International Journal of Agronomy and Agricultural Research (IJAAR)

ISSN: 2223-7054 (Print) 2225-3610 (Online)
http://www.innspub.net
Vol. 13, No. 5, p. 71-78, 2018

INNSPUB

RESEARCH PAPER

OPEN ACCESS

Kinetics study of drying at drying oven and microwawe oven of *Hura crepitans* seeds

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Article published on November 28, 2018

Key words: Hura crepitans, Drying kinetics, Drying oven drying, Oven drying with microwaves, Coefficient of diffusion, Activation energy.

Abstract

The objective of this work is to contribute to the valorization of *Hura crepitans* by kinetics study of drying at drying oven and microwawe oven of *Hura crepitans* seeds. The seeds were dehydrated until obtaining a constant mass, respectively in a drying oven and a microwawe oven. Drying was carried out at temperatures of 50, 60 and 70°C and powers of 140, 280 and 420 W respectively with the drying oven and the microwawe oven. The results show that, the samples kiln-dried with microphone-of (140 W and 280 W) present a phase at constant pace, which is not the case for drying with the drying oven. The rise in the temperature to the drying oven from 50 to 70°C and in the power of heating to the microwaves of 140 to 420W varies the coefficient of diffusion of $7.12\times10^{-9}m^2.s^{-1}$ with $8.76\times10^{-9}m^2.s^{-1}$ and of $5.03\times10^{-8}m^2.s^{-1}$ with $8.64\times10^{-8}m^2.s^{-1}$.The energy of seed activation of *Hura crepitans* is about 9.53 $kJ.mol^{-1}$.

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Introduction

Hura crepitans is a plant under used of Nigeria being used as shade in the villages and the cities. It is a dicotylédon pertaining to the family of 'Euphorbiacées. It is recognized by its many dark and pointed, flexible spines chestnut, with spread out branches. *Hura crepitans* can push up to 30 m. It has some 0.5m broad broad and oval sheets, with the long, the shape of heart, thin stem like paper.

The seeds of *Hura crepitans* are very rich in linoleic acid (52.8 ± 0.10 %) (Adewuy *et al.,* 2012). The oil yield of seeds of *Hura crepitans* relatively high is compared with those of other oleaginous seeds (Princen *et al.* 1984). This content of relatively high oil of seed of *Hura crepitans* as a good source of oil makes it economically viable.

In order to preserve seeds of this product and to make them available during all the year, they undergo specific technological treatments such as drying. Drying is one of the oldest techniques of conservation of the agricultural produce. It is a technique of drainage of the water which implies a transfer of heat and a mass transfer. It makes it possible to decrease the water content of the products (Barel, 2013).

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). Thus, this work aims to characterize the kinetics of drying of seeds of *Hura crepitans* to the drying oven and the microwawe oven.

Materiel and methods

Vegetable material

The vegetable matter which was the subject of this work is consisted of seeds of *Hura crepitans*. The fruits of *Hura crepitans* were gathered of its tree were broken and peeled in order to withdraw seed. After shrinking of seeds, the thickness of those was measured using a slide caliper.

Drying with the drying oven

The drying of seeds of *Hura crepitans* was carried out at temperatures of 50, 60 and 70°C. Seed 10g of *Hura crepitans* was placed at drying oven (INDELAB; 0-250°C), then weighed after each ten minutes (min). Using a balance with precision of mark EXPLORER-PRO (0-210± 0.0001g), the mass of seeds was followed in the course of time until this one does not vary any more between 3 successive measurements.

Oven drying with microwaves

The drying of almonds of *Hura crepitans* was carried out with powers of 140, 280 and 420W. 10g of each sample were placed on the rotary table of the microwawe oven (GEEPAS) and the follow-up of this one was carried out after each minute (1 min) until its stabilization.

Determination of the parameters of the 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.

$X= [M_h-M_s] / M_s$ (1)

X: Water content;

M_h: Mass wet sample (g);

M_s :Mass dry sample (g);

Kinetics of drying

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

$dX/dt= [-X(t-\Delta t)-X(t)]/ \Delta t$ (2)

With:

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

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

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

Effective diffusivity (D_{eff})

According to the literature the water content reduced (X*) can be exploited to calculate the coefficient of diffusion. Indeed, one has (Gulcimen *et al.,* 2016).

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

$\ln(X^*) = \ln(8/\pi^2) - [(\pi^2 \times D_{eff})/4 \times L^2] * t$ (4)
Avec $X^* = (X_t - X_{eq})/(X_o - X_{eq})$ (5)
The equation (4) becomes:
$Ln(X^*) = \ln[(X_t - X_{eq})/(X_o - X_{eq})] = \ln(8/\pi^2) - ((\pi^2 \times D_{eff})/4L^2) \times t$ (6)

with
X^*: water content reduced

D_{eff} ($m^2.s^{-1}$) : coefficient of effective diffusion;
L(m) : Half-thickness of the sample;
t(s): time of drying.

The coefficient of 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 lines giving ln (X^*) according to time makes it possible to calculate the coefficient of diffusion of moisture.

Energy of activation
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 function at the temperature of drying starting from the following equation of Arrhenius (Doymaz *et al.*, 2002).

$D_{eff} = D_o * \exp(-E_a/RT)$ (7)
$\ln(D_{eff}) = \ln(D_o) - (E_a/RT)$ (8)

The energy of activation is calculated starting from the slope of the graph $\ln(D_{eff})$ according to 1/T; one obtains a line of equation $Y = K_O X + B$ (9)
With a slope $K_O = E_a / R$ (10)
Then $E_a = K_O * R$ (11)
D_{eff} : Coefficient of diffusion ($m^2.s^{-1}$)
D_o: Parameter of diffusion of Arrhenius (m^2s^{-2});
E_a: Energy of activation ($J.mol^{-1}$);
R: constant of perfect gas (8.314 $J.mol^{-1}K^{-1}$)
T: absolute temperature of the draining air (K);

Results and discussion

1-effect of the temperature and the power on the kinetics of drying
The effect of the temperature and the power heating on the kinetics of drying are presented on Fig.1 and 2 respectively for drying at the drying oven and the microwawe oven.

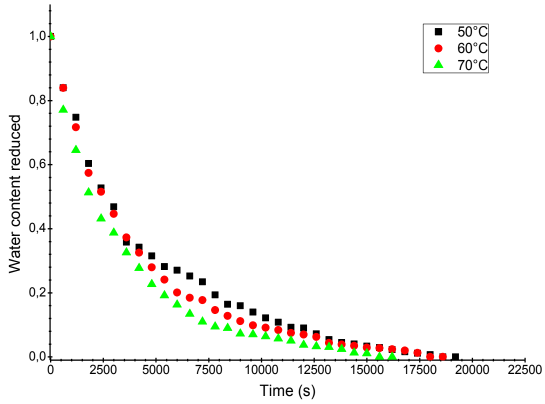

Fig. 1. Variation of the water content according to the time of seeds of *Hura crepitans* (drying oven).

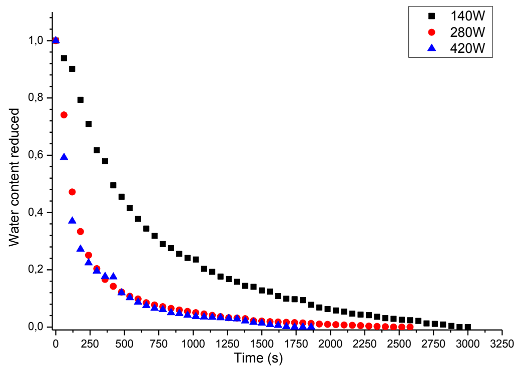

Fig. 2. Variation of the water content according to the time of seeds of *Hura crepitans* (microwaves).

The analysis of these fig. s shows that the curves have the same paces and take a decreasing exponential form. The rise in the temperature to the drying oven or the power of heating to the microwawe oven increases the speed of evaporation and consequently, the reduction of the time of drying of the samples. Indeed, the rise in the temperature or the power of heating accelerates the phenomena of heat transfer of matter (internal migration of water) (Belachi, 2009). Thus, to reach a reduced moisture of $X^* = 0.2$ (Fig. 1) one notes a reduction in the time of drying of order 16 and 28 % when the temperature increases respectively by 50 to 60°C and 50 °C with 70°C. For the case of drying to the drying oven, this reduction of time is approximately 66.67 and 73.33% at the time of the passage of the power of heating from 140 to 280 W and 140 to 420 W (Fig. 2).

For the two techniques, the reduction of the time of drying is observed during the oven drying with microwaves than with the drying oven. Similar results were proven for other products (Midilli and Kucuk, 2003b; Panchariya *et al.*, 2002).

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 respectively passed from 450 to 600 W and 450 to 700 W, and of one 70 %, when the power passed from 140 W with 350 W.

Silou *et al.* (1991) showed that the reduction of the time of drying of the pulp of safou was significant at the time the temperature of drying increases by 50 with 90.

The difference in time of drying observed for the two techniques (with the drying oven and the microwawe oven) indicates that the mass transfer within the sample was fast during the heating by microwaves in comparison with that carried out with drying oven. That can be explained by the electric properties of the product which influence more technology of heating to the microwaves (Maskan, 2000; Coffey *et al.*, 1988).

2-curves speed of drying

The evolution the speed of drying for the various temperatures and powers are presented respectively at the drying oven (Fig. 3 and 5) and at the microwawe oven (Fig. 4 and 6).

The speed of drying increases with the temperature and the power.

It is noted that for the two techniques of drying, the curves speed present two phases for drying at the drying oven (Fig. 3 and 5) and three phases for the oven drying with microwaves (Fig. 4 and 6). It is acted of a phase of temperature setting relatively short, of a phase at constant speed and as end of a phase at decreasing speed.

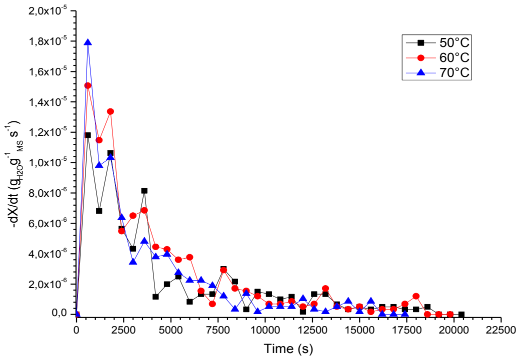

Fig. 3. Variation speed according to time of seeds of Hura crepitans (drying oven).

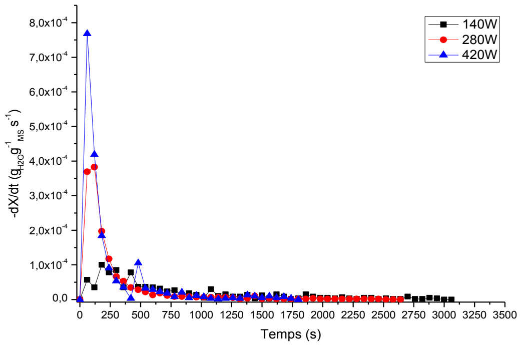

Fig. 4. Variation the speed of drying of seeds of *Hura crepitans* according to time (microwaves).

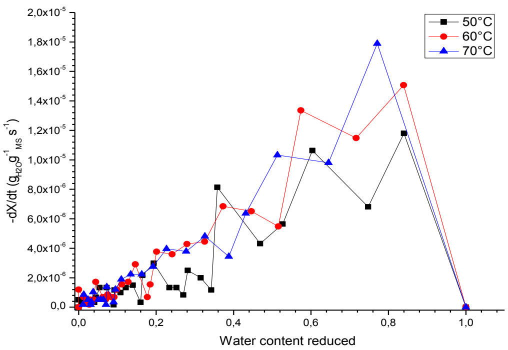

Fig. 5. Variation speed according to the water content of seeds of *Hura crepitans* (drying oven).

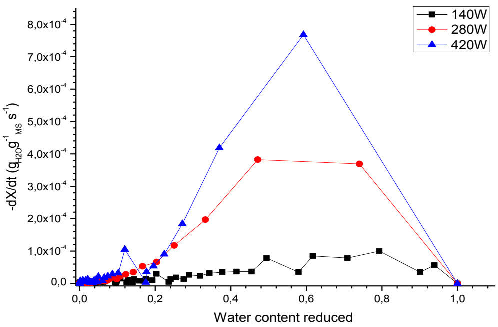

Fig. 6. Variation the speed of drying of seeds of Hura crepitans according to the content of reduced (microwaves).

The presence of the phase at constant speed for the samples kiln-dried with micro waves is due to the interstitial water elimination per boiling during the course of drying (Bonnazi and Bimbenet, 2003). It is also noted that, more the power of heating to the microwawe oven increases, the stage or the phase at constant speed disparate. The appearance of the phase at constant speed for the powers from 140W and 280W shows that on these levels power, the flow of water evaporation of the interior towards surface of the product is optimal to maintain the speed of constant evaporation for a few seconds. The shape of the curves reflects well that obtained by Alibas (2007) and Al-Harahsheh, Al-Muhtaseb, & Magee (2009).

The absence of the phase at constant speed during drying was also highlighted by several authors for foodstuffs and biological at the time drying convective (Mujumdar (2006), Bonazzi and Bimbenet (2003) and Van Brakel, (1980)).

The appearance of these various phases of the curve of kinetics is explained by phenomenon of change of structure in the product. The same report was shown by Boughali *et al., (*2008); Rizvi (2005); Bonnazi and Bimbenet (2003) and EL Hiss (1987).

3-coefficient of diffusion

The effect of the conditions of drying on the coefficient of diffusion of *Hura crepitans* are presented in 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.

Table 1. influence temperature and the power on the coefficient of diffusion.

Products	Condition of drying	Effective diffusivity ($m^2.s^{-1}$)	References
Hura crepitans	50°C	1.19×10^{-10}	Present work
Hura crepitans	60°C	1.28×10^{-10}	Present work
Hura crepitans	70°C	1.46×10^{10}	Present work
Hura crepitans	140 W	8.39×10^{-10}	Present work
Hura crepitans	280W	1.15×10^{-9}	Present work
Hura crepitans	420W	1.44×10^{-9}	Present work
Carrot	60 -90°C	2.58×10^{-10} -1.72×10^{-9}	Zielinska and Markowski (2010)
French bean	/	9.34×10^{-9}	Doymaz (2005a),
seeds of gombo	60 -90°C	2.58×10^{-10} - 1.72×10^{-9}	Ouoba *et al* (2010),
Kiwi	30- 90°C	3.0×10^{-10} -1.72×10^{-9}	Simal *et al.,* (2005)
Green pepper	50-70°C	4.38×10^{-11} -1.09×10^{-10}	Sanjuán *et al.* (2003)
Tomato	55- 70°C	3.91×10^{-10} - 6.65×10^{-10}	Doymaz (2007)

Also, the increase in the temperature and the power involves a great agitation of the molecules and consequently, an increase in the coefficients of matter and heat transfer. Diffusivities vary $7.12\times10^{-9}m^2.s^{-1}$ with $8.76\times10^{-9}m^2.s^{-1}$ for temperatures ranging between 50 and 70°C and of $5.03\times10^{-8}m^2.s^{-1}$ with $8.64\times10^{-8}m^2.s^{-1}$ for powers going of 140W with 420W.

These results show that the coefficient varies primarily with the temperature and the power of drying. The elevation of the coefficient of diffusion for temperatures ranging between 30°C and 90°C are in agreement with those obtained in the literature (Zielinska and Markowski, 2010 Doymaz, 2005a; Ouoba *et al.*, 2010; Simal *et al.,* 2005; Sanjuán *et al.*, 2003; Doymaz, 2007) (Table 1). By comparing our results with those of the literature, one notes that the coefficient of diffusion varies from one product to another.

4-energy of activation

Activation energy of *Hura crepitans* seeds was given graphically starting from the equation of Arrhenius (Fig.7). The energy of activation makes it possible to know the influence of the temperature on the coefficient of diffusion. The larger the sample is, the more the need of a great energy to activate the reaction. Activation energy of the evaporation reaction during drying of *Hura crepitans* seeds is of 9.53 kJ mol^{-1}.

The comparison between this energy of activation and those quoted in the literature for other products

(Table 2), makes it possible to affirm that the interaction between the water and the matrix of *Hura crepitans* is weak.

Table 2. Comparison of the value of the energy of activation with those of the literature.

Products	Energy of activation Ea (kJ mol-1)	References
Hura crepitans	9,52	Present work
Round mint	62,96	Doymaz (2007)
Spear mint	82,93	Park *et al* (2002)
Carrots	28,36	Doymaz (2002)
Red pepper	42,8	Kaymak-Ertekin (2002)
Green pea	24,70	Simal *et al.* (2005)
Black tea	406,02	Panchariya *et al.*(2002)

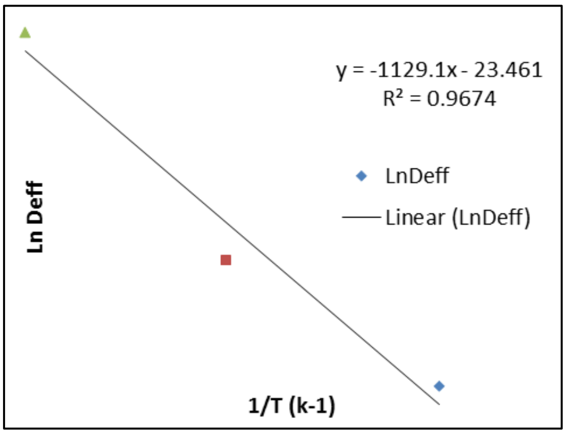

Fig. 7. Determination of coefficient of diffusion of seeds of *Hura crepitans*.

Conclusion

The objective of this work was to study the kinetics of drying of seeds of *Hura crepitans* to the drying oven and the microwawe oven. The experimental study was carried out at temperatures of 50, 60 and 70°C with the drying oven and powers of heating of 140, 280 and 420 W with the microwawe oven. The results show that the temperature and the power of drying influence significantly the kinetics of drying of seeds of *Hura crepitans* more the temperature or the power is high, the speed of dehydration is significant what has as a consequence the reduction of time of drying. The oven drying with microwaves makes it possible significantly to reduce the time of drying obtained to the drying oven. It is also noted that the oven drying with microwaves with 140W and 280W made apparaitre the three phases of curves of kinetics compared to that achieved by means of a drying oven which into present that two. The values of the coefficient of diffusion increase with the temperature and the power of heating. The seed energy of *Hura crepitans* is about 9.53 kJ mol^{-1}

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