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CONVECTION DRYING INFLUENCE ON THERMO-PHYSICAL PROPERTIES, BIOACTIVE SUBSTANCES, COLOR AND TEXTURE PROFILE OF RED PEPPER (*CAPSICUM SPP)*

– Research paper –

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Abstract : This work aimed to study the effect of convection drying on bioactive substances and on the texture profile of red pepper. Four mathematical models were used to model the drying kinetics, as a function of the temperature and the thickness of slices. These models are largely in agreement with experimental data. Effective diffusivity, Arrhenius constant, activation energy and thermal properties changed with temperature of dry process. The two varieties of pepper used in this work demonstrated a very high degree of spiciness (144799.37-160899.37 SU). This property is related to the high contents of capsaicin (39.60-44.01 mg/g) and dihydrocapsaicin (32.33-35.95 mg/g). Our results revealed that brittleness, hardness 1 and 2, firmness, chewiness, gumminess appearance and Young's modulus are very important attributes in determining the textural profile of dried red pepper. Also, drying causes a strong degradation of natural pigments of red pepper and consequently decreases attractiveness of the texture profile. To avoid that, red pepper should be pretreated before the application of hot air drying.

Keywords: Red pepper. Modelling. Thermophysical properties. Pigments. Texture Profile analysis (TPA).

INTRODUCTION

Red pepper (*Capsicum spp)* is an annual herbaceous plant, which belongs to the Solanaceae family and includes 20 species and about 300 varieties, originally developed in the humid and tropical regions of Central and South America (Joseph et al., 2020). It is currently cultivated around the world where China, Mexico, Indonesia and Spain are the main producers (Baenas et al., 2019). Red pepper is popular and widely known due to its aromatic, and flavouring properties. It is also considered as an excellent source of bioactive compounds such as capsaicin (trans-8-methyl-N-vanillyl-6-nonemide, colorless odorless alkaloid) (Reyes-Escogido et al., 2001), vitamins, specially vitamin C, and E (α –tocopherol) (Kantar et al., 2016) and provitamin A (Baenas et al., 2019). Also, red papper contains colouring capsaicinoids such as capsaicin and dihydrocapsaicin, and polyphenols, in particular flavonoids, quercetin, luteolin, and some phenolic acids (Asnin and Park, 2015) and carotenoids (Hallmann and Rembiałkowska, 2012). Several studies have investigated the carotenoids; such as Rodriguez-Amaya et al., (2008) for β-carotene, lutein, and capsathin; Dong et al., (2014) and Asnin and Park, (2015) for cryptoxanthin and zeaxanthin and also Zhang et al., (2018) for neoxanthin, neochrome, violaxanthin, antheraxanthin anthocyanins and capsinoides. Carotenoids fraction is lipophlic yellow-orange-red pigments found in photosynthetic plants are responsible of plants colors such as red pepper. The values of these

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bioactive molecules are influenced by many factors including cultivars, enzyme activity, endogenous antioxidants, water activity, climatic and storage conditions. The red pepper fruit has high commercial values in terms of flavors characteristics, colors, and antioxidants properties (Baenas et al., 2019). Moreover, the presence of these substances in red pepper offers fairly important protective properties against several diseases such as cardiovascular diseases, antibiotics, and anti-algesic, which makes it very effective product in pharmacology (de Sá Mendes and Branco de Andrade Gonçalves, 2020).

The textural properties of food are defined as being the physical characteristics which reflect the structure of the product; they are related to fracture, disintegration or flow under the effect of stress. Few studies have dealt with the changes of textural properties during drying. The texture, along with the flavor and appearance of the food are undoubtedly the main factors in the sensory acceptability of a food product (Tijskens and Luyten, 2004).

Drying is one of the most traditional processes to preserve foodstuffs. It consists of the water removal from food products to a level that would highly minimize the microbial damages and deterioration reactions. During drying, most modifications are appreciated for the vegetable product quality such as physical, structural, chemical, organoleptic and nutritional properties. Dried red pepper or paprika is considered as one of the most important condiments used as vegetable spices in sauces and as a food coloring. The quality of this vegetable is determined by carotenoids content, responsible for its coloring.

The transfer of heat from the air to the product to be dried is associated with a transfer of mass; transfer of water vapor from product to the air. Many mathematical models have been used to describe the drying process of agricultural material such as Diffusion approach, Modified Hendrson-Pabis, Logarithmic, Two Trem, Hii Law & Cloke, Verma…etc (Di Scala and Crapiste, 2008; Guiné et al., 2011; Onwude et al., 2016; Kutltu and Isci, 2017).

Barika region, where we collected the pepper samples, is located in the east of Algeria. It is well known for its large production of hot pepper powder obtained by the farmers using, until the present day, traditional methods which present many inconvenient such as long drying time, weather dependency, generating wastes, microbial contamination. For this, the need to move towards modern and standardized dry techniques is undeniably of interest.

In the present work, the drying of two red pepper varieties is carried out in an experimental drying oven with natural convection drying. Among the four selected models, three are newly proposed to describe the experimental behavior of drying kinetics at three drying temperatures (50°C, 70°C and 80°C). Effective diffusivity, Arrhenius constant, activation energy, density, surface area, specific hot, and thermal conductivity were calculated. The changes of color pigment for red pepper caused by enzymatic browning reactions and caramelization is quantified by determination of L, a, b components and the indexes of enzymatic activity using the Browning index (BI), Yellowness index (YI), and Whitening index (WI). Effect of the drying on texture profile and Young's modulus (E) are studied, also.

MATERIALS AND METHODS

Determination of the chemical composition

Moisture, pH, and total soluble solids (TSS) contents were analyzed for both fresh and dried red peppers using AOAC methods descripted by Robert and Bradley (2010). TSS contents were measured using hand refractometer expressed by Brix degree. These parameters were giving in triplicate from milled samples. The size including length and diameter of selected samples was measured by Digital Electronic Vernier Caliper.

Drying kinetics

The drying tests were carried out using an experimental drying oven of natural convection drying type Memmert. Two varieties of red pepper samples were dried at three temperatures: 50°C, 70°C and 80°C. The raw materials must be of good visual and organoleptic qualities; then were washed with water ensuring the reductions of surface microbial flora. The weights of red peppers samples were periodically measured and controlled during the drying operation, a sampling has been obtained every 30 minutes until the stable weight.

A total of 10 experimental series were approved out with five replications and the mean values were used for the moisture determination. The moisture content was expressed as a percent wet basis and converted to kg of water per kg of dry red pepper.

Mathematical modelling

According to Onwude et al. (2016), the moisture ratio (MR) was simplified to $^{M_t}/_{M_0}$ as written in the following equation (1):

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (1)$$

where M_0, M_e and Mt are initial moisture content, equilibrium moisture content and moisture content at time t, respectively.

To model the drying kinetics of peppers we used three new models reported in the bibliography (Cabrales et al., 2018; Nie and Guo, 2019; Sasaki et al., 2022). Indeed, logarithmic model is one of the most common models used in modeling the food drying kinetics. These models are given by the following equations (2 to 5):

Logarithmic:

$$MR = a\ exp^{(-kt)} + c \quad (2)$$

New model 1: Gompertz model (Cabrales et al., 2018) (this paper)

$$MR = a\ exp^{(-exp^{\left(-\frac{(t-t0)}{k}\right)})} + C \quad (3)$$

New model 2: Exponential linear combination model (Sasaki et al., 2022) (this paper)

$$MR = a\ exp^{(-kt)} + k't + b \quad (4)$$

New model 3: Chapman model (Nie and Guo, 2019) (this paper)

$$\mathrm{MR} = \mathrm{a}\left(1 - \exp^{(-\mathrm{kt})}\right)^{\mathrm{b}} + \mathrm{c} \quad (5)$$

X : moisture content (Kg water/ Kg of dry matter), a, b, c, k, k': models coefficients and constants, t: drying time.

Determination of effective diffusion coefficient and activation energy

The diffusion coefficient and activation energy were used to improve drying conditions since they are among the main parameters influencing the water transfer from the food to the texture. These two parameters are calculated using the equation given by Guiné et al. (2011) and Kutltu and Isci (2017):

$$D_{eff} = D_0 exp^{-\left(\left(\frac{E_A}{RT}\right)\right)} \quad (6)$$

Activation energy (E_A) is the energy barrier that must be overcome to activate the diffusion of water. This parameter is obtained using the slope of straight line of In D_{eff} versus reverse drying temperature (1/T). It is given by the formula (7):

$$slope = \frac{E_A}{R} \quad (7)$$

where D_{eff} is the effective diffusivity (m^2/s), L is half thickness of samples (m), t is drying time (s), D_0 is the diffusivity for an infinite temperature (m^2/s), E_A is the activation energy for moisture diffusion (kJ/mol), R is the constant perfect gas (kJ/mol k), T is drying temperature (K).

Thermophysical properties of red pepper

To ensure development in food process engineering, it is necessary to determine some characteristics related to food called the thermos-physical parameters which include: density, surface area, specific heat and thermal conductivity. These indices were given by the equations reported in study of Di Scala and Crapiste (2011).

Bioactive compounds of red pepper

Bioactive compounds of red pepper pigment were detected using the UV Spectrophotometer. 0.01g of sample was solubilized using methanol as solvent, and stirred for 60 min by a magnetic shaker (RCT Basic, IKA). The sample absorbance and transmittance spectra were measured by performing the wavelength scan using Spectrophotometer (SHIMADZU, UV -1800).

For capsaicin and dihydroxycapsaicin (González-Zamora et al., 2015) (eq. 8):

$$\mathrm{C}(mg/g) = \frac{\mathrm{A}_{280}}{\mathrm{L}*\varepsilon} \quad (8)$$

where C is content of capsaicin or dihydroxycapsaicin (mol /l), A is absorbance at 280 nm, L is the path length through the sample (cm), ε is the molar absorbance coefficient of capsaincin (ε_{280} = 3410 mol/cm) and dihydroxycapsaicin (ε_{280} = 4175 mol/cm).

For capsanthin (Wang et al., 2018) (eq. 9):

$$C_{capsanthin}\left(\frac{g}{kg}\right) = \frac{A \times f \times 2.5 \times 10^5}{2250 \times (100 - M) \times w} \quad (9)$$

Where $C_{capsanthin}$ is concentration of capsanthin (g/kg), A is absorbance value at 460 nm, f instrument wM is moisture of sample (%), and W is weight of the sample (g).

The total carotenoid, lycopene, content of hexane extracts was giving by following equations:

For β- carotene (Potosí-Calvache et al., 2017) (eq. 10):

$$\boldsymbol{T}\mathrm{C}\left(\frac{\mathrm{mg}}{100\mathrm{g}}\right) = \frac{\mathrm{A}_{450} * M_W * \mathrm{V}}{\mathrm{Ms} * \varepsilon} \quad (10)$$

where A is absorbance at 450 nm, M_w is the molecular weight of β- carotene (533.85 g/mol), V is the volume of hexane (3 ml), ε is the extinction coefficient of β- carotene in hexane (137.4 m. M), and Ms is the weight of sample (0.01g).

For lycopene (Gordon and Diane, 2007) (eq. 11):

$$y\left(\frac{\mathrm{mg}}{100\mathrm{g}}\right) = \frac{\mathrm{A}_{503} * M_W * \mathrm{V}}{\mathrm{Ms} * \varepsilon^{1\%}} \quad (11)$$

where A is absorbance at 503 nm, M_w is the molecular weight of lycopene (g/mol), V is the volume of hexane (ml), Ec is the extinction coefficient of lycopene in hexane: 172 mM, and 0.01 is the weight of sample.

Scoville heat unite (SUH) was obtained by conversion of the capsaicinoid concentration in

parts per million (ppm) and multiplying by the coefficient of the heat value for each compound (16.1) for the capsaicin and dihydroxycapsaicin (Lo Scalzo et al., 2020).

Drying effect determination on red pepper color

Color components (a, b, L, C and h) of fresh and dry red pepper at three temperatures were determined using Konica Minolta Chroma meter. The colorimeter was calibrated with white and black standard plates before use.

Measurements were performed on the surface of each pepper sample. The chrome C and hue angle (h°) values were read directly on instrument. The total color difference (△E) can be calculated using three components of color space: "L" is lightness coordinate, "a" is CIE red (+)/green (-) color attribute), and "b" is (CIE yellow (+)/blue (-) color attribute).

△E parameter is giving by the equation (12):

$$\Delta E = \sqrt{(a_0 - a_f)^2 + (b_0 - b_f)^2 + (L_0 - L_f)^2} \quad (12)$$

where a_0, b_0 and L_0 are the values of the fresh samples and a_f, b_f and L_f are the values of the dry ones.

In order to quantify the red pepper color deterioration during dry processes, we used three indices: browning index (BI), yellowness index (YI) and whitening index (WI) that equations were given by Pathare et al. (2013).

These indices were confirmed by determination of red and yellow fraction.

Red and Yellow fractions

According to Lo Scalzo1 et al. (2020), the two colored fractions were quantified by the following equations and further reported to the amount of mg/100 g dry weight:

For red fraction (Eq. 13):

$$\text{Red fraction } \left(\frac{\mu g}{mL}\right) = \frac{(A_{508}\times 2144)-(A_{472}\times 403.3)}{270.9} \quad (13)$$

For Yellow fraction (Eq. 14)

$$\text{Yellow fraction } \left(\frac{\mu g}{mL}\right) \frac{(A_{472}\times 1724.3)-(A_{508}\times 2450.1)}{270.9} \quad (14)$$

Texture analysis of red pepper

The texture evolution of two red pepper varieties during drying operation was recorded by periodically texture profile measurement using EZ-LX Shimadzu texturometer with Trapezium X software.

Sample with cylindrical form was undergoes two compression cycles at force 50 N and 50mm /min test speed. After applying load up to 25 mm, rectums to stroke = 0, continues to apply load up to 25 mm, and then stops at force = 0. This analysis is carried out for fresh and dried products at 50 °C using texturometer instrument (EZ-LX Shimadzu).

Textural profile analysis measures included: Hardeness (force, N), cohesiveness (ratio, dimensionless), adhesiveness (work, N.mm), springiness or elasticity (displacement, mm) and chewiness (work, N), brittleness (Brittleness) (force, N), Gumminess (force, N), absolute energy (J), Young's modulus (E) and Poisson index. These attributes were calculated by Trapezium X software using the equations from 15 to 21:

$$\text{Brittleness, } B = F_1 \quad (15)$$

$$\text{Hardeness, } H = F_2 \quad (16)$$

$$\text{Cohesiveness, } Co = \frac{A2}{A_1} \quad (17)$$

$$\text{Springiness, } S = \frac{D_2}{D_1} * 100 \quad (18)$$

$$Adhesivenss, A = A_3 \quad (19)$$

$$\text{Gumminess} = H * C \quad (20)$$

$$\text{Chewiness, } Ch = H * Co * S \quad (21)$$

where F_1 and F_2 are the forces (N), A_1, A_2 and A_3 are the areas (N. mm) and D_1 and D_2 are the displacement (mm).

Statistical analysis

The data represent the average of three replicates pretreatment. ANOVA analysis using SigmaPlot software was applied to evaluate differences among treatments. Level of significance was defined at p-value < 0.05.

According to Onwude et al. (2016), the goodness of fit of the thin layer models to the experimental data was evaluated using the coefficient of determination (R^2), root mean square error (RMSE) and reduced Chi-square (X^2) values. Similarly to Gurlek et al. (2009) study, the modelling efficiency (EF) value was used to determine the quality of the fit.

RESULTS AND DISCUSSION

Physicochemical composition of fresh red pepper

Table 1 shows the chemical composition of two varieties of fresh red peppers. Morphological characteristics determine pepper calibration. The results show that the two studied varieties are homogeneous (P < 0.001) and can be classified in the same calibration category. Average weight, length and diameter of the two fresh red peppers were a commercial differentiation parameter. Red pepper is among vegetables with high water

contents, the obtained values vary between 81.11 to 88.19 %.

Drying is one of the common technic used to preserve peppers by reducing their water content to less than 5 % and therefore obtaining the pepper red powder named paprika. Dry matter varies from 11.81 % to 18.89 % and TSS varies from 9.88 % to 11.14 %. The acidic pH of pepper, which varied from 4.64 to 4.71, plays an important part in minimizing danger of the pathogenic germs proliferation. The obtained results are in accordance with those reported by Ergünes and Tarhan (2006), Sharma et al. (2014), and Ertani et al. (2015).

Table 1. Morphological and physicochemical properties of the two fresh red pepper varieties

Parameter		**ARBI**	**AGHOUAT**
Weight (g)		14.64	17.37
Length (cm)		7.27	7.04
Diameter (cm)		2.87	3.20
Moisture (%)		81.11	87.28
Dry matter (%)		18.89	12.87
Total soluble solids (%)		11.14	10.61
Capsaicin (mg/g)		44.01	39.60
Dihydrocapsaicin (mg/g)		35.95	32.35
Capsanthin (g/kg)		5.17	8.47
Carotenoids (mg/100g)		118.78	125.42
Lycopene (mg/100g)		19.98	18.05
Color	a	31.82	30.12
	b	21.02	20.89
	L	38.51	38.36

Mathematical modeling of hot air drying kinetics of red pepper

Figure 1 shows the drying kinetics curves moisture ratio as a function of drying time of the two red pepper varieties at three drying temperatures (50°C, 70°C and 80°C). Regarding our results, the drying temperature had a significant effect on the drying kinetics of red pepper samples.

Increasing drying temperature accelerates the water evaporation and consequently decreases the drying time. Similar findings were obtained on various fruits and vegetables by several authors: Ergünes and Tarhan (2006) and Di Scala and Crapiste (2011) for red pepper, Gurlek et al. (2009) for Tomato, Kumar and Verma (2009) and Romano et al. (2012) for bell pepper, Velickova et al. (2014) for apple and chips, Sharma et al. (2014) for sweet belle-pepper, Onwude et al. (2016) for pumpkin and Kutlu and Isci (2017) for zucchini.

The obtained drying time was fitted using four models, three of which are new. Figure 1 illustrates the regression analysis and variation of the latest parameter revealed by these models.

Constants and coefficients of the best-fitting mathematical models involving hot air drying variables (temperature and moisture) were determined for the two red pepper varieties (Tables 2 and 3). According to these tables, the values of RMSE, R^2, X^2 and EF for the used models ranged from 0.001 to 1.96, from 0.912 to 0.999, from 2.010×10^{-6} to 8.21 and from 0.857 to 0.999, respectively.

Table 2. Statistical results of moisture content and drying time modelling for Arbi variety red pepper

Model name	Coefficients and Constant	RMSE	X^2	EF	R^2
Temperature 50 °C					
Logarithmic	K=0.003, a=3.16 , c= -1.69e^{-23}	1.183	1.92	0.995	0.912
New model 1	K=-0.001, t_0=83.87, a=10.89, c= -1.07	0.012	0.0002	0.999	0.999
New model 2	K=0.87, k''=-0.005, a=0.091, b=3.34	0.368	0.16	0.992	0.998
New model 3	K=7.99e-4, a=-8.85, b=1.06, c= 3.41	0.11	0.015	0.992	0.999
Temperature 70 °C					
Logarithmic	K=0.001, a=6.58 , c=-2.23	0.725	0.68	0.999	0.973
New model 1	K=0.002 , t_0=-87.22, a=-9.20, c=8.30	0.045	0.002	0.999	0.973
New model 2	K=0.001, k''=-1.64e-4, a=6.12, b= -1.86	0.986	1.15	0.999	0.973
New model 3	K=0.002, a=-5.47, b=1.15, c=4.28	1.96	4.55	0.999	0.974
Temperature 80 °C					
Logarithmic	K=0.003, a=6.50 , c=-0.77	1.09	8.21	0.998	0.996
New model 1	K=-0.003 , t_0= 27.40, a=12.40, c=0.56	0.029	0.001	0.951	0.999
New model 2	K=0.77, k''=-0.01, a=0.74, b=4.82	0.069	0.006	0.998	0.955
New model 3	K=0.006, a=-5.49, b=1.48, c=5.50	1.66	3.61	0.998	0.999

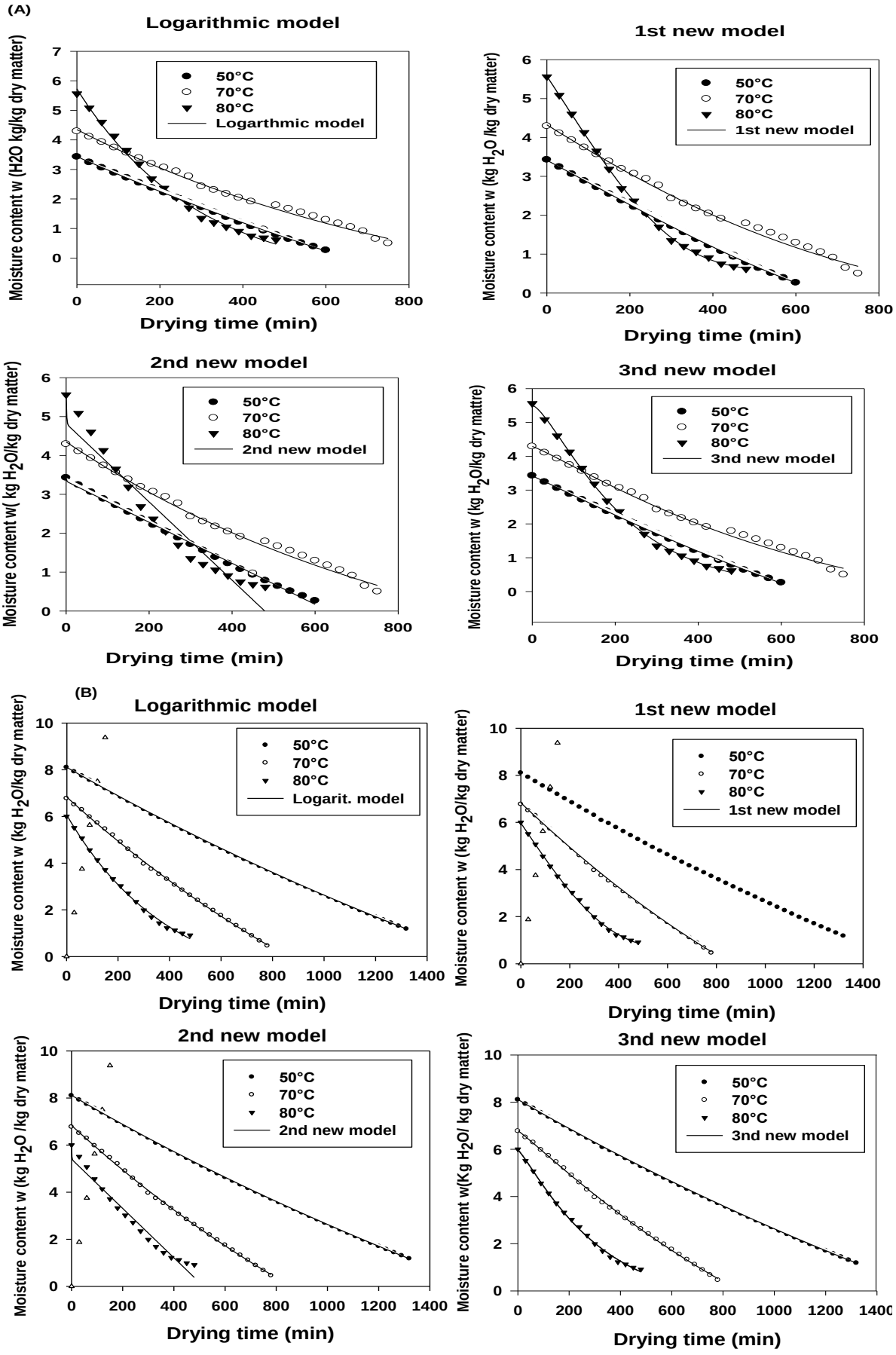


Figure 1. Comparison between the experimental and predicted data of red pepper drying by hot air at 50 °C, 70 °C, and 80 °C, (A): Arbi variety and (B) Aghouat variety.

Table 3. Statistical results of modelling of moisture content and drying time for Aghouat variety red pepper

Model name	Coefficients and Constant	RMSE	X^2	EF	R^2
	Temperature 50 °C				
Logarithmic	K=2.83e-4, a=22.20 , c=-14.09	0.004	1.54e-05	0.999	0.999
New model 1	K=-9.64e-4 , t_0= -806.00, a=-6.92, c=-1.11	1.81	3.58	0.999	
New model 2	K=5.85e-4, k''=-0.003, a=6.27, b=1.84	1.47	2.37	0.999	0.999
New model 3	K=2.72e-4, a=-22.79, b=0.99, c=8.11	0.015	2.58e-04	0.999	0.999
	Temperature 70 °C				
Logarithmic	K=5.54e-4, a=18.07 , c=-11.23	0.009	1.02e-04	0.999	0.999
New model 1	K=-9.07e-4 , t_0= 26.95, a=-34.49, c=-681.13	0.001	2.10e-06	0.999	0.999
New model 2	K=4.39e-4, k''=-0.002, a=27.60, b=-20.76	0.27	0.08	0.999	0.999
New model 3	K=7.93e-4, a=-5.49, b=1.07, c=6.79	0.018	3.90e-04	0.999	0.999
	Temperature 80 °C				
Logarithmic	K=0.003, a=7.58 , c=-1.50	1.52	3.04	0.999	0.998
New model 1	K=-2.75e-3 , t_0= -11.85, a=15.25, c=0.55	0.002	5.06E-06	0.938	0.999
New model 2	K=0.86, k''=-0.01, a=0.60, b=5.41	0.47	0.29	0.857	0.977
New model 3	K=0.004, a=-6.60, b=1.21, c=5.97	1.031	1.391	0.999	0.999

Best model describing hot air drying characteristics of red pepper was chosen as the one with highest R^2 and EF values and lowest X^2 and RMSE values. Regarding these results, the four models are largely in agreement with experimental data. In comparison to logarithmic model, three new models were found to be best suited to describe hot air drying curves at tested temperatures for the two considered red pepper varieties.

Effective diffusion coefficient, activation energy and thermophysical properties

Effective diffusivity (D_{eff}), Arrhenius constant (D_0) and activation energy (EA) for red peppers dried at hot air are presented in table 4. It reveales that values ranged from 6.01E-10 m²/s to 6.98E-07 m²/s, 2.96E-15 m²/s to 2.65e-1 m²/s, 12.10 kJ/mol at 142.23 kJ/mol, respectively for the effective diffusivity, Arrhenius constant and activation energy.

Table 4, pointed out that the effective diffusivity values giving by the three new models are nigh to those obtained by the reference model (logarithmic). While the Arrhenius constant and activation energy values estimated by the new models were highest, compared to those given by the above mentioned model.

Similar values on other fruits and vegetables are reported by Guiné et al. 2011) for pumpkin (4.08 $*10^{-8}$ m²/s to 2.35 * 10^{-7} m²/s of D_{eff}, 0.0028 m²/s of D_0 and 33.74 kJ/mol of EA) and Kurmar et al. (2012) for carrot marc (2.74 $*10^{-9}$ to 4.27 * 10^{-9} m²/s). According to Wang et al. (2007), the range of published values concerning the estimated effective diffusivity for food materials is comprised between 10 * 10^{-11} and 10 * 10^{-9} m²/s.

Table 4. Effective diffusion coefficient and activation energy calculated by principals' models (Logarithmic and three news models)

Model name	D_{eff} (m²/s)			D_0 (m²/s)	EA (kJ/mol)
	50 °C	70 °C	80 °C		
Arbi variety					
Logarithmic	2.74E-09	9.13E-10	2.74E-09	1.792E-07	12.10
New model 1	1.28E-09	1.83E-09	2.74E-09	6.12E-06	22.85
New model 2	7.87E-07	8.22E-09	6.98E-07	2.93E-13	37.38
New model 3	9.13E-10	1.83E-09	5.48E-09	2.65E-01	52.65
Aghouat variety					
Logarithmic	6.25E-10	1.22E-09	6.62E-09	2.32E-02	67.56
New model 1	2.13E-09	2.00E-09	6.07E-09	4.72E-05	27.30
New model 2	7.92E-09	5.39E-09	1.90E-06	2.96E-15	142.23
New model 3	6.01E-10	1.75E-09	8.83E-09	3.05E-04	79.21

The thermal properties of foods are of key importance to perform the various heat transfer calculations involved in designing storage and refrigeration equipment and also in estimating process times for refrigerating, freezing, heating, or drying of foods.
Table 5 points out the following thermal properties of red pepper after dry process: density, surface, specific heat and thermal conductivity. These properties change with dry temperature.

Bioactive compounds

Figure 2 show that absorbance spectra of methanol extracts long wavelengths varies from 190 nm to 1100 nm for both varieties. It appears also that samples have a high absorption at detected in UV-VIS region (190 to 400 nm).

Wide bands whose absorption maximums are close to 225, 234, 245, 259, 268, 279, 284 nm, refer to the energy difference for the π-π * transitions of the double bond (C,C) in hydrocarbons.
Contents of the main bioactive substances of pepper were determined namely by capsaicin and dihydrocapsaicin (A_{228}: 3.844, A_{230}: 3.487 and $A_{280:}$ 3.75), capsanthin (A_{460}: 0.792), β-carotene (A_{450}: 0.818), and lycopene (A_{503}:0.476) from Arbi variety. Concerning the other variety (Aghouat), the observed absorbance values are 3.293, 2.819, 2.239, 0.335, 0.354 and 0.237 for A_{228}, A_{230}, A_{280}, A_{460}, A_{450} and A_{503}, respectively. The energy associated to the light absorption can be obtained using equation given by Einstein-Bohr for spectrum; it is comprised between 90 to 1100 nm. In this pelage, the energy value varies between 1.805 *10 $^{-19}$ J/ photon and 10.45 *10^{-19}J/ photon.

Table 5. Thermophysical properties of red pepper varieties during and after drying process

Variety		Density (Kg/m^3)	Surface (m^{-1})	Specific heat (kJ/Kg°C)	Thermal conductivity (W/m°C)
Arbi variety	50 °C	1315.57	5.95	1528.52	0.2138
	70 °C	1294.25	11.77	1948.58	0.3054
	80 °C	1145.76	9.55	2108.97	0.3560
Aghouat variety	50 °C	1177.632	9.46	2446.792	0.512
	70 °C	1331.838	8.14	1877.466	0.286
	80 °C	1190.226	9.42	2431.250	0.503

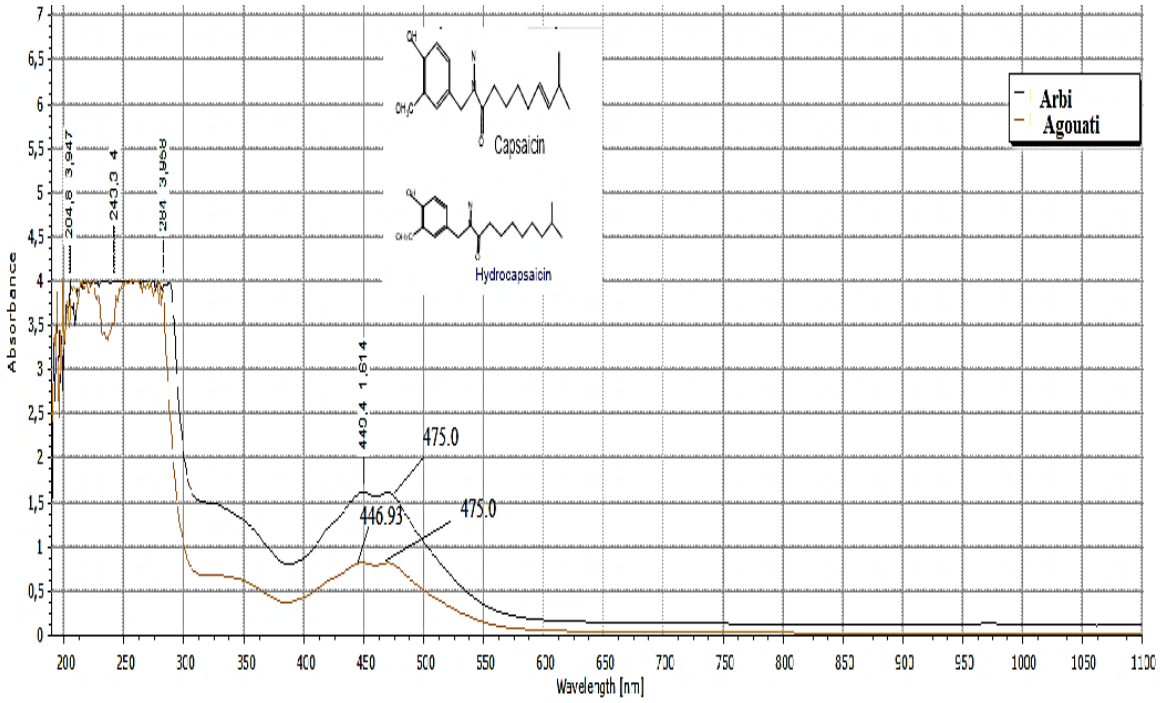


Figure 2. Absorbance readings in spectrum scan between the wavelengths 190 nm and 1100 nm of fresh red pepper solubilized using methanol.

The results (Table 1) for different molecules vary from: 39.60 mg/g to 44.01 mg/g for capsaicin, from 32.35 mg/g to 35.94 mg/g for dihydrocapsaicin, from 5.17 g/kg to 8.47 g/kg for capsanthin with a total of capsinoids comprised between 71.95 mg/g and 79.95 mg/g, 118.78 mg/100g and 124.72 mg/100g for β- carotene and 10.69 mg/100g and 14.82 mg/100g for lycopene. The values of red and yellow fractions corroborate the findings of Lo Scalzo1 et al. (2020). Similar data were found by Gonzàlez-Zamora et al. (2015) for capsaicinoids, Wang et al. (2018) for capsanthins and de Sá Mendes and Branco de Andrade Gonçalves (2020) for capsaicin, dihydrocapsaicin, and β-carotene. Nevertheless, moderate low values of capsanthin and β-carotene have been recorded by Kim and Yoo (2016). Giuffrida et al. (2013) highlighted that the most important compounds of chilli pepper are capsaicin, dihydrocapsaicin, capsanthin and β-carotene. The genus *Capsicum* is very rich in carotenoids and the different colors presented by the species belonging to this genus are due to the profile of carotenoids present in each of the species (Carvalho et al., 2015; Antonio et al., 2018). Results of spiciness degree are 144799.37 SU for the Aghouat variety and 160899.37 SU for the Arby variety. Therefore, our results confirm the fact that these two varieties are of a very high degree of spiciness as attested by local population.

Effect of drying on bioactive compounds and enzymatic activity

Drying causes a strong degradation of pepper carotenoids, especially at high temperatures. Table 6 illustrates the effect of hot air drying on color of fresh and dried red peppers; this effect is expressed with the three following indices: BI, YI and WI. These indexes express the reactions of enzymatic and non-enzymatic browning that are accelerated at high temperatures (70 °C and 80 °C). Several studies have reported that convection drying can lead to a strong deterioration of color which results in biochemical reactions (enzymatic browning) (Heras-Ramírez et al., 2012).

Changes in the texture of the pepper during drying

Figure 3 reveals the texture profile of fresh and dry pepper which allows the determination of different attributes values. Table 7 summarizes the results obtained from the evolution of the texture parameters during drying for the two varieties. Values of texture attributes decrease during drying, the lowest values have been obtained at the end of drying.

Regarding the profile analysis, Aghouat variety presents the highest values of brittleness (51.2 N), hardness 1 (72.28 N), hardness 2 (54.55 N), firmness (2.25 N/mm), chewiness (23.047) and gumminess (46.982 N) compared to Arbi variety which has the following values: 11.9 N, 21.7 N, 20.96 N, 0.86 N/mm, 15.02 and 18.38 N, respectively for brittleness, hardness 1 and 2, firmness, chewiness and gumminess appearance. On the other hand, this latest variety has high cohesiveness (0.817) compared to the Aghouat variety (0.49). In addition, significant differences were recorded for all texture attributes for the two varieties.

Table 6. Colors indices of fresh and dry red pepper for the two studied varieties

Samples	**Vareity**	△E	BI	WI	Y1
Fresh Samples	Arbi	-	131.58	61.66	77.97
	Aghouat	-	128.98	61.80	77.79
Dried samples	50 °C				
	Arbi	32.06	46.67	69.17	48.54
	Aghouat	31.53	46.57	70.473	50.19
	70 °C				
	Arbi	29.64	51.24	67.68	48.50
	Aghouat	31.05	43.43	68.17	47.918
	80 °C				
	Arbi	23.90	93.16	70.60	71.18
	Aghouat	30.09	50.12	68.48	52.44

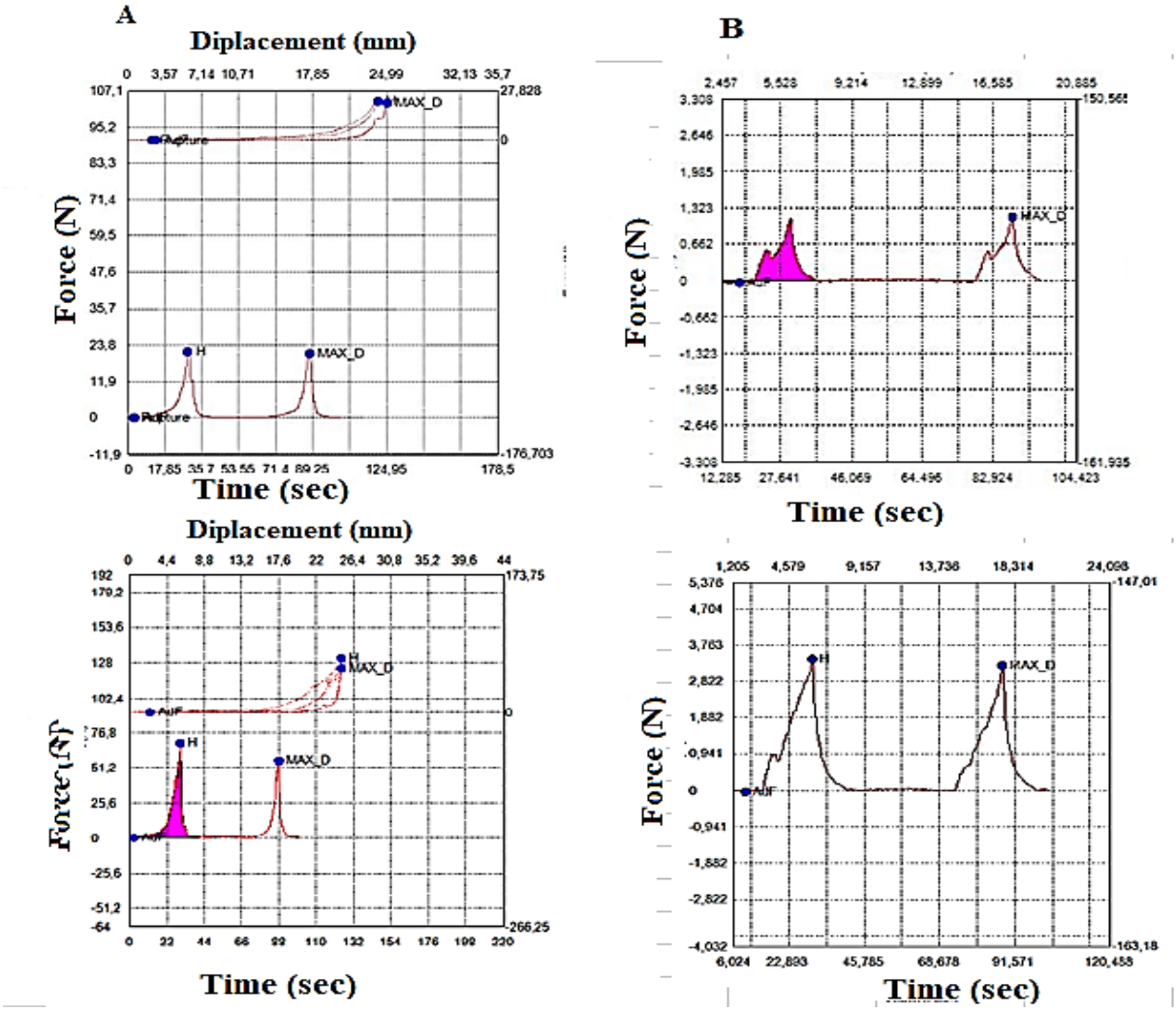


Figure 3. Texture profile of fresh (A) and dry red pepper (B) at 50 °C.

Table 7. Attributes of texture of fresh and dried red pepper at 50 °C

	Arbi		Aghouat	
	Fresh	Dried	Fresh	Dried
Brittleness (N)	11.9	0.6	51.2	0.914
Hardness 1 (N)	21.7128	1.32	72.28	3.38
Hardness 2 (N)	20.96	1.29	54.55	3.23
Adhesive force (N)	-0.0405	-0.086	-0.038	-0.03
Springiness (%)	84.667	50.00	84.667	41.929
Cohesiveness	0.817	0.827	0.491	0.618
Resiliences	0.847	0.500	0.60	0.80
Chewiness	15.025	0.546	23.047	2.243
Gumminess (N)	18.384	0.660	46.982	2.708
Firmness (N/mm)	0.868	0.052	2.258	0.129
Absolute energy (J)	0.1187	0.019	0.333	0.026
Young's modulus (E)	3.897	0.219	5.012	1.146
Poisson index	0.329	0.575	0.165	0.139

According to Seerangurayar et al., (2019), the hardness is the most important attribute among all the texture attributes; it is relative to chewing strength. This force is due to the presence and concentration of fibers in fruits and vegetables. For certain varieties of dates, these authors found hardness values varying from 1.46±0.30 to 67.44±22.09 N and suggested that the softer fruits are of higher quality. Therefore, drying causes a decrease in hardness which improves chewingness of the product.

A sharp decrease is recorded at the end of drying for hardness, elasticity, chewiness, gumminess appearance and firmness for both varieties. For Arbi variety, values ranged from 11,9 to 0.6 N, 21.71 N to 1.32 N; 20.96 to 1.29 N; 84.66 % to 50 %; 15.02 to 0.54, 18.38 to 0.66 and 0.86 to 0.052 N/mm were observed for brittleness, hardness 1, hardness 2, springness, chewiness, gumminess appearance and firmness, respectively. Following the same order, the values for Aghouat variety, varied from 51.2 to 0.914 N, 72.28 to 3.38 N, 54.55 to 3.23 N, 84.66 to 41.92%, 23.04 to 2.24, 46.98 to 2.70 and 2.25 to 0,129 N/mm (Figure 4).

Drying improves quality of dried products. Elasticity is a parameter related to the presence of gelling agents such as pectin. It expresses the elastic behavior of the product and the penetration force.

A fresh pepper has good elasticity which decreases during hot air drying. Cohesion (Cohesiveness) measures rate at which the material disintegrates under mechanical action. This parameter decreases at the start of drying then it increases at the end. This variation is due to the decrease in moisture content which alters the structure of the cell membrane during drying.

Chong et al. (2009), reported that the chewiness and springiness values of dried fruits such as apricot, fig, guava, kiwi, pear, persimmon, pineapple, mango, strawberry, cherry, and tomato ranging from 1.87 to 4.07 N and from 0.75 to 1.007, respectively. Products with springiness values within this range are of good quality.

Stickiness expresses the resulting work of the surface; it is the result of the combined effect of two forces: cohesive force/stickiness and viscosity force/viscoelasticity. According to Seerangurayar et al. (2019), this attribute may be related to the content of total sugars. It expresses the energy necessary for the chewability of solid products and contributes to the sticky behavior. The low values obtained after the drying process indicate that the juicy appearance affects the mouth feels cavities.

This energy is imported by the object in contact during the deformation of the sample (tooth, texturometer); it is stored by the sample in the form of elastic deformation energy (Luyten and Van Vliet, 2006). It decreases during the drying process. This explains why resistance to mastication decreases with the time the food remains in the mouth.

Nicoleti et al. (2005) claimed that drying has a very significant influence on the rheological properties of foods, especially Young's modulus and relaxation time. These parameters are influenced by drying temperature, air speed, and water activity as demonstrated in the present work. Young's modulus decreases from 5.012 to 1.146 and from 3.897 to 0.219 for both studied varieties Aghouat and Arbi, respectively.

According to Swackhomer and Bornhost (2019), texture parameters of food depend on intrinsic factors. Moreover, its geometry and test parameters have no effect on the texture. The intrinsic factors include: Young’s modulus, fracture stress, fracture toughness and critical stress intensity factor (Ross and Scanlon, 2004).

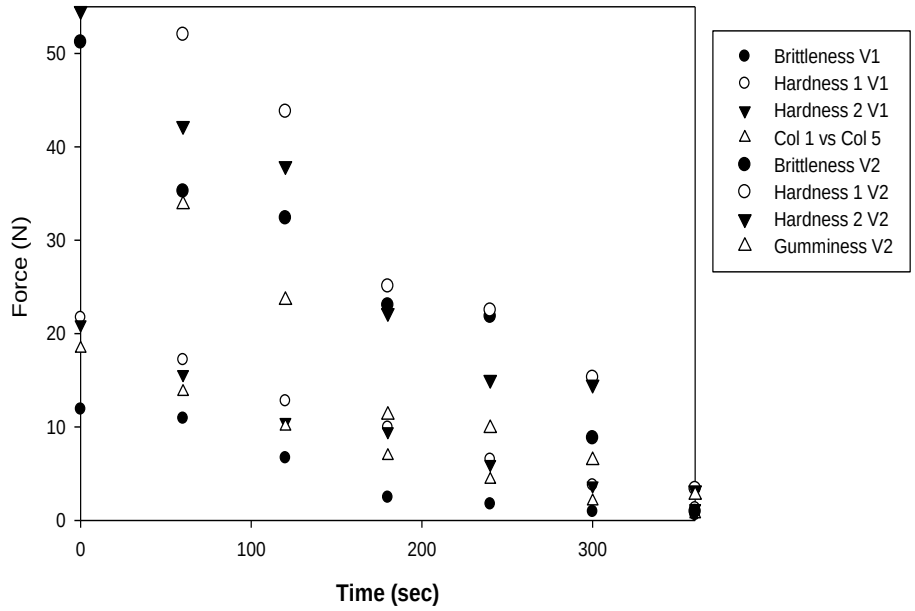


Figure 4. Evolution of forces of Brittleness, Hardness 1, Hardness 2 and Gumminess of two variety of red pepper at 50°C.

CONCLUSION

Red Pepper is good source of nutrients and bioactive compounds such as vitamins, carotenoids, phenolic acids and flavonoids, so we can consider it as a real functional food. The objective of this work is to explain the drying processes of two varieties of red pepper and their behaviors by modeling the hot air drying kinetics using four mathematical models from which three new models. Regarding four statistics parameters (R^2, X^2, RMSE, and EF), these models describe adequately the hot air drying of red pepper samples. The values of effective diffusivity, Arrhenius constant and activation energy for the hot air drying of red pepper samples are very important parameters to be used to evaluate the dry quality. Based on our results, drying can cause a strong degradation of natural pigments of red pepper and consequently can affect the color of products, for instance, when they are used as a condiment. Hot air drying decreases attractiveness of the texture profile.

Finally, to preserve the natural colors of dried red pepper, the product should be pretreated before the application of hot air dryings by blanching, osmotic dehydration, and others techniques.

Ethics approval and consent to participate: Not applicable, the manuscript does not report on or involve the use of any animal or human data or tissue.

Consent for publication: Not applicable, manuscript does not contain data from any individual person.

Availability of data and material: data include

Conflict of interest: The authors declare that they have no conflict of interest.

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Authors' contributions: S. Baississe: Data curation, Investigation, Methodology, Conceptualization, Validation, Writing – original draft. N. Boulelouah: Investigation, Validation, Supervision, Conceptualization. H. Bedjaoui: Conceptualization, Visualization supervision, review. M.S. Mehaoua: Conceptualization, L. Reguieg: Validation. Conceptualization, Validation. All authors read and approved the final manuscript."

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Symbols used

AE	activation energy	Kj/mol
a_v	Surface area	m^{-1}
a	color attribute	
b	color attribute	
BI	Browning index	
C	Chroma	
Cp	Specifique hot	kJ/kg°C
D	Diffusion coefficient	m^2/s
EF	efficiency	
H°	hue angle	°
K+	Thermal conductivity	w/m°C
l	half thickness of samples	m
M0	Initial moisture content	Kg water /kg dry matter
Me	Equilibrium moisture content	Kg water /kg dry matter
Mt	Moisture content at t	Kg water /kg dry matter
MR	Moisture content	Kg water /kg dry matter
R	constant perfect gas	kJ/mol
R^2	coefficient of determination	
RMSE	root mean square error	
TSS	soluble solids	g/100
T	Time	min
T	Temperature	°C or K
X^2	reduced ki-square	
YI	Yellowness index	
WI	Whitening index	
ρ_s	Density	Kg/m^3
ΔE	total color difference	
E	Young's modulus	
B	Brittleness	N

H	Hardeness	N
CO	Cohesiveness,	
S	Springiness	%
A	Adhesivenss	N.mm
Gu	Gumminess	N
Ch	Chewiness	
Fi	Firmness	N/mm
SHU	Scoville heat unite	SU