International Journal of Engineering Sciences & Research Technology

(A Peer Reviewed Online Journal)
Impact Factor: 5.164

IJESRT

RESEARCHERID
THOMSON REUTERS

[Daouda *et al.*, 11(3): March, 2022]
IC™ Value: 3.00

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

COMPARTMENTAL MODELING AND DYNAMIC SIMULATION OF GINGER DRYING

Karidioula Daouda[*1], Kouakou Yao Urbain[1], Manouan W. Max Robin[1], Assidjo Nogbou Emmanuel[2] & Trokourey Albert[3]

[*1]UFR Sciences et Technologies, Laboratoire de chimie, Université de Man, BP 20 Man, Côte d'ivoire

[2] UMRI Sciences des Procédés Alimentaires Chimiques et Environnementaux, Institut National Polytechnique Félix Houphouët-Boigny (INP-HB), BP 1313 Yamoussoukro, Côte d'Ivoire

[3]Laboratoire de chimie physique, UFR SSMT, Université Félix Houphouët Boigny, 22 BP 582 Abidjan 22, Côte d'Ivoire

DOI: 10.29121/ijesrt.v11.i3.2022.2

ABSTRACT

Ginger is one of the most important spices in the world due to its medicinal properties. Introduced in Côte d'Ivoire since the 1960s, ginger is an industry with a future that is just as important as certain perennial crops. In order to avoid post-harvest losses and to ensure the availability of the product throughout the year, it is necessary to carry out in-depth studies on the techniques of conservation and stabilization of ginger: in particular drying. A compartmentalized modeling of ginger was carried out in order to simulate the phenomenon of drying by entrainment and to predict it.

The mass and heat transfer coefficients were fitted using curves of experimental drying kinetics at different temperature conditions (60 ºC , 80 ºC, 100 ºC et 120 ºC). A constancy of the value of these coefficients was observed for the different drying air temperatures.

The dynamics of an experimental drying is correctly predicted by the model with coefficients of determination (R^2) between the experimental and simulated values of the parameters studied greater than 0.85.

KEYWORDS: Drying, Modeling, Simulation, Ginger, compartment, water content, temperature.

1. INTRODUCTION

In many tropical areas, potential sources of food exist, but are poorly exploited due to a lack of means of conservation. In sub-Saharan Africa, the cultivation of products such as ginger occupies an important place in the production of food crops. Post-harvest losses are considerable. They amount to more than 25% for certain products and are caused by the method of conservation [1].

Ginger (Zingiber officinale Rosc.) is one of the most important spices in the world. It is of major economic importance throughout the world [2]; because it generates resources for producers. It is a perennial annual herb thanks to its fleshy, elongated rhizome formed of several tuberous and gnarled branches.

Ginger is a spice of great importance given its medicinal properties. This species contains many compounds such as gingeroles, gingerdioles and gingerdiones [3]. These compounds possess high antioxidant activity [4].
In Chinese medicine, ginger is traditionally used to treat stomach and indigestion problems, diarrhea, nausea [5], rheumatism, nerve diseases, toothache, asthma, constipation, diabetes, etc. [6]. The plant therefore represents a plant of major interest for the pharmacopoeia.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Introduced in Côte d'Ivoire since the 1960s, ginger is an industry with a future that is just as important as certain perennial crops.

An economically profitable sector and provider of jobs, Côte d'Ivoire unfortunately does not have reliable data on the ginger production chain.

The state of Côte d'Ivoire through the Ministry of Agriculture and Rural Development, in collaboration with the Interprofessional Fund for Agricultural Research and Advice (FIRCA) intends to organize and develop this sector; through university research on varieties, processing and conservation structures with the aim of a total revival.

The general objective of this study is to control the behavior of ginger during drying in order to optimize the drying process.

More specifically, it involves modeling and then simulating the phenomenon of drying by entrainment of ginger. In this work we will use the compartmentalized approach described by Courtois [7]. This approach is attractive because it conveniently represents the phenomena involved in the drying process with minimal parametrization..

2. MATERIALS AND METHODS

2.1 Approach used

An approach to modeling a drying process for a given product first involves modeling this process from a sensible heat exchange point of view. Then in a second step from a latent heat exchange point of view by integrating knowledge of the product. This knowledge can be seen either in terms of drying kinetics if global monitoring of the water content and temperature of the product is sufficient to predict its final quality, or in terms of complete modeling of internal physical processes if this quality forecast final product requires the knowledge and description of events taking place in the product during drying.

This modeling makes it possible to define the optimal drying conditions in view of the desired quality of the product. It also makes it possible to establish the energy performance of the process studied with regard to the quantity of water to be evacuated and thus to optimize the energy consumption of the process while respecting the desired quality of the product.

Several authors have established different models allowing the monitoring of the water content of the product and of the air, then of the temperature of the product. In our study we adopted the principle of the compartmentalized model described among others by F. courtois and collaborators [7] which is a typical example of a drying process by entrainment.

2.2 Establishment of the model

The modeling of the exchanges of matter was based on the gradient of the intra-ginger humidity rate because it is this which is responsible for the inertia observed during the response to a sudden variation in air temperature, for example. [8].

On the other hand, it is considered that the thermal gradient between the center and the surface of the product becomes negligible in a few minutes ([9-10], [7]). Then we subdivided the ginger into three concentric compartments for material exchanges and a uniform compartment for heat exchanges [11] (Figure 1).

The exchanges of matter inside the product are based on the diffusive principle, only compartment 3 is concerned by vaporization because the exchanges of water with air take place at the product-air interface (compartment 3).

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

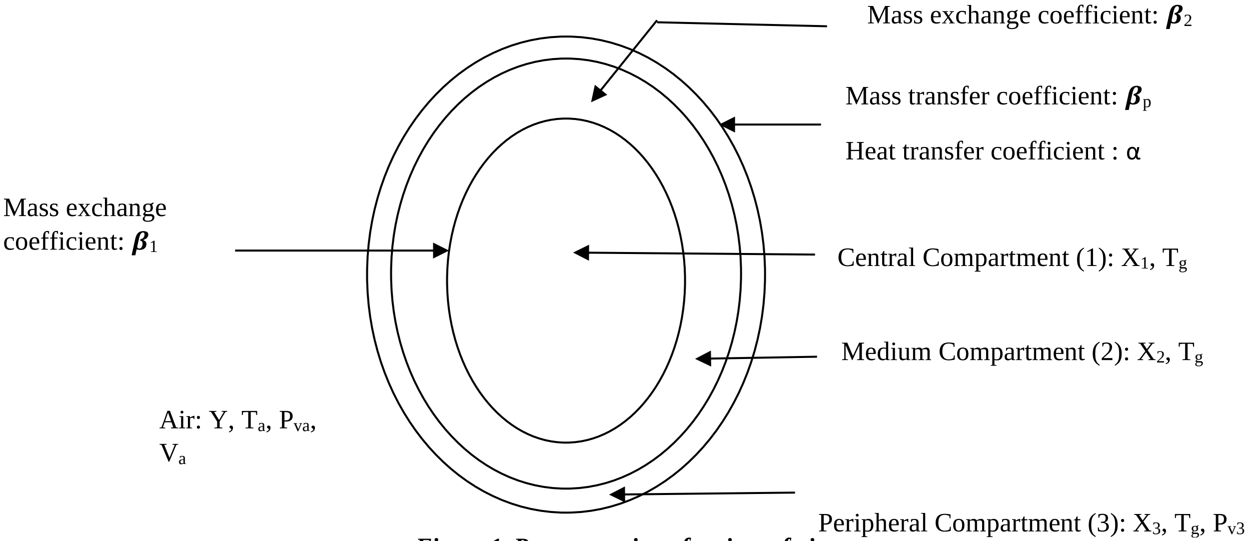

Figure 1. Representation of a piece of ginger

The only geometric assumption relates to the proportions of each compartment in relation to the entire piece: compartment 3 is arbitrarily set at 10% of the total volume, 40% for compartment 2 and 50% for compartment 1.
$\boldsymbol{\beta}_1$: Material exchange coefficient between the compartments 1 and 2 ($Kg.s^{-1}$);
$\boldsymbol{\beta}_2$: Material exchange coefficient between the compartments 2 and 3 ($Kg.s^{-1}$);
T_g : Ginger Temperature (°C) ;
T_a : Air Temperature (°C);
P_{va}: Pressure of air vapor (Pa);
P_{v3}: Pressure of compartment 3 vapor (Pa);
V_a : Air velocity (m/s) ;
X_1, X_2, X_3 : the water contents of the compartments 1, 2,3 (kg $_{water}$/kg $_{dry\ matter}$);
Y : air absolute humidity (kg water/kg dry air).
Considering the air-ginger transfers, we have the following flux densities:

- Exterior of Ginger (compartment 3)

$\boldsymbol{\varphi}_m = \boldsymbol{\beta}_p.(P_{v3} - P_{va})$ (1) with $P_{v3} = a_{w,s} .P_{vsat}$ (2)
$\boldsymbol{\varphi}_q = \alpha. (T_g - T_a)$ (3)
$\boldsymbol{\varphi}_m$ and $\boldsymbol{\varphi}_q$ are respectively the mass ($kg.m^{-2}.s^{-1}$) and heat ($W.m^{-2}$) flux densities between air and ginger.

- Inside the ginger, by analogy we pose, for the water flows between the internal compartments [11]:

$D_{12} = \boldsymbol{\beta}_1.(X_1 - X_2)$ (4) ;
$D_{23} = \boldsymbol{\beta}_2.(X_2 - X_3)$ (5).
D_{12} : Transition water flow between compartments 1 et 2 ;
D_{23} : Transition water flow between compartments 2 et 3.
The accumulation of water in a compartment is defined as follows[7]:
$ACC_i = D_{i-1} - D_{i+1}$ (6)
With :
ACC_i : Accumulation of water in the compartment i ;
D_{i-1}: Water flow coming from the compartment i-1 ;
D_{i+1} : Water flow coming from the compartment i+1.
Thus for compartments 1, 2 and 3 we can write:

$$\frac{d(\rho_g.V_g.\tau_1.X_1)}{dt} = -D_{12} = \beta_1(X_2 - X_1) \quad (7)$$
$$\frac{d(\rho_g.V_g.\tau_2.X_2)}{dt} = D_{12} - D_{23} = \beta_1(X_1 - X_2) + \beta_2(X_3 - X_2) \quad (8)$$
$$\frac{d(\rho_g.V_g.\tau_3.X_3)}{dt} = D_{23} - A_g.\varphi_m = \beta_2(X_2 - X_3) + A_g.\beta_p.(P_{Va} - P_{V3}) \quad (9)$$

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

The heat balance for ginger is as follows:

$$\frac{d(\rho_g.V_g.(C_{pg}+X.C_{pw}).T_g)}{dt} = -A_g.\varphi_q - A_g.\varphi_m.L_v \qquad (10)$$

Where,
ρ_g: Density of ginger (Kg.m^{-3}) ;
V_g : Volume of ginger (m^3) ;
τ_1, τ_2, τ_3 : Compartment 1,2 and 3 volume ratios to total volume (-);
C_{pg} : Specific heat at constant pressure of ginger (J.Kg^{-1}.°C^{-1}) ;
C_{pw} : Specific heat at constant pressure of water (J.Kg^{-1}.°C^{-1}) ;
X : Moisture content (kg $_{water}$/kg $_{dry\ matter}$) : $X = \tau_1.X + \tau_2.X + \tau_3.X$ (11)
A_g : Ginger surface area (m^2) ;
L_v : Latent heat of vaporization (J.Kg^{-1}).

The rewriting of equations 7, 8, 9, 10 and 11 allows us to obtain the system of differential equations below allowing us to translate the phenomenon of drying

$$\begin{cases} \frac{dX_1}{dt} = \frac{\beta_1}{\rho_g.V_g.\tau_1}(X_2 - X_1) & (12) \\ \frac{dX_2}{dt} = \frac{\beta_1}{\rho_g.V_g.\tau_2}(X_1 - X_2) + \frac{\beta_2}{\rho_g.V_g.\tau_2}(X_3 - X_2) & (13) \\ \frac{dX_3}{dt} = \frac{\beta_2}{\rho_g.V_g.\tau_3}(X_2 - X_3) + \frac{\beta_p.a}{\rho_g.\tau_3}(P_{va} - P_{v3}) & (14) \\ \frac{dT_g}{dt} = \frac{\alpha.a(T_a-T_g)+\beta_p.a(P_{va}-P_{v3}).L_v}{\rho_g.(C_{pg}+X.C_{pw})} & (15) \\ X = X_1 + X_2 + X_3 & (16) \end{cases}$$

With: $a = \frac{A_g}{V_g}$ (17)

Given the complexity and difficulty of determining the vapor pressures of air (P_{va}) and compartment 3 (P_{v3}) ; we used the approximation described by Lemaire and collaborators [12]. They estimate that the expression; $\beta_p(P_{va} - P_{v3}) = \beta_p(X_3 - X_{eq}) = \frac{\beta_3}{a}(X_3 - X_{eq})$ where $\beta_3 = \beta_p.a$ and X_{eq} is the moisture content at equilibrium (kg $_{water}$/kg $_{dry\ matter}$). Equations (14) and (15) become:

$$\frac{dX_3}{dt} = \frac{\beta_2}{\rho_g.V_g.\tau_3}(X_2 - X_3) + \frac{\beta_3}{\rho_g.\tau_3}(X_3 - X_{eq}) \qquad (18)$$

$$\frac{dT_g}{dt} = \frac{\alpha.a(T_a-T_g)+\beta_3(X_3-X_{eq}).L_v}{\rho_g.(C_{pg}+X.C_{pw})} \qquad (19)$$

The system of differential equations will be solved under Matlab software through a well-adapted program. The coefficients α , β_1, β_2 and β_3 are fitted on the basis of our experimental data and will therefore be assumed constant only for constant temperatures [13].

Solving the system of equations will provide us with the unknowns (X_1, X_2, X_3, X and T_g) thus allowing us to simulate the drying of ginger.

In addition, the table below provides the main thermo-physical properties of ginger taken from the literature.

Table 1. Thermo-physical properties of ginger and water

Properties	Values	Units	
C_{pg}	42	J.Kg^{-1}.^{0}C^{-1}	Calorific Capacity of dry matter
C_{pv}	2030	J.Kg^{-1}.^{0}C^{-1}	Heat capacity of steam
C_{pw}	4210	J.Kg^{-1}.^{0}C^{-1}	Heat capacity of water
Lv	2357000	J.Kg^{-1}	Latent heat of vaporization
ρ_g	974	Kg.m^{-3}	Density of dry matter
a	300	m^2.m^{-3}	Surface/volume ratio

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

τ_1	0.5		Compartment 1 volume ratio
τ_2	0.4		Compartment 2 volume ratio
τ_3	0.1		Compartment 3 volume ratio

a. Preparation of ginger

The samples tested were obtained with products purchased in the markets of the city of Man. They were wiped, washed, drained and cut into slices in the form of parallelepipeds of average length $L_{average}$ = 2 to 3 cm, width $l_{average}$ = 0.8 to 1.2 cm and thick E_{thick} = 0.4 to 0. 6 cm.

2.3 Drying experiment

The experimental study consisted of drying ginger samples placed in small baskets (6 cm × 4 cm × 1.5 cm) made of plastic mesh inside an oven.

The sample and container assembly remains in the oven in a previously established atmosphere. A precision balance (± 0.01 g) is used to weigh the product samples at regular time intervals until constant masses are obtained. The water contents on a dry basis were obtained by the following formula:

$$X = \frac{m_e}{m_s} \quad (20) \qquad \text{with } m_e = m(t) - m_s \quad (21)$$

Where: m_e is the mass of water and *m(t)* the mass at time (t)

Once the mass of the product has been stabilized, the anhydrous mass (m_s) of the product is determined by placing the samples in a drying chamber at 105°C for 24h.

The drying operation was carried out at different temperatures which are: 60 ^{0}C, 80 ^{0}C, 100 ^{0}C and 120 ^{0}C. Thermometers were used to control the stability of the temperature in the oven and to monitor the temperature of the product.

The drying experiment for each temperature was repeated three (3) times.

3. RESULTS AND DISCUSSION

3.1 Adjustment of coefficients

Table 2 presents the values of α , β_1, β_2 and β_3 for the different drying air temperatures.

Table 2. Values of the fitted parameters (α, β_1, β_2 and β_3)

Temperature	α ($W.m^{-2}.^oC^{-1}$)	β_1 ($Kg.s^{-1}$)	β_2 ($Kg.s^{-1}$)	β_3 ($Kg.m^{-3}.Pa^{-1}.s^{-1}$)
60 °C	22	3.10^{-5}	2.10^{-5}	12
80 °C	22	3.10^{-5}	2.10^{-5}	12
100 °C	22	3.10^{-5}	2.10^{-5}	12
120 °C	22	3.10^{-5}	2.10^{-5}	12

The results of the adjustment show us that these different coefficients are not a function of the temperature; contrary to what one might expect as in the case of other products such as rice [13] and maize [14].
This constancy of the coefficients for ginger can certainly be explained by its fleshy character.

3.2 Evolution of moisture content

Figures (2, 3, 4 and 5) present the experimental and simulated curves of the evolution of the moisture content of ginger (X) over time for the different drying temperatures.

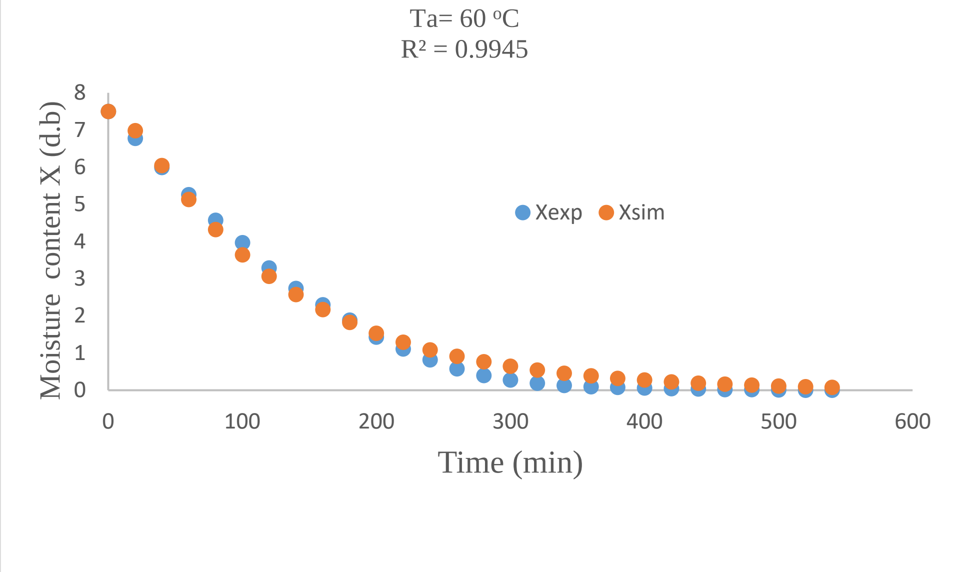

Figure 2. Variation curves of moisture content (X) with drying time for Ta = 60 ºC

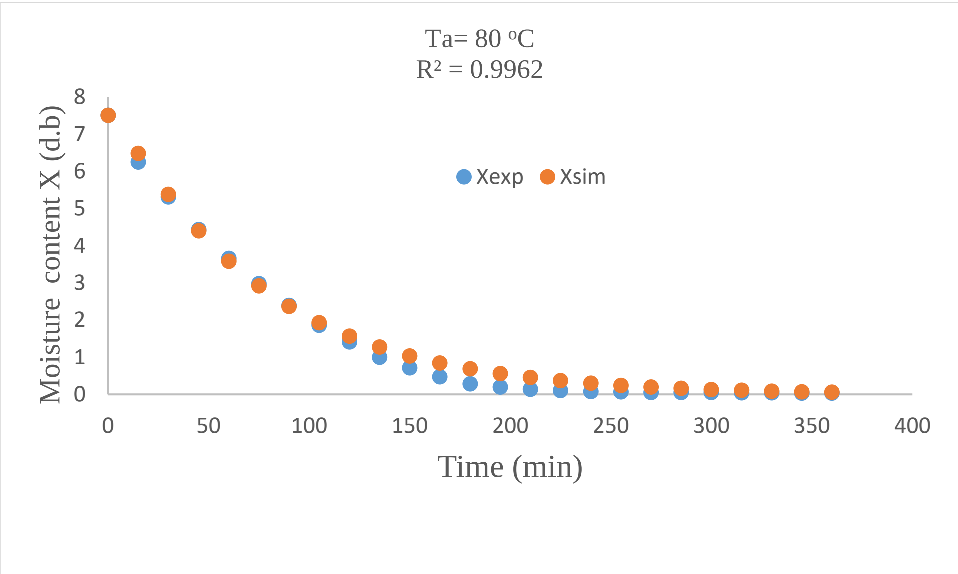

Figure 3.Variation curves of moisture content (X) with drying time for Ta = 80 ºC

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

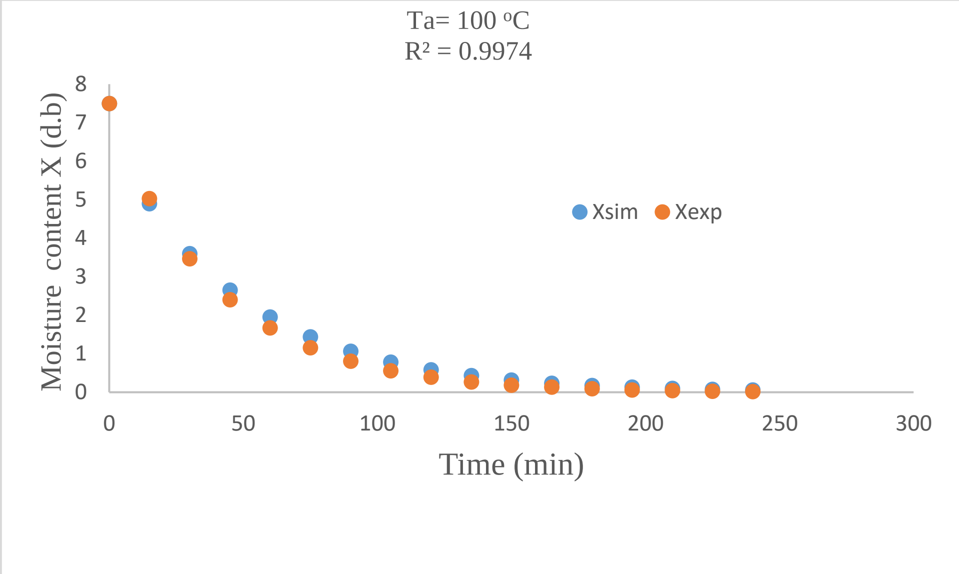

Figure 4. Variation curves of moisture content (X) with drying time for Ta = 100 ºC

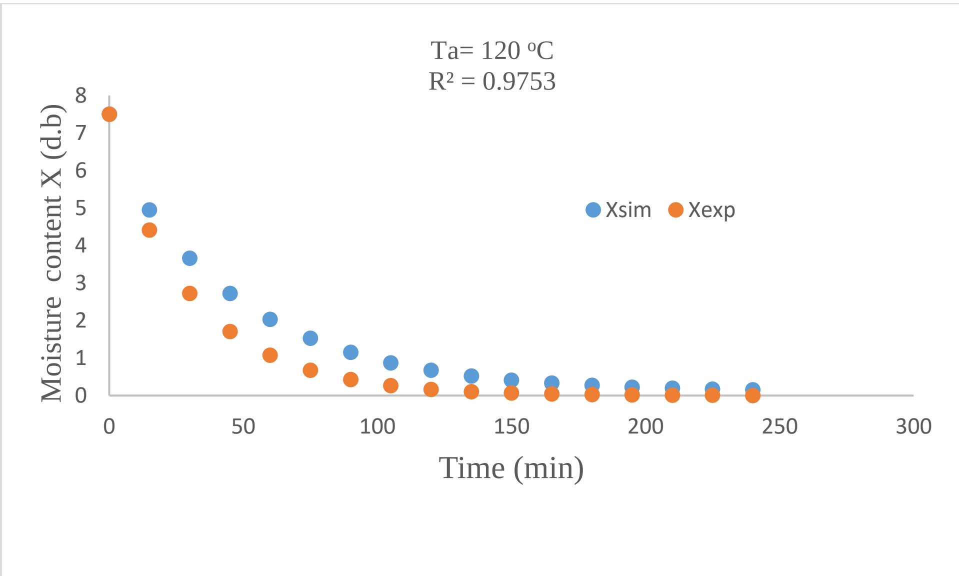

Figure 5. Variation curves of moisture content (X) with drying time for Ta = 120 ºC

On these different figures (2, 3, 4 and 5) one can observe a good agreement ($R^2 > 0.85$) between the experimental (Xexp) and simulated (Xsim) curves of the evolution of the moisture content (X) of ginger during drying for different temperatures.

3.3 Evolution of product temperature

Figures (6, 7, 8 and 9) show the experimental and simulated curves of the change in product temperature (Tp) over time for the different drying temperatures.

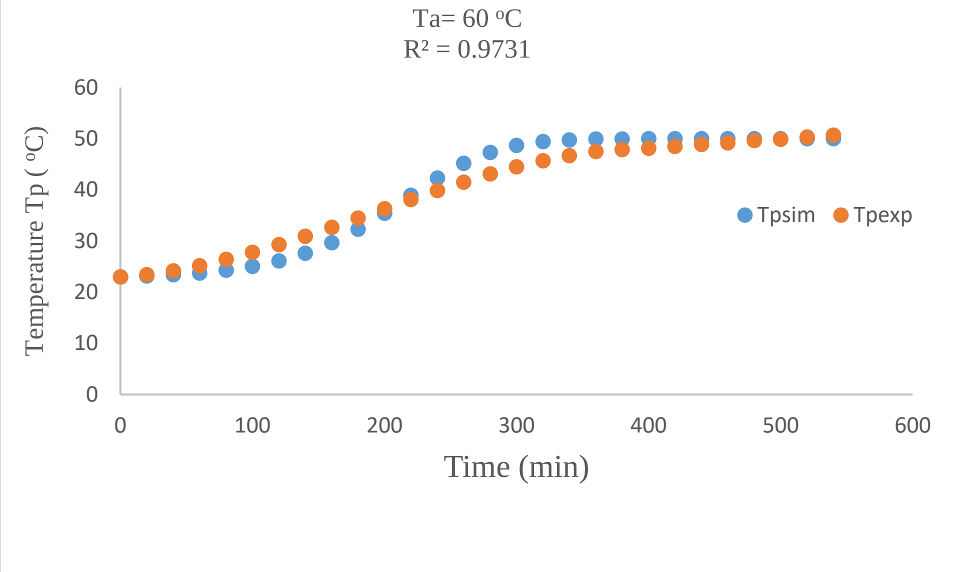

Figure 6. Variation curves of product temperature (Tp) with drying time for Ta = 60 °C

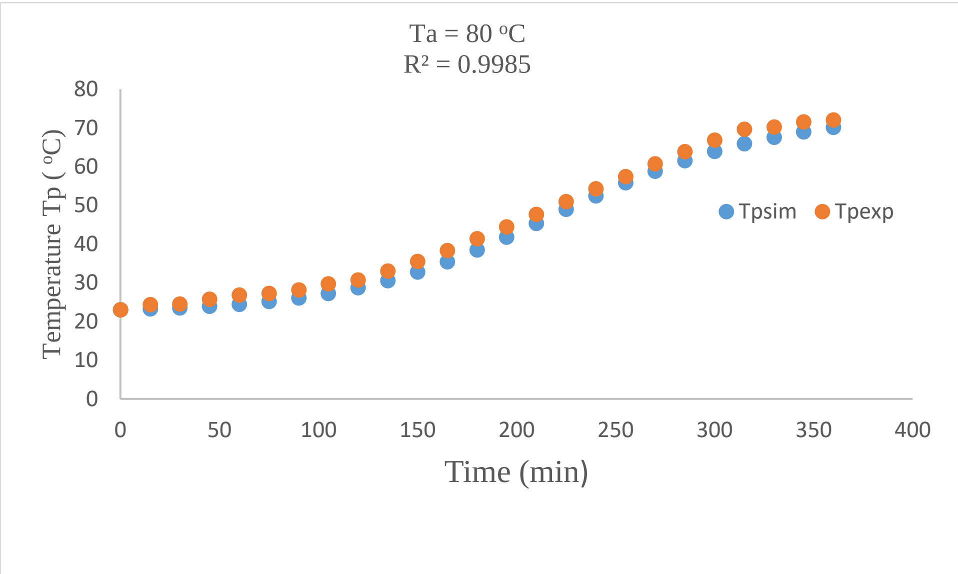

Figure 7. Variation curves of product temperature (Tp) with drying time for Ta = 80 °C

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

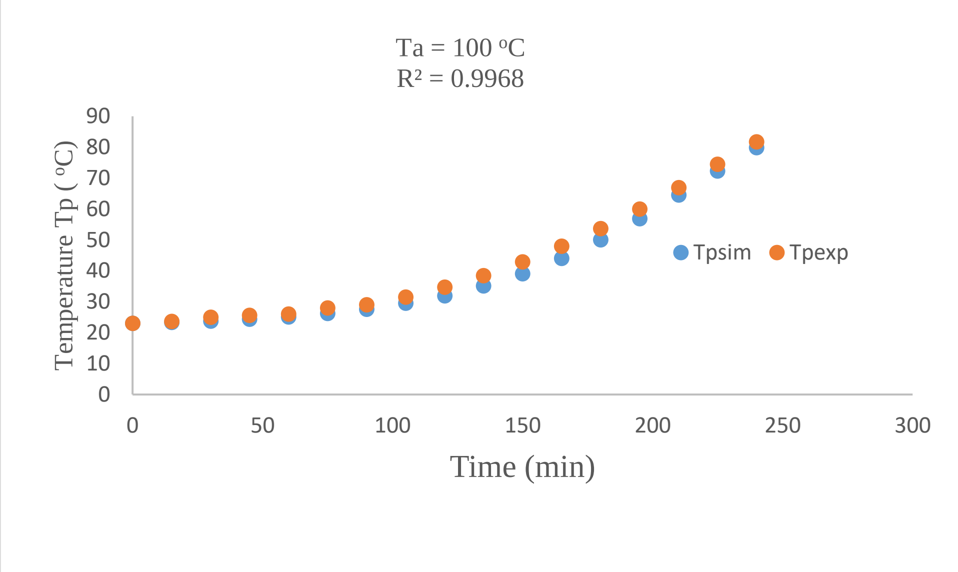

Figure 8. Variation curves of product temperature (Tp) with drying time for Ta = 100 °C

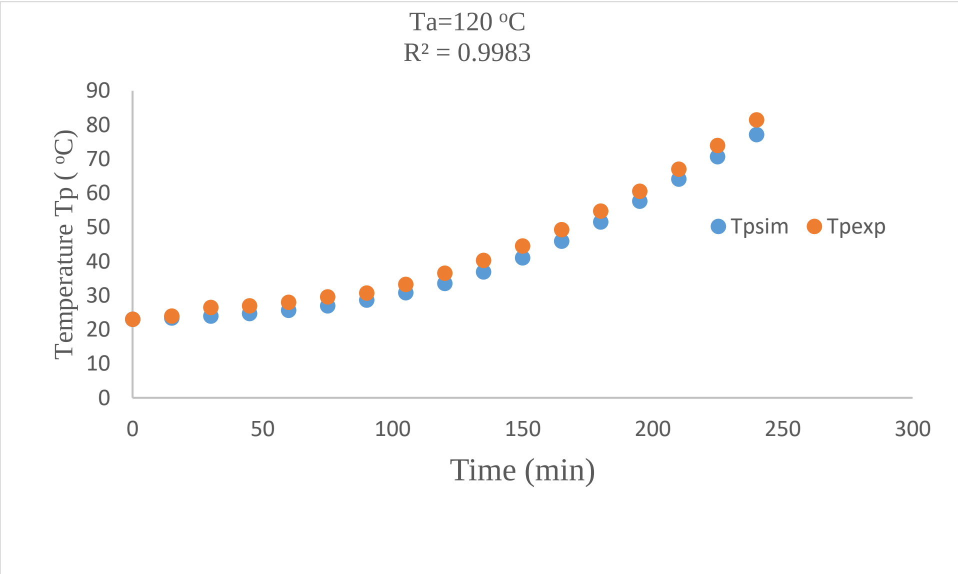

Figure 9: Variation curves of product temperature (Tp) with drying time for Ta = 120 °C

These figures (6, 7, 8 and 9) also show good agreement ($R^2 > 0.85$) between the experimental (Tpexp) and simulated (Tpsim) curves of the evolution of the temperature (Tp) of ginger during drying for the different temperatures.

4. CONCLUSION

A modeling and simulation of the phenomenon of drying by entrainment of ginger has been carried out.
Ginger was modeled as a three-chamber system of water; external heat and mass transfers are governed by Fick's and Fourier's laws.

The application of these laws on ginger, made it possible to define a system of 5 first order ordinary differential equations.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

The mass and heat transfer coefficients were fitted using curves of experimental drying kinetics at different temperature conditions (60 ºC , 80 ºC, 100 ºC et 120 ºC). A constancy of the value of these coefficients was observed for the different drying air temperatures.

The dynamics of an experimental drying is correctly predicted by the model with coefficients of determination (R^2) between the experimental and simulated values of the parameters studied greater than 0.85.

This simple compartmentalized model, with only 4 adjusted coefficients, seems to be a very good compromise between precision (especially in variable conditions) and speed of calculation, to simulate the dynamics of real ginger drying.

These data already represent a qualitative basis of considerable practical interest for the design and adjustment of industrial dryers for ginger.

This dynamic model could eventually be used to test control algorithms of experimental large-scale dryers for ginger.

REFERENCES

[1] C. Ahouanou, Y. Jannot, B. Lips, A. Lallemand, "Caractérisation et modélisation du séchage de trois produits tropicaux : manioc, gingembre et gombo" in Sciences des aliments, Vol. 20, pp. 4-5, 2000.
[2] S. Nayak, P. K. Naik, L. Qcharya, A. K. Mukherjee, P. C. Panda, P. Das, "Assessment of genetic diversity among 16 promising cultivars of ginger using cytological and molecular markers" in Z. Naturforsch, Vol. 60, pp. 485-492, 2005.
[3] N. A. S. Colleen, Y. A. Bailey-Shaw, S. L. Hibbert, C. Green, A. M. Smith, L. A. D. Williams, "Characterization of cultivars of Jamaican ginger Zingiber officinale Roscoe) by HPTLC and HPLC" in Food Chem., Vol. 131, no 4, pp. 1517-1522, 2012.
[4] G. Singh, I. P. S. Kapoor, P. Singh, C. S. Heluani, M. P. Lampasona, "Chemistry, antioxidant and antimicrobial investigations on essential oil and oleoresins of Zingiber officinale" in Food Chem. Toxicol., Vol. 46, pp. 3295–3302, 2008.
[5] R. Azam, A. Jabeen, T. Alam, S. Mushtaq, S. H. Mohmad. "Zanjabil (Zingiber officinalis): A Review. " in J. Pharm. Sci. Innov., Vol. 3, no 4, pp. 278-282,2014.
[6] Y. Soong, J. L. Rong, T. Y. Yu, Y. L. Jun, Y. C. Chung, " A new phenylalkanoid from the rhizomes of Zingiber officinale" in . Nat. Prod. Res., Vol. 26, pp. 1318-1322, 2011.
[7] F. Courtois, A. Lebert, A. Duquenoy, J. C. Lasseran, J.J. Bimbenet, "Modelling of Drying to Improve Processing Quality of Maize" in Drying Technology, Vol. 9, no 4, pp. 927-945, 1991.
[8] J. C. Laguerre, A. Lebert, G. Trystram, J. J. Bimbenet, "Dynamique du Séchage, Modélisation du Comportement de Produits Agro-Alimentaires" in Proc. 4ème Colloque Université-Industrie CEE CFE, Marseille, 1989.
[9] J. C. Lasseran," Evolution de la température au centre d'un grain pendant son séchage, compte-rendu technique, action ACTA-MRT (séchage du maïs) " in ITCF, Boigneville, France, 1989.
[10] M. Abid, H. Gibert, C. Laguerie, "Analyse expérimentale et théorique des mécanismes de transferts de matière et de chaleur au cours du séchage d'un grain de maïs dans un lit fluidisé" in Entropie N°139, pp. 3-12. 1988.
[11] K. Toyoda, "Study on intermittent drying of rough rice in a recirculation dryer" in sixth International Drying Symposium, Versailles, France, pp. 171-178, 1988.
[12] R. Lemaire, F. Courtois, G. Trystram, "Application of identifiability test to drying models", in Communication presented at COST-945 Copernicus CIPA CT94-0120 Workshop on Food Quality Modelling, Leuven, Belgium, 1997.
[13] F. Courtois, A. M. Archila, C. Bonazzi, J. M. Meot, G. Trustramg, "Modelling and control of a mixed-Flow rice dryer with emphasis on breakay quality" in Journal of Food Engineering, Vol. 49, no 4., 2001, pp. 303-308.
[14] F. Courtois, A Lebert, J. J. Bimbenet, J. C. Lasseran, " Dynamic modelling and simulation of industrial corn dryers" in Journal of computers and chemical engineering, vol. 17, suppl., 1993, pp. S209-S214.