_o \times t +B$ (6)

With K_o the slope:

One poses $K_o= -(\beta^2 \times D_{eff}) / r^2$ (7)

Thus $B = \ln (4/\beta^2) \rightarrow \beta^2 = \exp (B)/4$ (8)

With r = D/2 $D_{eff} = -(K_o \times D^2)/ \exp (\beta^2)$ (9)

Ray of the cylinder (m); D: diameter of the cylinder (m); D_{eff} : coefficient of effective diffusion (m^2/s); E: initial thickness of samples (m); L: Initial half-thickness of samples (m).

Activation energy

The energy of activation it is the energy which it is necessary to start the mass phenomenon of diffusion in the agricultural produce (Sacilik, 2007).

The coefficient of effective diffusion (D_{eff}) is corolla at the temperature of drying starting from the following equation of Arrhenius (Doymaz *et al.*, 2002)

$D_{eff} = D_o \exp(-E_a/RT)$ ou $\ln(D_{eff}) = \ln(D_o) - (E_a/R)\times(1/T)$ (10).

The energy of activation is calculated starting from the slope of the graph Ln (D_{eff}) according to 1/Tone obtains a line of equation $Y' = K_o' \times t + B'$.

With a slope $K_o' = E_a/R$ $E_a = K_o' \times R$) (11) →

D_{eff}: coefficient of diffusion ($m^2.s^{-1}$); D_o : parameter of diffusion of Arrhenius ($m^2.s^{-2}$) ;

E_a: energy of activation (J $mole^{-1}$) ; R: constant of perfect gas (8.314 kJ $mole^{-1}$ K^{-1}) ;

T: absolute temperature of the draining air (K);

Statistical Analysis

The data reported in all tables and figs. are average values determined in triplicate. They were subjected to analysis of variance (ANOVA) and multiple scatter tests by the Fisher method (LSD) in order to classify the samples at the significant level of 5% using the program Statgraphics XVII Centurion Version 17.1.12 (Statpoint Technologies, Inc. USA). The Excel 2007 software was used for the plotting of curves.

Results and discussion

Effect of the temperature and the power on the kinetics of drying

The effects of the temperature and the power on the kinetics of drying were noted respectively for the techniques of drying to the drying oven (Fig. 1 and 2), and to the microwawe oven (Fig. 3 and 4).

The analysis of these fig. s shows that more the temperature or the power of drying increases, the time of drying decreases. Thus, for dryings with the drying oven of the samples diameter D = 15mm, to reach a residual reduced moisture (X*=10%). On notes a reduction in the time of drying of the order 13,79% at the time the temperature increases 50°C with 60°C and about 20.69% while passing from 50°C with 70°C (Fig. 1). One also observes the same effects for the parallelepipedic form. Between 50 and 70°C, this time decreases by 27.65% (Fig. 2).

The reduction of the time of drying is observed, for the oven drying with microwaves compared to that of the drying oven. Time drying decreases significantly with the increase in the power. For the samples of cylindrical form of diameter D = 20mm, the time of drying decrease respectively by a factor of 1/1.5 and 1/4.4 while passing from 140 to 280W ($t_{280W} = 1.15\times t_{140W}$) and from 140 to 420 W ($t_{420W} = 4.4\times t_{140W}$) (Fig. 3).

For the samples of parallelepipedic form thickness E=14mm (Fig. 4), one also notes a reduction in the time of drying of a factor of 1/4 while passing from 140 to 280 W ($t_{280} = 1.4\times t_{140}$ and about 1/6.76 while passing from 140 to 420 W ($t_{420} = 6{,}76\times t_{140}$).

It is advisable to mention that, for the two shapes of sample, the parallelepipedic form presents more effects on the factor of reduction of time of drying.

Indeed for Locin (1961), the increase in the temperature and or the power of drying causes the increase in potential of exchange between the air and the product, thus supporting the fast evaporation of the water of the product, consequently a reduction in the duration of drying. This influence is due to the increase in the osmotic pressure of water inside the product which accelerates the migration of the water of the product towards outside. It is noted that at the end of drying, the speed of evaporation decreases as drying proceeds.

The influence of the temperature and the power of drying were studied by several authors (Menasra and Fahloul (2015), Arslan and MusaOzcan (2007), Krokida *et al, (*2003) and Silou *and al.,* (1991) on the foodstuffs. The shape of the curves (Fig.3 and Fig. 4), reflects the same pace well as that obtained by Menasra and Fahloul (2015), Arslan and MusaOzcan (2007) and Krokida *et al, (*2003), which also worked on the foodstuffs.

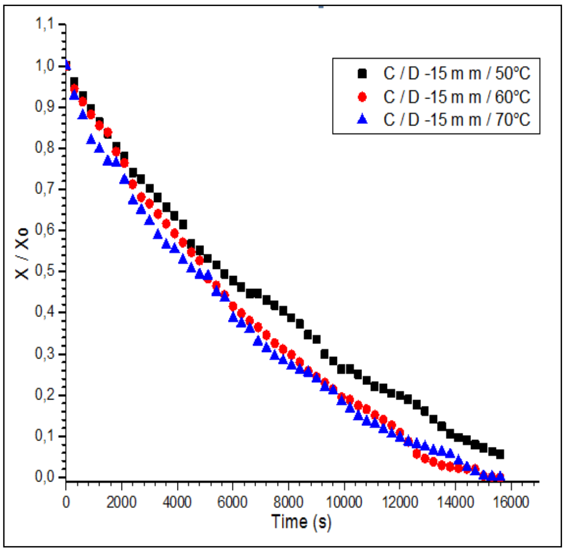

Fig. 1. Influence temperature on the kinetics of drying (Diameter = 15mm).

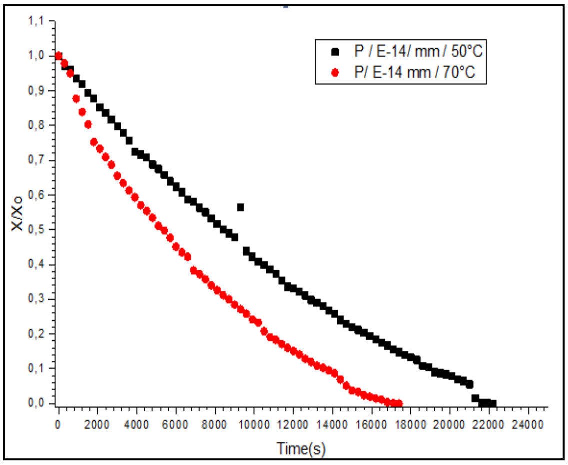

Fig. 2. Influence temperature on the kinetics of drying (Thickness = 14mm).

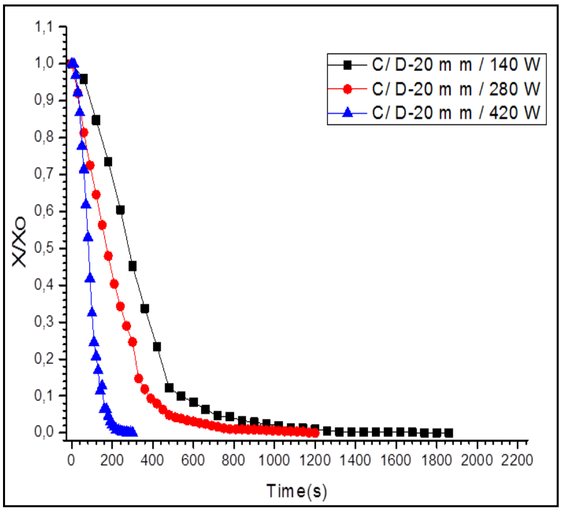

Fig. 3. Influence power on the kinetics of drying (Diameter = 20mm).

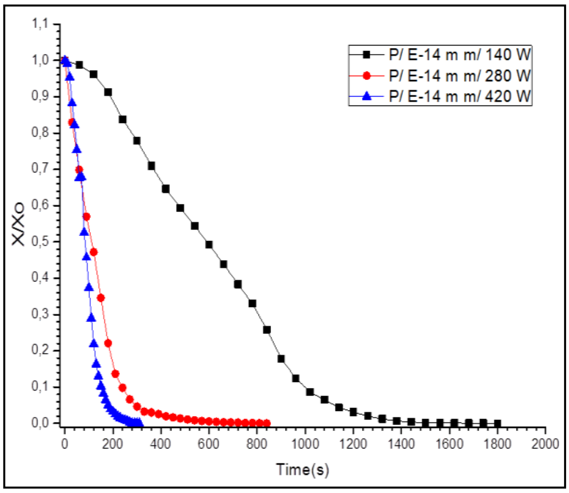

Fig. 4. Influence power on the kinetics of drying (Thickness = 14mm).

Curves speed of drying

The evolution the speed of drying for the various temperatures and powers are presented respectively in Fig. 9 and 10.

The results show that the speed of drying increases proportionally with the rise in the temperature (50 with 70°C) or in the power (140 to 420 W) of drying.

One notes that for two techniques of drying, the curves speed present in general, two phases: a phase of temperature setting relatively short and a phase at decreasing speed. This absence of the phase at constant speed was reported in literature and was highlighted by several authors, in connection with the foodstuffs and biological.

In addition for the various powers, one notices that the phase at decreasing speed is divided into two pennies periods (Fig. 5), period at high speed (0.15≤ X ≤ 0.65)) and period at low speed (X ≤ 0.15). For Bonnazi and Bimbenet (2003), the appearance of these periods corresponds to structural changes in the product. Indeed, the deceleration the speed of drying is explained by the fact why the cellular walls disturb the fast migration of moisture towards surface external of the product, by the migration of the aqueous solutions which block the pores and by the hardening and the retraction of the surface of the product (Boughali, 2008; El Hiss, 1987).

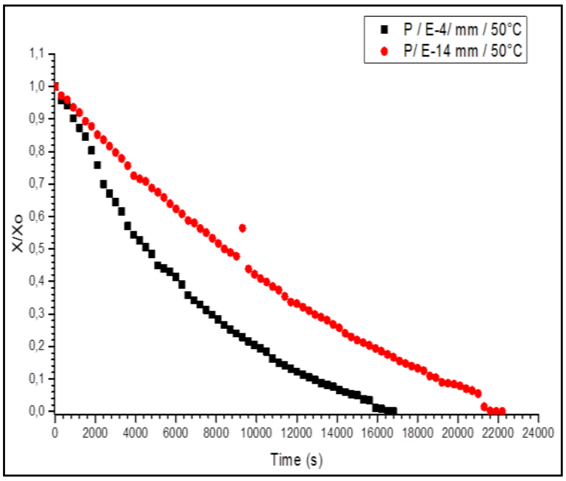

Fig. 5. Influence thickness on the kinetics of drying to drying oven (Thickness = 4 and 14mm).

Coefficient of diffusion

The results of the coefficient of diffusion of sweet potato are presented (Table 1).

The results show that the temperature and the power have significant effects on the coefficient of diffusion. Indeed, the rise in the temperature or the power of drying accelerates the transfer of heat and consequently the fast elimination of water in the product.

Diffusivities vary 8.92×10^{-8} with $9.90\times 10^{-7} m^2.s^{-1}$ for the drying oven for temperatures ranging between 50 and 70°C.

Table 1. Coefficient of diffusion of the samples of sweet potato and other products.

Products	Temperature (°C)	Effective diffusivity ($m^2.s^{-1}$)	References
Sweet potato (Diameter 15mm)	50-70	$6,006\times10^{-7}$-$8,290\times10^{-7}$	Present work
Sweet potato (Diameter 20mm)	50-70	$7,904\times10^{-7}$ - $9,900\times10^{-7}$	Present work
Sweet potato (Thickness 4mm)	50-70	$8,916\times10^{-8}$ - $1,29\times10^{-7}$	Present work
Sweet potato (Thickness 14mm)	50-70	$8,340\times10^{-7}$ - $9,532\times10^{-7}$	Present work
Carrot	60 -90	$2,58\times10^{-10}$ - $1,72\times10^{-9}$	Zielinska and Markowski (2010)
Fig (Figue)	55- 85	$7,77\times10^{-10}$ - $2,43\times10^{-9}$	Babalis and Belessiotis (2004)
Break into leaf of mint	30 -50	$2,15\times10^{-8}$ -$1,031\times10^{-7}$	Aghfir *et al.*, (2008)
Kiwi	30- 90	$3,0\times10^{-10}$ -$17,2\times10^{-10}$	Simal *et al.*, (2005)
Green pepper	50 -70	$4,38\times10^{-11}$ -$10,99\times10^{-11}$	Sanjuán *et al.* (2003)
Apple	35 -55	$0,483\times10^{-10}$ - $2,019\times10^{-10}$	Kaya *et al.*(2007)
Tomato	55- 70	$3,91\times10^{-10}$ - $6,65\times10^{-10}$	Doymaz (2007)

The variation in the temperature of drying from 50 to 70°C increases the coefficient of diffusion of 7.90×10^{-7} to $9.90\times10^{-7} m^2.s^{-1}$ for a sample with a diameter 20mm and 8.34×10^{-7} to $9.53\times10^{-7} m^2.s^{-1}$ for a plate thickness 14mm. Indeed, the increase in temperature involves a great agitation of the molecules and consequently, an increase in the coefficients of matter and heat transfer.

It is also noted that the increase thickness or diameter of the samples generates an increase in diffusivity. That is explained by the fact why the effect of the side diffusion is taken into account in the thick samples.

These results show that the coefficient varies primarily with the temperature of drying, thickness and diameter of the products; that was illustrated by several authors. The variations of the coefficient of diffusion for temperatures ranging between 30 and 90°C were reported in the literature (Table 1) (Messaoudi *et al.,* 2015; Aghfir *et al.,* 2008). While comparing, the results obtained with those of the literature (Table 1), it should be noted that, the coefficient of diffusion varies from one product to another. It is of 2.15×10^{-8} to $1.71\times10^{-7} m^2.s^{-1}$ for sheets dry of mint at the temperatures $30 \leq T \leq 50$°C, of 2.58×10^{-10} to $1.72\times10^{-9} m^2.s^{-1}$ for the drying of carrot of 60 to 90°C (Zielinska and Markowski, 2010) and of 3.91×10^{-10} to $6.65\times10^{-10} m^2.s^{-1}$ for the drying of tomato of 55 to 70°C (Doymaz, 2007).

Activation energy

The energy of activation of the various samples of sweet potato was given graphically starting from the equation of Arrhenius (Fig. 11).

The energy of activation makes it possible to know the influence of the temperature on the coefficient of diffusion. According to the results obtained one notes that the energy of activation increases according to the temperature. The larger the sample is, the more the need of a great energy to activate the reaction.

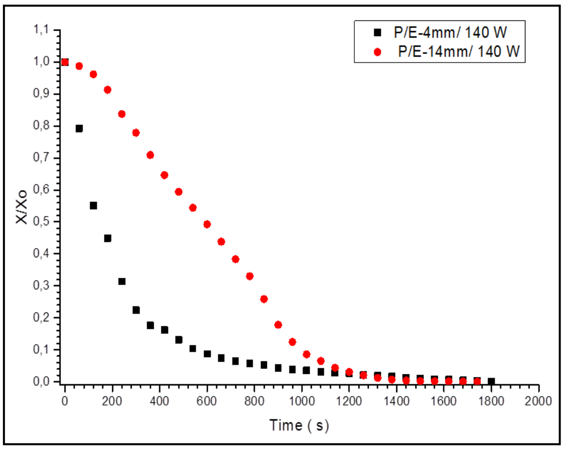

Fig. 6. Influence diameter on the kinetics of oven drying with microwaves Thickness = 4 and 14mm).

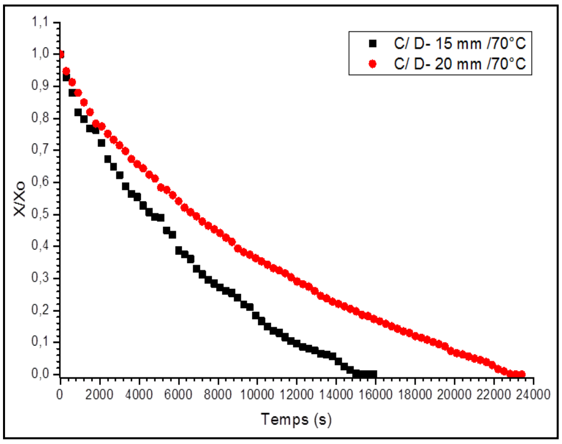

Fig. 7. Influence diameter on the kinetics of drying in Etuve (Diameter = 15 and 20mm).

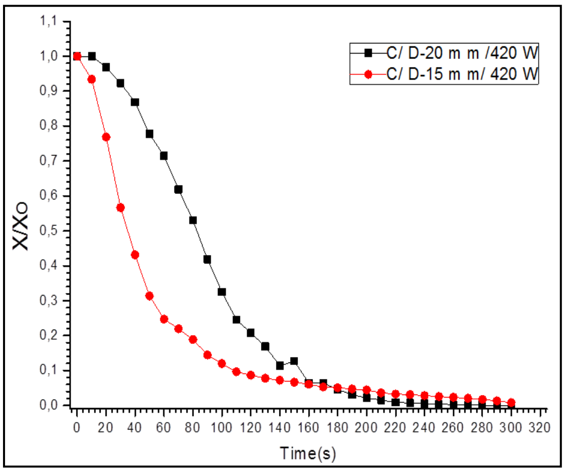

Fig. 8. Influence diameter on the kinetics of oven drying with microwaves (Diameter = 15 and 20mm).

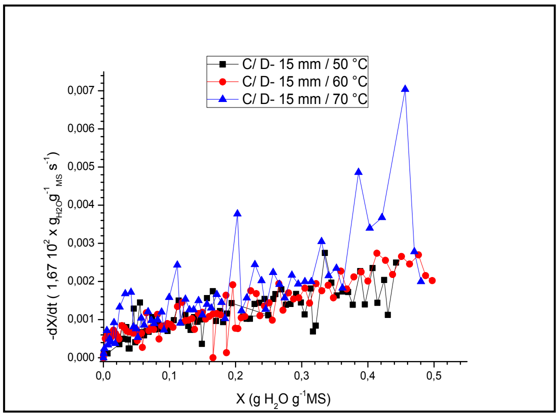

Fig. 9. Influence temperature on the speed of drying (Diameter = 15mm).

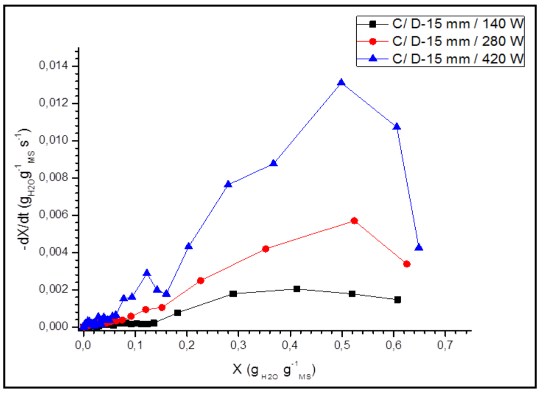

Fig. 10. Influence power on the speed of drying ((Diameter = 15mm).

The energy of activation of the reaction of evaporation during drying of sweet potato varies from 0.93 to 5.54 kJ mol-1.The values of energy of activation strongly depend in the operating conditions and the matrix on the product to be dried. The energy of activation increases with the thickness and the diameter of the product.

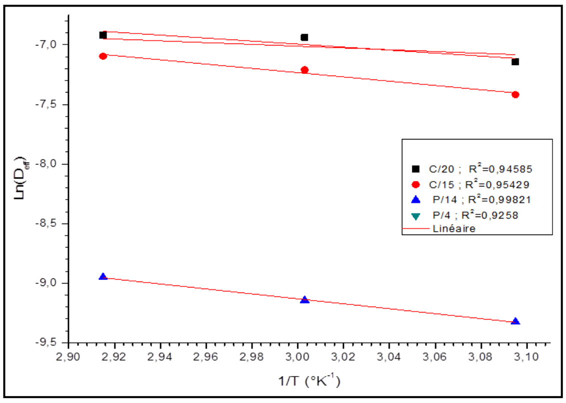

Fig. 11. Law of Arrhenius applied to the drying of sweet potato.

Table 2. Energie d'activation de la patate douce et autres produits.

Products	Energy of activation (kJ/mol⁻¹)	References
Sweet potato (Diameter 15mm)	0,931	Present work
Sweet potato (Diameter 20mm)	1 ,338	Present work
Sweet potato (Thickness 4mm)	1,554	Present work
Sweet potato (Thickness 14mm)	5,537	Present work
Mint	84,796	Aghfir *et al.* (2008)
Spearmint	82,93	Park *et al.* (2002)
Carrots	28,36	Doymaz (2004)
Red pepper	42,8	Kaymak-Ertekin (2002)
Green pepper	24,70	Simal *et al.* (1996)
Black tea	406,02	Panchariya *et al.* (2002)

By comparing the results obtained with those of the literature (Table 2), one notes that energies of activation of diameter are weak. That can be by the fact that the sweet potato is a product very rich in water (72.8% in wet base) and by consequence a weak energy necessary to ensure the evaporation of the water molecules.

Conclusion

The maitrise of the process of drying of the foodstuffs remains a significant means to ensure their conservation. This present study consists being studied of the characterization of drying to the Drying oven and with the Microwawe oven of *Ipomoea batatas* Lam. the experimental study was carried out on *samples of Ipomoea batatas* Lam of cylindrical form of diameter 15 and 20mm and of parallelepipedic form of thickness 4 and 14mm at temperatures 50, 60 and 70°C and powers 140, 280 and 420 W. The thickness and the diameter of the samples on the one hand, the temperatures and the powers of drying of other share, influence significantly the kinetics of drying of *Ipomoea batatas* Lam. The more the temperature is raised, the shorter time of drying is and the speed of dehydration is significant. The oven drying with microwaves made it possible to only reduce significantly the time of drying a few hours to a few minutes. To this end, one noted that for samples with a diameter 20mm, the time of drying are reduced of 99.16%, when one passes from drying to the drying oven (70°C) to the oven drying to microwaves (420W). The water evaporation during the drying of potato does not require great quantity of energy. This energy is about 0.93 to 5.54kJ.mol^{-1} under various operating conditions.

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