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(Research Article)

Influence of two drying methods (oven and solar dryer) in modeling the drying kinetics of *Ricinus communis* L. capsules

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Abstract

Castor beans are herbaceous perennials found in tropical and subtropical climates. They are very cold-hardy and belong to the *Euphorbiaceae* family. The aim of this work was to study the drying kinetics of castor oil capsules and the variations in thermal quantities that can occur during drying. Two drying methods were used: conduction drying in an oven at temperatures ranging from 50 °C, 60 °C and 70 °C, and radiation drying in a boat-type direct solar dryer at an average temperature of 49 °C. The results showed that the mass loss of castor oil capsules varied as a function of time and applied temperature, and was faster in the oven at 60 °C and 70 °C than in the solar dryer at an average temperature of 49.2±0.03 °C. It was found that the higher the drying temperature, the shorter the drying time. Seven (7) models were used for modeling. Modeling data based on analysis of R^2 ; χ^2 and RMSE showed that the best models for oven-drying castor oil capsules were those of Midili et al., for drying temperatures of 50 °C and 70 °C, and the logarithmic model for drying at 60 °C. For sun-drying, the best model was that proposed by Henderson and Pabis, modified.

Keywords: Comparison; Models; Temperature; Reduced water content; R^2

1. Introduction

The castor bean (*Ricinus communis L.*), is a shrub native to tropical Africa that is now cultivated in tropical and subtropical areas (America, in Africa as well as in Asia) [1]. Belonging to the *Euphorbiaceae* family, castor is the only species in the monotypic genus *Ricinus* and subtribe *Ricininae* [2]. The plant is cultivated for its oil-rich seed, used mainly in cosmetics [2]. Its fruit is a spherical capsule, varying in color from green to red, covered with soft spines and divided into three compartments, each containing a smooth, oil-rich seed [3]. Castor oil is rich in ricinoleic acid [4], which easily penetrates the epidermis to restore skin elasticity and gently nourish it. It is essential for fortifying and protecting hair, strengthening nails, making them shinier and preventing breakage ([2]; [5]). Castor oil can also be used for biofuel production [6]. Congo-Brazzaville has agricultural potential, with 10 million arable hectares. To date, only 4 % of this land is farmed, contributing only 5 % to GDP [7]. Castor cultivation is underdeveloped due to a lack of processing and preservation resources and techniques. However, to ensure the availability of seeds and combat post-harvest perishing, it is important to be familiar with seed drying techniques that best preserve the therapeutic properties of the seeds.

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Drying is defined as a unitary operation that reduces the water content by evaporation until a moisture content is reached that will enable the product to be preserved over a long period [8]. Eliminating water inhibits the action of microbial germs (yeasts, molds, bacteria) responsible for product degradation. There are several drying methods: forced convection drying, conduction drying and radiation drying. An example of radiation drying is solar drying. This is an alternative to other drying methods, as one of its main advantages is reduced energy consumption and, consequently, lower electricity costs [9]. The solar dryer is an ecological and economical alternative for food dehydration.

The aim of this study is to evaluate the influence of different drying methods on castor oil capsules. Through modeling, the study will determine the best model for drying castor oil capsules in forced convection ovens and forced convection solar dryers.

2. Material and methods

2.1. Materials (Sampling)

The castor bean capsules used were harvested from plots in Brazzaville precisely in the Mikalou district in borough 6 (Talangaï) in August 2024. The capsules were separated from the stems. Work was carried out on mature capsules.

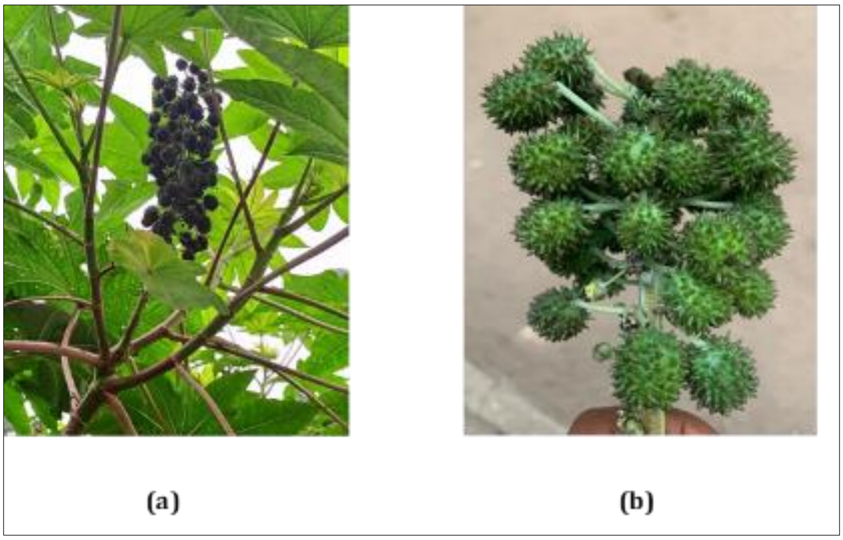

Figure 1 a) Castor plant ; b) Castor capsule

2.2. Methods

2.2.1. Drying kinetics

Drying kinetics were carried out using :

- The forced convection oven (BIOBASE BJPX-HGZ270 with temperatures ranging from 10 to 300 °C) at three (03) temperatures : 50 °C, 60 °C and 70 °C.
- The locally manufactured direct solar dryer with forced convection, boat type, at an average temperature of 49.2±0.03 °C).

Capsule mass loss was measured on an OHOUS/Explorer Pro precision balance (0 - 210 g) at intervals of 5 min for oven drying and 30 min for direct solar drying.

Continuous measurement of mass loss over time made it possible to determine the variation in water content in the dry base over time, and the variation in drying speed over time, according to the formulas below :

Variation in water content on a dry basis : $\mathbf{M} = \frac{m - MS}{MS}$ [10] (1).

- Où : M : water content on a dry basis (kg water/kg dry matter)

- m : product mass
- MS : dry matter mass (MS = total starting mass - starting water mass (calculated from the water content in the wet base).

$$\text{Drying speed} = \frac{dM}{dt} = -\frac{(M(t+\Delta t) - M(t))}{\Delta t} \quad (2)$$

Where

- dM/dt : drying rate in kg water/kg dry matter/sec
- M : water content in dry basis (kg water/kg dry matter)
- Δt : time difference in seconds

2.2.2. Mathematical modeling of drying kinetics

The drying kinetics data were used to model the drying process. Seven (7) models presented in Table 1 were used for the modeling.

Origin Pro 8 software was used for modeling. Reduced moisture content was calculated using the formula opposite :

$$\text{Reduced water content} : M^*_R = \frac{M}{M_{initial}} \ [11] \ (3)$$

Where

- M* : Reduced water content
- M : Water content on a dry basis (kg water/kg dry matter) at a given time t,
- $M_{initial}$: Initial water content of the product

Table 1 Empirical models used

Models	Equations
Lewis [12]	*MR = exp (-k t)*
Page [13]	*MR = exp(-k t)*
Henderson et al., [14]	*MR = a ×exp(-k t)*
Midilli – Kucuk [15]	$MR = a \times exp(-k\, t^n) + b \times t$
Henderson and Pabis modified [14]	*MR = a ×exp(- k t) + b×exp(- k' t) + cxexp(- k" t)*
Verma [16]	*MR = a ×exp(- k t) + (1 - a)×exp(- k' t)*
Logarithmique [17]	*MR = a×exp(-kt) + c*

Where: a, k, c and n are drying constants that depend on the air temperature and the nature of the product. b is an empirical constant [11].

The following parameters were determined for each model generated: the R^2 (coefficient for predicting the best equation describing the drying curves), the reduced ki-square (χ^2) and the root mean square error (RMSE).

$$R^2 = \frac{\sum_{i=1}^{n}\left(M_{Ri} - M_{Rpre,i}\right)^2}{\sqrt{\left[\sum_{i=1}^{n}\left(M_{Ri} - M_{Rpre,i}\right)^2\right]\cdot\left[\sum_{i=1}^{n}\left(M_{Ri} - M_{Rexp,i}\right)^2\right]}} \ [18] \ \text{.........}(4)$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(M_{Rexp}(i) - M_{Rpre}(i)\right)^2}{N-n} \ [19] \ \text{...............} \ (5)$$

$$RMSE = \sqrt{\frac{1}{N} \times \sum_{i=1}^{N}\left(M_{Rexp(i)} - M_{Rpre(i)}\right)^2} \ [20] \ \text{...........}(6)$$

With $M_{Rexp(i)}$ the ith experimental reduced water content, $M_{Rpre\ (i)}$ the ith predicted reduced water content, N the number of experimental points and np the number of constants in the model studied.

The best model is the one with the highest R^2, the lowest χ^2 and RMSE ([21] ; [22]).

2.2.2. Data analysis

Drying kinetics data were processed using Excel and OriginPro 8 software.

3. Results and discussion

3.1. Drying curves

Three curves were obtained by monitoring the mass loss of castor oil capsules : the mass versus time curve, the water content versus time curve and the velocity versus reduced water content curve.

The effects of temperature on the drying of castor oil capsules are illustrated in the curves shown in figure 2 below :

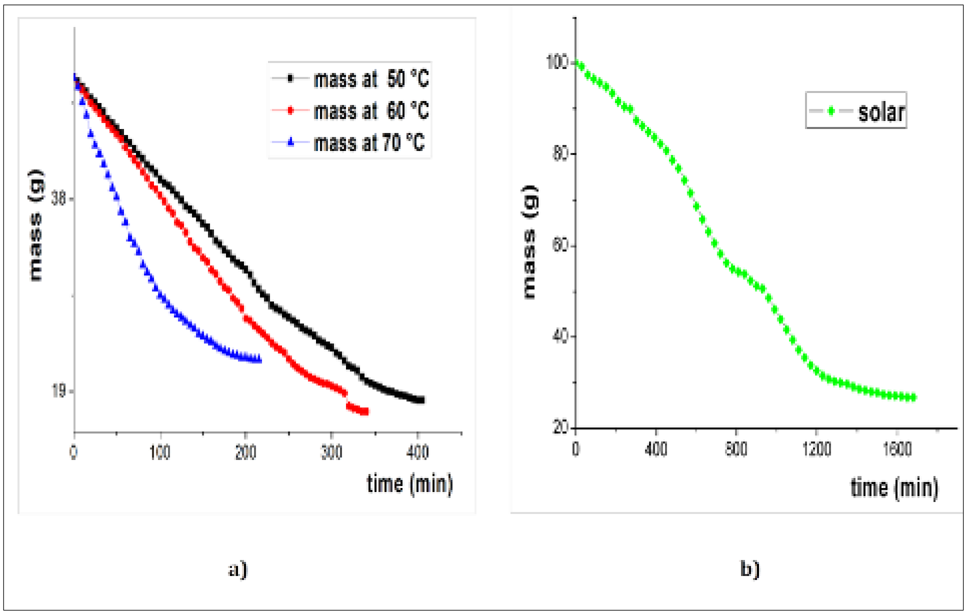

Figure 2 a) Variation in mass versus time during oven drying at the three temperatures; b) Variation in mass versus time in the solar dryer at an average temperature of 49.2±0.03 °C

Figure 2 shows that, during drying, mass loss is faster for oven drying, with 215 min or 3h35 min for the curve at 70 °C, 340 min or 5h40 min for that at 60 °C and 405 min or 6h45 min for 50 °C (figure 2.a). On the solar dryer, the total drying time was 1,680 min or 28 hours. This time was considerably longer than that achieved in the oven at all three temperatures. Castor oil capsules dried faster in the oven than in the solar dryer. This difference in drying time can be explained on the one hand by the lack of temperature stability in the solar dryer, and on the other by the lack of solar radiation received, which is a function of the weather and clouds [23]. Solar drying is inexpensive, but not as easy to manage as dehydration using sophisticated methods [24]. In an oven, the drying temperature can be kept stable throughout the drying process. In addition, solar dryer drying was carried out during the dry season, from May to September. During this period, there is less sunshine in Congo-Brazzaville.

The variation curve of reduced water content as a function of time is shown in figure 3 below:

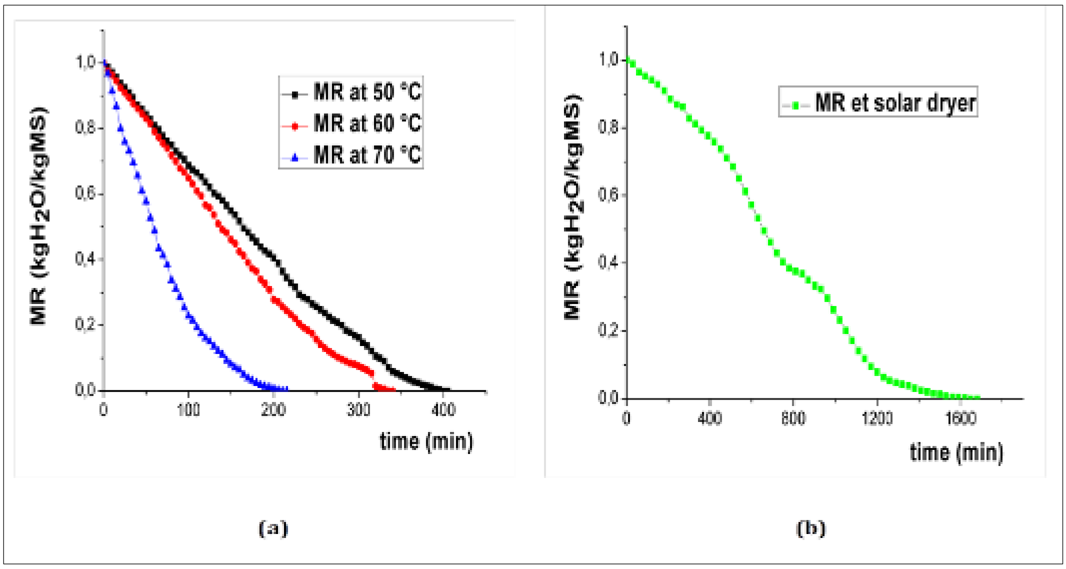

Figure 3 a) variation in reduced water content as a function of time during oven drying over the three temperatures ; b) variation in reduced water content as a function of time in the solar dryer at an average temperature of 49.2±0.03 °C

This curve shows that the variation in reduced water content follows a similar pattern to that of mass loss.

The velocity versus reduced water content curve is shown in figure 4 below :

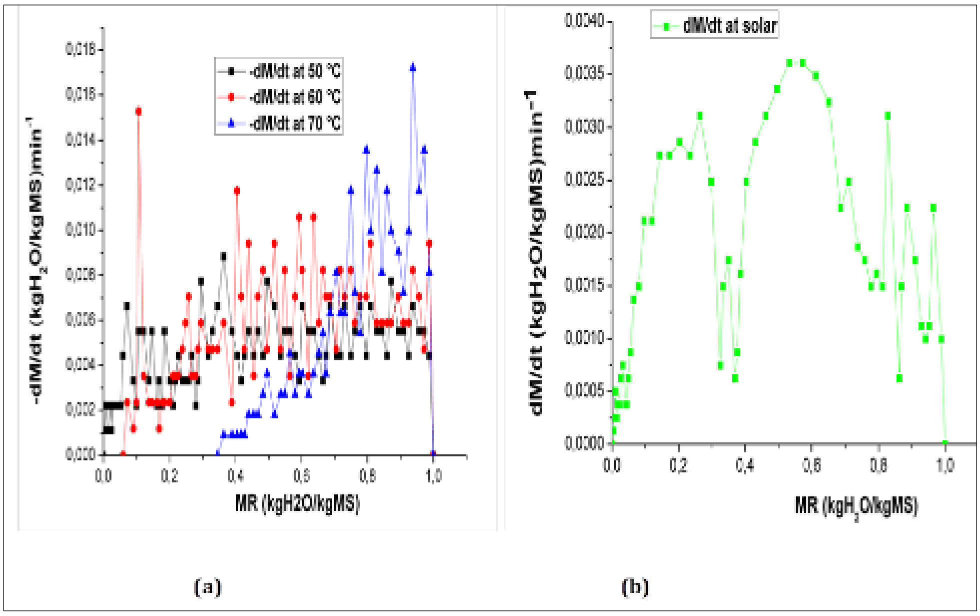

Figure 4 a) Velocity variation as a function of reduced water content in the oven over the three temperatures ; b) Velocity variation as a function of reduced water content in the solar dryer at an average temperature of 49.2±0.03 °C

The above curves show that the speed is zero at the start and increases as the product loses free water. This speed is variable simply because the amount of water released is not stable over the drying period, since it can vary from a point t_n to a point t_{n+1}. The fresher the product, the more porous its outer wall, allowing water molecules to pass through easily [21]. As drying progresses, the product shrinks and hardens, which can disrupt the internal migration of water molecules. The decrease in drying speed occurs when all the free water in the product has been eliminated, leaving only the bound water, which is strongly adsorbed and requires large amounts of energy to remove [21].

3.2. Modeling data

Table 2 Model parameters

Modèle	**K**	**K'**	**K''**	**a**	**b**	**c**	**n**	**R^2**	**RMSE**	**χ^2**	**T°C**
Lewis	0,00512	-	-	-	-	-	-	0,96775	0,07848	0,00616	50
Page	2,84186E-4	-	-	-	-	-	1,54229	0,99494	0,03151	9,92959E-4	
Henderson et al.,	0,00577	-	-	1,1221	-	-	-	0,97707	0,06674	0,00445	
Midilli et al	6,67582E-4	-	-	0,98157	-4,76012E-4	-	1,31316	0,9995	0,01001	1,00176E-4	
Henderson and Pabis modified	0,01017	0,01189	0,01026	3,98005	-6,44105	3,40341	-	0,99323	0,03736	0,0014	
Verna et al	0,00577	0,00577	-	0,12742	0,99468	-	-	0,97707	0,06759	0,00457	
Logarithmique	0,00188	-	-	1,99166	-	-0,96985	-	0,99904	0,01385	1,91921E-4	
Lewis	0,00597	-	-	-	-	-	-	0,96866	0,07721	0,00596	60
Page	3,41524E-4	-	-	-	-	-	1,55416	0,99679	0,02507	6,28568E-4	
Henderson et al.,	0,00674	-	-	1,12356	-	-	-	0,97845	0,06465	0,00418	
Midilli et al	-0,83583	-	-	0,41993	-0,00312	-	2,70316E-11	0,96632	0,08181	0,00669	
Henderson and Pabis modified	0,01936	0,01886	0,01837	876,68476	-1794,06819	918,40432	-	0,99839	0,01831	3,35168E-4	
Verna et al	0,01292	0,01312	-	69,23802	-68,29678	-	-	0,99544	0,03032	9,19215E-4	
Logarithmique	0,00236	-	-	1,91443	-	-0,88486	-	0,99852	0,01716	2,9443E-4	
Lewis	0,01387	-	-	-	-	-	-	0,98804	0,04761	0,00227	70
Page	0,00337	-	-	-	-	-	1,31792	0,99901	0,01432	2,05098E-4	
Henderson et al.,	0,01507	-	-	0,01507	-	-	-	0,99226	0,03879	0,0015	
Midilli et al	0,00397	-	-	0,98932	-1,64935E-4	-	1,26458	0,99961	0,00899	8,07392E-5	
Henderson and Pabis modified	0,03606	0,03468	0,03335	221,15242	-466,80221	246,66107	-	0,99946	0,01082	1,17098E-4	
Verna et al	0,01507	0,01507	-	0,68237	0,40887	-	-	0,99226	0,03975	0,00158	
Logarithmique	0,0111	-	-	1,17796	-	-0,13438	-	0,99847	0,01748	3,0552E-4	

Lewis	0,00128	-	-	-	-	-	-	0,9413	0,11593	0,01344	Séchoir solaire
Page	0,11593	-	-	-	-	-	1,95393	0,99679	0,02775	7,70096E-4	
Henderson et al.,	0,00157	-	-	1,22758	-	-	-	0,09161	0,09161	0,00839	
Midilli et al.,	-5,08027	-	-	-5,08027	-6,06646E-4	-	-0,01123	0,98506	0,06082	0,0037	
Henderson and Pabis modified	0,00167	-468,75699	0,00173	0,00167	-443,62971	-468,75699	-	0,99784	0,02364	5,58812E-4	
Verna et al	2,94387E-4	3,43842E-4	-	-14,42222	15,52564	-	-	0,99179	0,04516	0,00204	
Logarithmique	5,68013E-4	-	-	1,93217	-	-0,82941	-	0,99155	0,04538	0,00206	

With k = drying constant (s^{-1}) ; T° = temperature in °C

Analysis of Table 2 shows that:

3.2.1. Oven drying

For modeling at 50 °C

Values range from 0.96775 - 0.9995; 0.01001 - 0.07848 and 1.00176x10^{-4} - 0.00616 respectively for R^2, RMSE and χ^2. The best model is that of Midili et *al*., [15] with R2=0.9995; χ^2 =1.00176x10^{-4} ; RMSE= 0.01001).

Modeling at 60 °C

R^2, χ^2 and RMSE parameters range from 0.99544 - 0.99852; 2.9443x10^{-4} - 0.00669 and 0.01716 - 0.07721 respectively. The best model is the Logarithmic model [17] (R^2=0.99852; χ^2=2.9443x10^{-4} ; RMSE= 0.01716).

For modeling at 70 °C

R^2, χ^2 and RMSE values range from 0.98804 - 0.99961; 8.07392x10^{-5} - 0.00227 and 0.00899 - 0.04761 respectively. The best model is that of Midili et *al.,* [15] (R^2=0.99961; χ^2 =8.07392x10^{-5} ; RMSE= 0.00899).

Case of solar dryer drying at an average temperature of 49.2±0.03 °C:

The proposed parameters given by modeling the kinetics at the solar dryer range from 0.9413 - 0.99784; 5.58812x10^{-4} - 0.01344 and 0.11593 - 0.02364. The best model is the modified Henderson and Pabis model [14] (R^2=0.99784 ; χ^2=5.58812x10^{-4} ; RMSE= 0.11593).

Work carried out on modeling tomato drying kinetics showed results as, according to this study, the best models for modeling tomato drying kinetics were the models of Page and Midili et *al.,* [25]. Gampoula et *al.,* 2021 [21] found similar results for modeling the drying of both ends of Gamboma yam (*Dioscorea cayenensis*) oven-dried and solar-dried. For this study, the best models were those of Midili et *al.,* and Page. These studies showed that for the same matrix to be dried, the model could change when drying conditions changed.

Thus, modeling drying kinetics is important, as the data it provides can be used in the design of dryers adapted to product drying [26].

Simulations of the best models are shown in Figure 5 below :

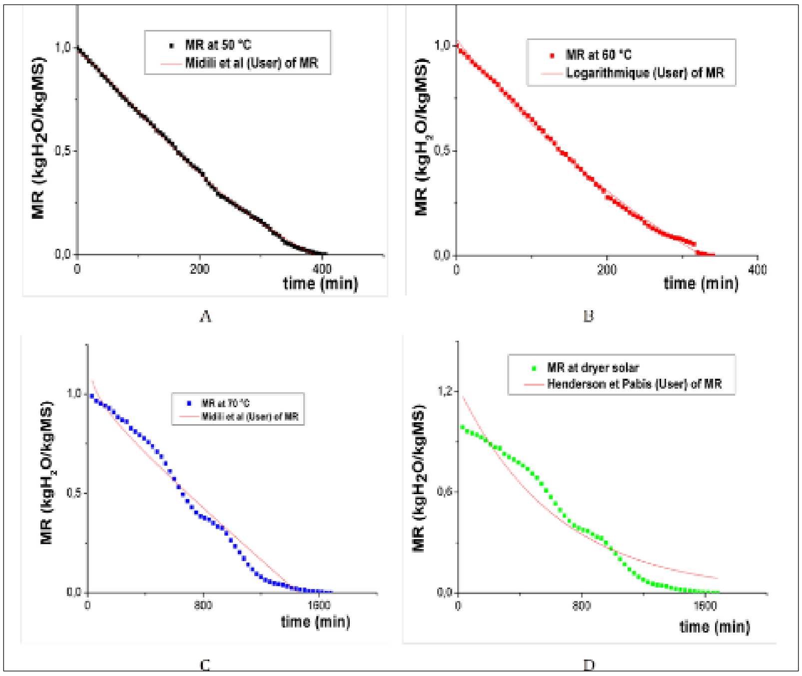

Figure 5 a) Modeling of oven drying at 50 °C; b) Modeling of oven drying at 60 °C; c) Modeling of oven drying at 70 °C and d) Modeling of solar dryer drying at an average temperature of 49.2±0.03 °C

4. Conclusion

The aim of this study was to investigate the influence of two drying methods (oven and solar dryer) in modeling the drying kinetics of *Ricinus communis* L. capsules. Data analysis showed that oven drying was faster than solar drying. Drying time decreases with increasing temperature. The best models to represent the modeling of castor bean capsules are those proposed by Henderson and Pabis, modified for the case of solar drying using the direct solar dryer, and those of Midili et *al.,* and logarithmic for oven drying over the three temperatures (50, 60 and 70 °C).

Drying modeling is important because it enables drying mechanisms to be predicted and controlled efficiently in certain fields such as food, pharmaceuticals and chemicals. This helps to improve drying conditions and reduce energy bills, but also to ensure the quality of finished products and reduce the risk of contamination or deterioration.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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