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Research Article

Modelling the Influence of Hot Air on the Drying Kinetics of Turmeric Slices

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ABSTRACT

The influence of different drying temperatures and slice thickness on the drying kinetics of turmeric slices was studied. The best model to predict the drying kinetics was also determined. Turmeric slices (3 mm, 5 mm and 7 mm) were dried at 40, 50 and 60°C in a laboratory oven dryer. Four thin layer drying models (Newton, Henderson and Pabis, Logarithmic and Page) were fitted to the experimental data and selection was done based on model with highest correlation coefficient (R^2), and lowest reduced chi-square, sum square error (SSE) and root mean square error (RMSE). Drying time varied between 420 and 1020 min, 540 and 1080 min and 660-1140 min as the air temperature increased from 40 to 60°C. The effective moisture diffusivity coefficient increased with increasing drying temperature and was found to be between 1.35×10^{-10} m^2s^{-1}, and 5.00×10^{-10} m^2s^{-1}, 3.00×10^{-10} m^2s^{-1} and 10.91×10^{-10} m^2s^{-1} and 4.56×10^{-10} m^2s^{-1} and 13.00×10^{-10} m^2s^{-1} at 40, 50 and 60°C, respectively. The values obtained for the activation energy for moisture diffusion was found to be 56.809, 56.060 and 45.561 $kJmol^{-1}$ for 3, 5 and 7 mm, respectively. Page model was found to best describe the oven drying of turmeric slices.

Keywords: Turmeric slices; Phenolic pigment; Dehydration

INTRODUCTION

Turmeric (*Curcuma longa Linn*) belongs to the genus Curcuma and to the family of Zingiberaceae and consist of many species [1,2]. According to, turmeric is a shallow rooted and herbaceous plant which has a thick and fleshy rhizome. This rhizome according to some researchers is valued to contain a yellow coloured phenolic pigment also known as curcumin which is a natural colouring agent in food, cosmetics, dye and an active ingredient in the pharmaceutical industries [3] also reported that oleoresin which is the active ingredient in turmeric and turmeric oil are used for culinary, confectionary, and pharmaceutical purposes. Turmeric is an important spice which is acceptable both locally and globally as fresh, preserved, dried, powdered turmeric and in processed forms such as turmeric oil, turmeric oleoresin, turmeric candy, turmeric soft drinks, turmeric shreds, turmeric prickles, ginger chutney.

Nigeria is the fourth largest producer of turmeric with about 3% of the global annual production. This is due to the favourable soil and climatic conditions in the country. Turmeric is cultivated mostly on subsistent bases in about 19 of 36 states in Nigeria. Turmeric like ginger has shown a great potential in supporting livelihood and improving the health and economic level of many turmeric farmers and users in the main producing areas [4].

However, turmeric is highly perishable due to its high moisture content which must be kept below 14% db to prolong shelf life without further spoilage and reduced quality deterioration. There are other preservation technologies on an industrial scale to preserve food products such as canning, freezing and dehydration. Among these, drying (dehydration) is especially suited for developing countries with poorly established low-temperature and storage facilities. It is an effective and practical means of preservation to reduce postharvest losses and off-set the shortages in supply [5].

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Moreover, in order to overcome the current global energy crisis, an efficient drying process in terms of energy utilization is desirable. This according to can be achieved through understanding and appropriate modeling of the drying characteristics of food crops. Two major factors that affects moisture removal from any food products are the drying air conditions and material dimensions. During drying, heat and mass transfer phenomena occur concurrently which led to the development of many models used in describing the drying kinetics of food materials. Drying kinetics determination of various types of food is very important due to varied responses which different food and biological materials have. Several researchers have reported model that best fits experimental values of various food materials during drying process. Newton and Page equations are among the most commonly used model for thin-layer drying [6]. Due to the potential of turmeric in solving challenges that relates to food and pharmaceutical industries, There is need to study the drying characteristics of turmeric slices in other to understand the food material and also known the appropriate modeling of the drying process. Therefore, this study is carried out to (i) determine the drying characteristics of turmeric slices (3 mm, 5 mm and 7 mm) in a convective hot air oven at temperatures of 40, 50 and 60°C and (ii) to fit the experimental data obtained to some of the generally accepted thin-layer drying models so as to select the model that best describes the drying process.

MATERIALS AND METHODS

Materials

Freshly harvested turmeric rhizomes were procured from the medicinal plant unit of Bioresources Development Centre, National Biotechnology Development Agency, Ogbomoso, Oyo State. Selection was based on visual assessment of uniform colour and geometry. The tumeric was cut into slices of 3 mm, 5 mm and 7 mm thickness using knife and Vernier caliper after which the turmeric slices were dried at 40°C, 50°C and 60°C using oven (Gallenkamp BS oven, UK). Reading was taking at an interval of 60 min at each varied temperature until constant weight was obtained.

Drying kinetics

Moisture content: The initial moisture content of turmeric slices (3 mm, 5 mm and 7 mm) before drying was determined using Radway Mac50/NH moisture analyser at 120°C.

Effective moisture diffusivity, activation energy: The method reported in which Fick's second equation of diffusion was used to calculate the effective moisture diffusivity (Deff) putting into consideration the constant moisture diffusivity, infinite slab geometry, and a uniform initial moisture distribution.

RESULTS AND DISCUSSION

Determination of the drying curve, moisture ratio and drying rate curve

The plots of moisture content against time as shown in Figure 1 gave the drying curves for the turmeric slices at temperatures (40, 50 and 60°C) observed. The graphs followed the characteristic curve reported for different food materials. Initially, moisture evaporates rapidly in an exponential way and later decreased as drying time increases until equilibrium moisture content was reached. Equilibrium moisture content for the turmeric slices (3 mm, 5 mm and 7 mm) was achieved between 420-1020 min, 540-1080 min and 660-1140 min at drying temperatures range of 40 to 60°C, respectively. There was reduction in the moisture content as drying time increased. This may be due to the reduction in the available free water that was evaporated during the process of drying. The drying time also increases with turmeric slice thickness at a different temperature. This could be attributed to the fact that the distance the water molecules will travel from the core of a smaller slice thickness to the outer layer where evaporation takes place is shorter compared to larger slice thicknesses. This suggests that drying at smaller slice thickness helps in reducing the drying time which may reduce the cost of drying [10]. Reduction in the total drying time as temperature increases was also observed. This reduction according to, may be due to increase in vapour pressure available within the product as temperature increases which in turn resulted in rapid migration of moisture to the product surface. Reports on food materials such as; kurut, spinach leaves cocoyam and okro slices are similar to the results in this experiment. The variation of the experimental data moisture ratio with respect to drying time is shown in Figure 2. The drying of the turmeric slices exhibited a moisture desorption characteristic in which moisture is removed initially at constant and higher rate followed by falling rate that is slower in the latter stages. This characteristic behavior is the numerous forms in which water is present in food products according to Kingsly et al [11]. Moisture ratio, as drying continues, decreases non-linearly as drying time increases for all the thicknesses. This trend is supported by the reports of on tomatoes, pre-treated cassava chips, pre-treated cocoyam and minced meat, respectively. The drying rate versus drying time curve of the turmeric slices is shown in Figure 2. Higher drying rates were observed at higher drying temperature for each thickness. This reports resulted in more rapidly moisture evaporation and subsequently leads to reduction in moisture content thus, reducing the total drying time [12,13].

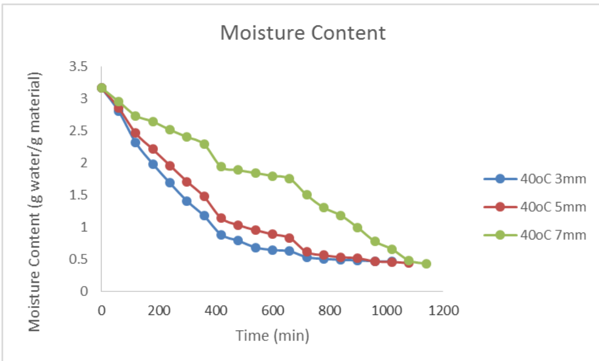

Figure 1: Graph of moisture content against drying time for turmeric slices.

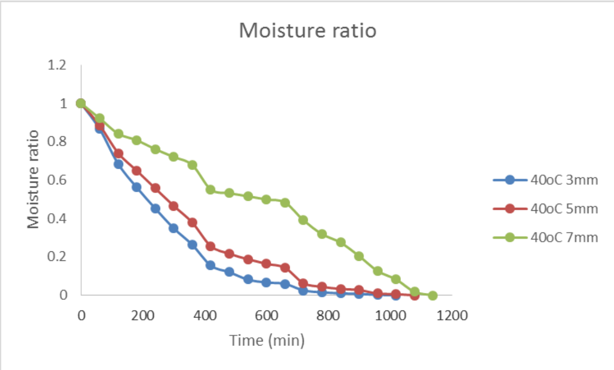

Figure 2: Graphs of moisture ratio against drying time for turmeric slices.

Effective moisture diffusivity (Deff) and activation energy

The value of Deff were obtained, from the slope of the linear graph of InMR versus time. Table 1 shows that the Deff for the turmeric slices increases with temperature and decreases as slice thickness increases. This was in line with the report on the drying kinetics of mango slices [14]. The trend was as a result of the water diffusion which increasingly move from the first phase of drying as drying temperature increases reported that moisture diffusion is a major factor that is responsible for moisture movement in the falling rate drying period where most of the drying took place. The slopes of the linear plots of InDeff versus temperature as shown in Figure 2 gave the activation energy, 56.809, 56.060 and 45.561 kJmol^{-1} at 3 mm, 5 mm and 7 mm, respectively. Activation energy which a function of temperature sensitivity, is needed to initiate the moisture diffusion within the slice. The result obtained shows that as turmeric slice thickness increases, the activation energy that is needed to drive the moisture out of the turmeric slices decreased.

Model name	Model
Newton	MR=exp (-kt)
Henderson and Pabis	MR=A exp (-kt)
Logarithmic	MR=a exp (-kt)+c
Page	MR=exp (-kt^n)

Table 1: Thin layer mathematical models used to describe turmeric slices drying.

Mathematical modelling of drying curves

The moisture ratio versus drying time obtained for the different slice samples were fitted by Newton, Handerson and Pabis, Logarithmic and Page models. The four models were evaluated based on the coefficient of determination (R^2), Chi-square (χ^2), sum square error (SSE) and root mean square error (RMSE). The best model to describe the drying behavior of the turmeric slices was selected based on the highest R^2 and lowest χ^2 SSE and RMSE values. The drying constants k and c and coefficients a and n values for the thin-layer drying models are shown in Table 2, while the statistical analysis results for the four models are also shown. R^2 values were found to be greater than 0.92 for all the models except for the one obtained at 7 mm when the temperature was 40°C. The page model was found to have the highest R^2 value compared to the other models. The implication is that page model gave a better correlation between the moisture ratio and drying time. The χ^2 values ranged between 0.000665- 0.003735 (3 mm), 0.000722-0.004881 (5 mm), 0.003628-0.008072 (7 mm); 0.000612-0.003039 (3 mm), 0.000733-0.004278 (5 mm), 0.003351-0.007282 (7 mm); 0.000199-0.00194 (3 mm), 0.000287-0.00271 (5 mm), 0.000836-0.003351 (7 mm) and 0.000071-0.000563 (3 mm), 0.000416-0.001049 (5 mm), 0.001229-0.004132 (7 mm) for Newton, Henderson and Pabis, Logarithmic and Page models respectively. The Page model was chosen to represent the thin layer hot-air drying of the turmeric slices as it gave the lowest values for chi-square.

	Effective moisture diffusivity (m^{2}s^{-1})		
	Temperature (°C)		
Slice thickness (mm)	40	50	60
3	1.35 × 10^{10}	3.00 × 10^{10}	4.56 × 10^{10}
5	2.72 × 10^{10}	6.28 × 10^{10}	9.00 × 10^{10}
7	5.00 × 10^{10}	10.91 × 10^{10}	13.00 × 10^{10}

Table 2: Effective moisture diffusivity (m^2/s) of the turmeric slices.

Page model was suitable in describing the drying characteristics of turmeric slices as it agrees with the experimental results based on the highest R^2 values and lowest χ^2 and RMSE. Similar results were reported in the literature for various food products [15]. Experimental and predicted values of the moisture ratio were compared with drying time as shown in Figure 2. Validation of the established model was made by comparing the experimental moisture ratio values with the predicted ones. There was good agreement between the experimental and predicted variables, which indicates that the Page model could be used satisfactorily to predict the thin layer hot-air drying of turmeric slices.

AGA is a very common hair disorder with a relevant impact on quality of life. Oral finasteride and topical minoxidil are the only two drugs approved for the treatment of AGA [16]. Both drugs, however, possess side effects and are effective in less than 50% of treated patients. PRP is considered an alternative therapeutic approach for AGA [17]. PRP is an autologous preparation of plasma with platelets that are capable of secreting growth factors and cytokines, which stimulate stem cells. The stimulatory factors in PRP, including fibrin, fibronectin and vitronectin, may be involved in hair follicle growth and development [18]. PRP contains a mixture of growth factors molecules such as PDGF, IGF and VEGF. However, the results of studies on the use of PRP in AGA treatment remain controversial [19]. PRP contains also TGF-β which could have a detrimental effect on hair growth [20], promoting the catagen phase and fibrotic processes. Rodrigues has shown that efficacy of PRP in AGA seems do not correlate with the amount of the most common growth factors present in the PRP preparation, suggesting that the efficacy could be, at least in part, ascribed to additional mechanisms of action [21]. In this trial we demonstrated that the addition of a lotion containing a mixture of 4 growth-factor like polypeptides, carried in nanosomes, and taurine significantly increase the clinical effect of PRP treatment in subjects with AGA. The complex of growth-factor like polypeptides, present in the tested lotion, contains copper-tripeptide, octapeptide 2, acetyl-decapeptide and oligopeptide 20. Copper tripeptide is able to increase the activity of FGF and VEGF and it also has a potent anti-oxidant and anti-inflammatory effect [22,23]. Octapeptide 2, known also as pro-hairin, can increase the hair growth rate, probably increasing the anagen phase, to reduce apoptosis and to increase keratinocyte proliferation. Oligopeptide 20 can increase the insulin-like growth factor (IGF-1) production [24]. IGF-1 produced by the mesenchymal cells, is an important growth factor in different biological systems: at the level of the hair follicle, it is produced by the dermal papilla and has the function of promoting the duration of the anagen. This lotion contains also taurine. This amino acid has several positive effects on hair bulb and hair growth [25]. These active components of the GFM-L are conveyed in nanosomes, which allow the rapid absorption and a deep release into the follicle. The nanosomes are small micelles within which are enclosed substances to be conducted at depths up to the follicular matrix and bulge, protecting them by the action of the endogenous protease during penetration [26]. Therefore, the composition and the formulation of this lotion (mixture of growth-factor like peptides in nanosomes and taurine) suggest a potential synergistic effect on hair growth with other therapeutic strategies like PRP treatment. The results of our study seem to confirm this hypothesis. At the moment is difficult to explain the mechanism of this additive clinical effect. The combined use of this lotion in subjects treated with PRP can amplify the growth hair stimulus but also counteract some negative actions on hair physiology of some components of PRP for example the TGF-β. Dissa et al [27] have demonstrated that taurine blocks the deleterious effect of TGF-β on human hair follicule. Some limitations should be taken in account in evaluating our results. First, this trial was not a double-blind study. To increase the internal validity of the trial results, we decided to adopt an assessor-blinded approach in evaluating the main clinical efficacy outcomes of the study (evolution of IGA score) [24,27]. Another limit of the present trial is the relatively small sample size (30 patients in total). However, taking in account previous trials, we have performed an accurate sample size calculation which justifies the number of subjects we have enrolled in the trial.

CONCLUSION

Based on the results obtained from this study, the following conclusions were made:

Turmeric slices at 3 mm had shorter drying times and higher drying rate compared to other slices. Drying curves of oven dried turmeric slices showed a falling rate-drying period only under the experimental conditions employed. Effective moisture diffusivity values of oven drying which ranged from 1.35×10^{-10} m^2/s to 13.00×10^{10} m^2/s are in the suitable range for similar products.

The highest R^2 value (0.999) and lowest value of χ^2 (7.1×10^{-5}), SSE (6.2×10^{-5}) and of RMSE (0.00788) for the thin layer oven drying process for turmeric slices was obtained from the Page model. Page model according to the results, best describe the drying characteristic of the turmeric slices compared to the other models (Newton, Henderson and Pabis and Logarithmic).

REFERENCES

1. Olajide OT, Akinlabi BH, Tijiani AA. Agriculture Resource and Economic growth in Nigeria. Eur Sci J. 2012; 8:103-115.
2. Nwaekpe J, Anyaegbulam H, Okoye BC, Asumugha GN. Promotion of Turmeric for the food/pharmaceutical industry in Nigeria. Am J Exp Ag. 2015;8:335-341.
3. Singletary K.Turmeric: An Overview of Potential Health Benefits. Nutrition Today. 2010;45:216-225.
4. Karim MR, Abedul H, Khairul A, Nurshad AS, Kazi A, Zahangir H, et al. Protective effects of the dietary supplementation of turmeric (Curcuma longa L.) on sodium arsenite induced biochemical perturbation in mice. Bangladesh Med Res Cou Bull. 2010; 36: 82-88.
5. Amadi POE, Adiele-Ezekiel C, Ibe MN, Nzeakor FC, et al. Turmeric Production Processing and Marketing for Sustainable Agricultural Development in Nigeria. J Comm Res. 2018; 2635-3318.
6. Amadi POE, Ibe MN, Kalu CI.Turmeric research in Nigeria: Challenge and Prospects for Economic Growth. Proceeding of the 51st Annual Conference of the Agricultural Society of Nigeria, Abuja. 2017; 19-21.
7. Amadi C, Olojede AO, Obasi M. Growth and yield of turmeric in a derived savanna agro-ecology of Nigeria. Int J Agri pol Res. 2015; 3:388-395.
8. Buch S, Pinto S, Aparnathi KD. Evaluation of efficacy of turmeric as a preservative in paneer. J Food Sci Tech. 2012; 51:3226-3234.
9. Kumar D and Kalita P. Reducing Postharvest Losses during Storage of Grain Crops to Strengthen Food Security in Developing Countries. Ann Plant Physiol. 2017; 6:8.
10. Afolabi TJ, Tunde-Akintunde TY, Adeyanju JA. Mathematical modeling of drying kinetics of untreated and pretreated cocoyam slices. J Food Sci Tech. 2015;52:2731-2740.
11. Kingsly RP, Goyal RK, Manikantan MR, Ilyas SM. Effects of pretreatments and drying air temperature on drying behaviour of peach slice. Int J Food Sci Tech. 2007;42:65-69.
12. Tunde-Akintunde TY, Afon AA. Modeling of hot-air drying of pretreated cassava chips. Agri Eng Int. 2010;12:34-41.
13. Aremu AK, Adedokun AJ, Abduganiyu OR. Effect of slice thickness and temperature on the drying kinetics of mango. Agri Eng J. 2013;15: 41-50.
14. Goyal RK, Kingsly ARP, Manikantan MR, Ilyas SM. Thin layer drying kinetics of raw mango slices. Bios Eng. 2006;95:43-49.
15. Pal US, Khan MK, Mohanty SN. Heat pump drying of green sweet pepper. Drying Tech. 2008;26:1584-1590.
16. Olajire AS, Tunde-Akintunde TY, Ogunlakin GO. Drying kinetics and moisture diffusivity study of okro slice. J Food Proc Tech. 2018;9: 751.
17. Vega-Gálvez A, Dagnino-Subiabre A, Terreros G, López J, Miranda M, Di Scala K. Mathematical modeling of convective air drying of

quinoa-supplemented feed for laboratory rats. Brazilian Archives of Bio and Tech. 2011;54:161-171.

18. Karabulut I, Adnan Hayaloglu A, Yildirim H. Thin-layer drying characteristics of kurut, a Turkish dried dairy by-product. Int J Food Sci Technol. 2007;42:1080-1086.
19. Doymaz I. Mathematical modelling of thin-layer drying of kiwifruit slice. J Food Proc Pres. 2009; 33:145-160.
20. Tunde-Akintunde TY, Afolabi TJ. Drying of chili pepper (*Capscium Frutscens*). J Food Pro Eng. 2010;33:649-660.
21. Doymaz I. Influence of pretreatment solution on the drying of sour cherry. J Food Eng. 2007;78:591-596.
22. Aksoy A, Karasu S, Akcicek A, Kayaca S. Effects of different drying methods on drying kinetics, microstructure, color, and the rehydration ratio of minced meat. Foods. 2019;8:216.
23. Lee JH, Kim HJ. Vacuum drying kinetics of Asian white radish (*Raphanussativus L.*) slices. LWT Food Sci Tech. 2009;42:180-186.
24. Doymaz I. Effect of citric acid and blanching pre-treatments on drying and rehydration of Amasya red apples. Food and Bioproduct Processing. 2010; 88:124-132.
25. Ojediran JO, Raji AO. Thin-layer drying characteristic of castor (*Ricinus Communis*) seed. J Food Proc Pres. 2011;35: 647- 655.
26. Kashaninejad, M, Tabil LG. Drying characteristics of purslane (*Portulaca oleraceae L.*). Drying Tech. 2004;22:2183-2200.
27. Dissa AO, Desmorieux H, Bathiebo J, Koulidiati J. Convective drying characteristics of Amelie mango (Mangifera indica L. cv. 'Amelie') with correction for shrinkage. J Food Engg. 2008;88:429-437.