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Thin layer drying characteristics of alligator pepper, ginger and turmeric

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Abstract: The delightful pungency, aromatic compounds and phytochemicals in some spices make them indispensable in local food systems and native medicine, hence, driving a robust market in many parts of the world. The understanding of their drying characteristics is very important for processing and adding value, and a thin layer drying study is a proven method for achieving this. In this study, changes in the moisture content, moisture ratio, drying rate and effective diffusivity of alligator peppers, ginger and turmeric were investigated at three drying temperatures 50, 60, and 70 °C following standard procedures. Five models were proposed to simulate the drying process. Non-linear regression was used to establish the coefficient of determination (R^2), sum of square error (SSE) and root mean square error (RMSE) for each model to determine the model of the best fit. The Page model gave the best fit for ginger while the logarithmic model was best fitted for alligator peppers and turmeric. The effective diffusivity ranged from 1.79–3.08 × 10^{-9}, 8.44–9.74 × 10^{-9}, and 4.06–6.49 × 10^{-9} $m^2 \cdot s^{-1}$ for alligator peppers, ginger and turmeric, respectively. The activation energy ranged from 16.5–22 $kJ \cdot mol^{-1} \cdot K^{-1}$ for the three spices. These findings promise improvement in the drying, processing and handling of spices, thereby boosting the obtainable income from the value chain.

Keywords: activation energy; effective moisture diffusivity; model fitting; moisture ratio

Spices are commonly used as seasonings, ingredients, and preservatives to improve the physical and nutritional values of food or as tenderisers to improve sensory and textural characteristics of food (Wohlmuth et al. 2005; Okunade et al. 2019). The delightful pungency and aromatic compounds in most spices make them indispensable in the preparation of some tasty delicacies. In addition to their use for worship in some socio-religious cultures in Africa and Asia, spices, such as cinnamon and negro peppers, have found great relevance in the cosmetic, perfumery and pharmaceutical industries (Park 2011). In African traditional medicine, cloves, garlic and ginger have been widely used as remedy for certain ailments (Peter and Babu 2012; Okunade et al. 2019). The chemical constituents of spices like peppermint and coriander make them suitable for their analgesic effect while cumin and celery have been reported as having anti-inflammatory properties (Peter and Babu 2012). Ajav and Ogunlade (2014) reported that the antioxidant properties in cloves and rosemary are very potent against numerous deadly diseases in human body systems.

The alligator pepper (*Aframomum melegueta*), also called guinea pepper or grain of paradise, is a common West African hot spice with a sharp aroma and pungency that makes it delightful in local and continental food systems (Umukoro and Ashorobi 2008).

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In addition to its use as an herbal remedy for certain diseases, the alligator pepper has been reported as being useful in treating male infertility associated disorders (Ajaiyeoba and Ekundayo 1999). In Nigeria and some sub-Saharan Africa countries, the alligator pepper is served with honey and kola nuts during naming and traditional marriage ceremonies. Adefegha et al. (2017) reported that powdered alligator pepper is administered orally to welcome newborn babies in the Eastern part of Nigeria. Ginger (*Zingiber officinale*) is another well traded tropical monocotyledon and herbaceous perennial rhizome. It is consumed fresh or dried and milled with other ingredients in confectionery, flavours, beverages and other food systems (Funk et al. 2016). Ginger is widely valued for its pungent aromatic qualities and rich composition of phenolic compounds and essential oils (Wohlmuth et al. 2005). It is widely consumed as a fresh paste, dried powder, slices preserved in syrup, candy (crystallised ginger) or for flavouring tea. In addition, it has been reported to be an antidote for indigestion, upset stomach, diarrhoea and nausea (Ravindran et al. 2002; Wohlmuth et al. 2005). Turmeric (*Curcuma longa*), from the Zingiberaceae family of plants is a widely cultivated perennial herb in India and China. The rhizome yields a distinctly yellowish powder which is the active ingredient that gives curry powder its distinctive colour as an ingredient for improving the physical appearance of foods. Turmeric has been widely used in Asian cuisines for its flavour and colour and in Ayurvedic medicine for its anti-inflammatory effect (Goel et al. 2008).

Agricultural products are normally dried to reduce their post-harvest moisture content to a level that protects them against microbial activities and spoilage. Mathematical models have been largely developed to simulate moisture movement during the drying of many biological products. These have been very helpful in understanding the drying kinetics and optimisation of drying conditions (Gupta et al. 2020). Although drying is a major unit operation in the processing and handling of alligator peppers, ginger and turmeric, information regarding their drying characteristics are rarely found in literature. The aim of this study is to investigate the thin layer drying characteristics of alligator peppers, ginger and turmeric with the view to understand their drying kinetics, optimising their drying conditions and ultimately reducing the post-harvest losses.

MATERIAL AND METHODS

Sample preparation. Ripe, matured and fresh alligator pepper seeds, ginger and turmeric rhizomes were purchased from the local market (Oja tuntun) in Ile-Ife, Nigeria. Each spice sample was sorted, graded and cleaned. The moisture content determination was carried out by oven drying technique (AOAC 2000). About 10 g of each spice was weighed using an electronic weighing balance (TDUB-63V09; Netzgerat, Germany, with an accuracy of $\pm$ 0.001 g) and oven dried at 105 °C in a laboratory oven (Uniscope SM9023; Surgifriend Medicals, England) until no significant changes were observed between the values obtained in two successive weights.

Drying experiment. About 200 g of each spice sample was spread in a thin layer on drying trays and fully exposed to an air stream at three different drying temperatures, 50, 60, and 70 °C. The samples weight was taken (using the earlier specified electronic balance) at the interval of 60 min until constant weight was reached. The samples were allowed to cool in a desiccator (1-4413-26 300; AS ONE, Japan) to curtail interference with the drying process and the weights were taken afterwards. The moisture content at any particular drying time (t) from the original moisture content was calculated using the weight loss from the original moisture content. The value obtained was converted to the moisture ratio (MR) using Equation (1). The drying curves were obtained by plotting MR against the drying time (t):

$$MR = \frac{M_t - M_e}{M_o - M_e} \tag{1}$$

where: MR – moisture ratio; M_t – moisture content wet basis at the drying time (t); M_e – equilibrium moisture content, wet basis; M_o – initial moisture content, wet basis.

Effective moisture diffusivity and activation energy. Fick's second diffusion law for slab geometry was used to estimate the effective diffusivity of the samples (Ogunsina et al. 2016)

$$MR = \frac{M_i - M_e}{M_o - M_e} = \frac{8}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{(2n+1)^2} \exp\left[\frac{-(2n+1)\pi^2 D_{eff} t}{4L^2}\right] \tag{2}$$

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where: M_i – moisture content at any given time; n – number of time in consideration; D_{eff} – effective diffusivity ($m^2 \cdot s^{-1}$); L – thickness of the spice samples (m).

This assumes that moisture migration is due to the diffusion, minimal shrinkage, constant diffusion coefficients and constant temperature. For lengthy drying times, Equation (2) may be simplified to just the first term of the series, the logarithmic form of the equation which is expressed as:

$$\ln(MR) = ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff} t}{4L^2}\right) \quad (3)$$

The effective diffusivity may be obtained when ln(MR) is plotted against the drying time (t), the slope of a straight line which is obtained may be expressed as:

$$k = \frac{\pi \ D_{eff}}{4L^2} \quad (4)$$

where: k – drying constant.

The temperature dependence of the effective diffusivity was estimated using the Arrhenius relationship (Akpinar et al. 2003; Simal et al. 2005):

$$D_{eff} = D_o \exp\left[-\frac{E_a}{RT_a}\right] \quad (5)$$

where: E_a – energy of activation ($kJ \cdot mol^{-1}$); R – universal gas constant (8.314 $kJ \cdot kmol^{-1} \cdot K^{-1}$); T_a – absolute air temperature (K); D_o – pre-exponential factor of the Arrhenius Equation ($m^2 \cdot s^{-1}$).

Model fitting. Five known mathematical models that express the relationship between the moisture ratio and the drying time were used to establish the parameters of the thin layer drying models by fitting the experimental data to the model equations (Table 1). A non-linear regression analysis was carried out using Curve Expert 3.1 and the coefficient of determination (R^2), sum of square error (SSE) and root mean square error (RMSE) were chosen as the criteria to determine the equation of the best fit. The model which has the highest R^2, the lowest SSE and RMSE was chosen as the most suitable for predicting the drying behaviour of the material (Ertekin and Firat 2017).

RESULTS AND DISCUSSION

The initial moisture content of the alligator pepper, ginger and turmeric were 41.23, 91.78, and 79.42% (wet basis), respectively. These values are relatively higher than that of Borah et al. (2015), Onyeneke (2018), Nukulwar and Tungikar (2021). The initial moisture content of biomaterials largely depends on their origin, degree of maturity, preharvest weather conditions, and method of moisture measurement. Drying minimises many microbial, enzymatic and other moisture driven deterioration which affects the physical, chemical and functional properties of biomaterials (Raghavan and Orsat 2007; Dewole et al. 2013).

Figure 1 shows the effect of the drying temperature on the moisture content of the alligator pepper at three drying temperatures. As applicable to most biomaterials, it was observed that, at the initial stage of drying, there was a rapid moisture loss from the products

Table 1. Mathematical models used for the drying characteristics

Model name	Model	Reference
Logarithmic model	$MR = a\exp(-kt) + b$	Borah et al. (2015)
Page model	$MR = \exp(-kt^n)$	Ogunsina et al. (2016)
Modified Page model	$MR = \exp(-kt)^n$	Ertekin and Firat (2017)
Henderson and Pabis	$MR = a\exp(-kt)$	Ogunsina et al. (2016)
Diffusion model	$MR = a\exp(-kt) + (1-a)\exp(-kbt)$	Joseph et al. (2021)

a, b, k, n – drying constants; t – drying time; MR – moisture ratio; exp – exponential

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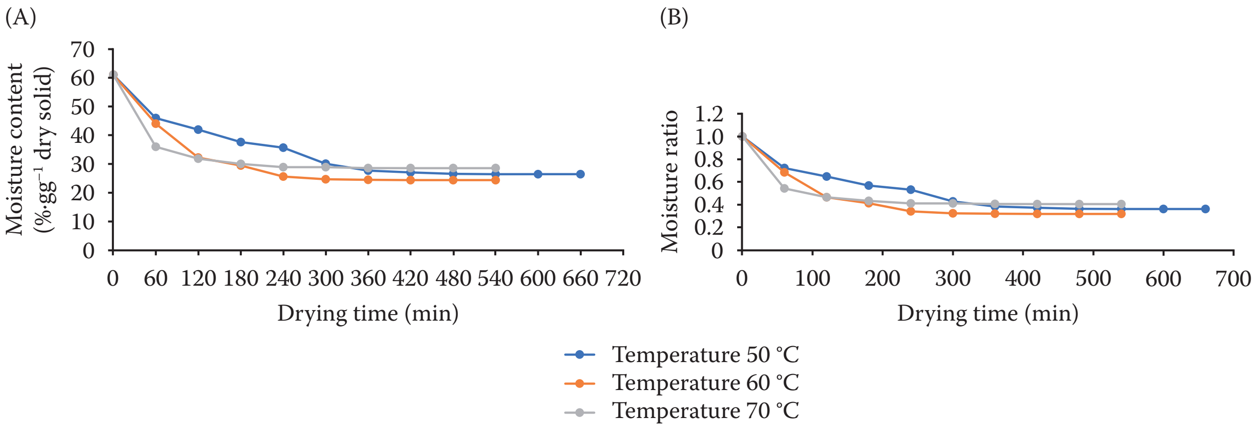

Figure 1. The alligator pepper – (A) the effect of the temperature on the moisture content and (B) the effect of the drying temperature on the moisture ratio (*MR*)

which later decreased as the drying time progressed. At a drying temperature of 50, 60, and 70 °C, the equilibrium moisture content (EMC) was established for the alligator pepper at 600, 540, and 480 min, respectively. Joy et al. (2002), in an investigation conducted on black pepper using solar dryer tunnel, found that the EMC was attained at 480 min, whereas Nwakuba and Okafor (2020) found that alligator pepper pods with an initial moisture content of 85.25% attained EMC at 900 min. However, it is expected that the alligator pepper pods will exhibit properties different from the alligator pepper seeds. In addition, at the initial stage, the moisture removal was more rapid at 70 °C than at 60 and 50 °C. After 180 min, the rate of moisture removal was minimal and this is attributable to the possible case-hardening of the material at a high temperature.

The drying curves of ginger and turmeric are shown in Figures 2 and 3, respectively. It is observed that both ginger and turmeric took 960, 840, and 660 min to attain EMC at drying temperatures of 50, 60, and 70 °C, respectively. Moreover, as compared to alligator pepper seeds, more time was required to dry the ginger and turmeric rhizomes. This may be due to the larger amount of water present in the rhizomes. Drying occurred during the falling rate period generally for the three spices; hence, it may be inferred that the main physical mechanism governing the moisture movement in these three spices was diffusion along the moisture concentration gradient as obtained for most agricultural products.

Fitting of drying data. Tables 2–4 show the result of the non-linear regression analysis of the thin layer drying data for the alligator pepper, ginger and turmeric as fitted into the five semi-theoretical models. From the table, it can be observed that the rise in temperature increases the drying constant (k) for all the models under consideration for ginger and

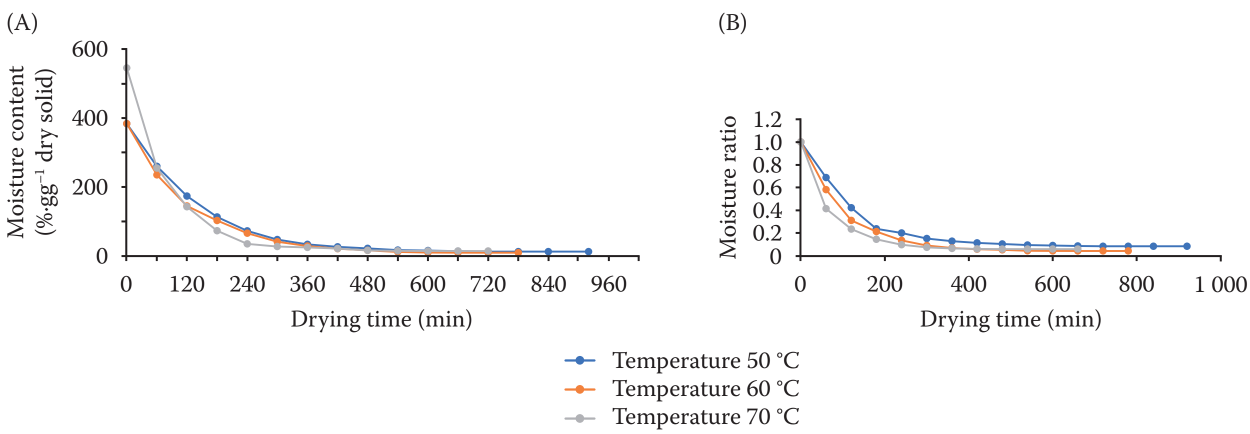

Figure 2. Ginger – (A) the effect of the temperature on the moisture content and (B) the effect of the drying temperature on the moisture ratio (*MR*)

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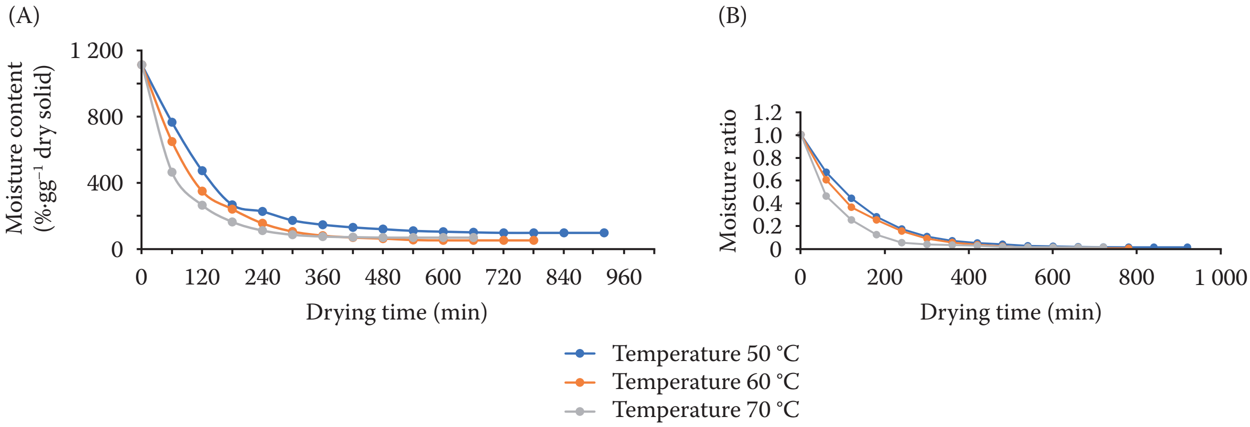

Figure 3. Turmeric – (A) the effect of the temperature on the moisture content and (B) the effect of the drying temperature on the moisture ratio (*MR*)

turmeric, but not those for the alligator pepper. Also, there was no definite trend in the values of the other model parameters. From the values of R^2, SSE and RMSE, all the models gave good results for the thin layer drying properties of the three spices with $R^2 > 0.97$. However, the selection of the most appropriate model was based on the highest R^2 values and the smallest SSE and RMSE values. The most suitable models for describing the thin layer drying characteristics are the logarithmic model for the alligator pepper and turmeric and the Page model for ginger at the different drying temperatures. Gulzar et al. (2017) also reported the Page model as the best fit for ginger; while Murthy and Manohar (2012) reported that the Midili model best described the drying characteristics of ginger. Nwakuba and Okafor (2020) mentioned that the Page model best described the drying characteristics for the alligator pepper and Nukulwar and Tungikar (2021) mentioned that the Page model is more suitable in describing the drying characteristics of turmeric. The difference in the drying model reported by several authors may be attributed to the varietal differences and the drying or pre-treatment methods.

Table 2. Non-linear regression analysis of the thin layer drying data for the alligator pepper

S/N	Model	Temperature (°C)	Parameters					R^2	SSE	RMSE
			k	*n*	*a*	*b*	*c*			
1	Page	50	0.0263	0.0434	–	–	–	0.9837	0.00075	0.02734
		60	0.0563	0.0693	–	–	–	0.9838	0.00174	0.04167
		70	0.0257	0.0241	–	–	–	0.9931	0.00024	0.01549
2	Modified Page	50	0.3728	0.3728	–	–	–	0.9721	0.00767	0.08757
		60	0.4669	0.4675	–	–	–	0.9701	0.01301	0.11410
		70	0.4200	0.4205	–	–	–	0.9899	0.02587	0.16084
3	Henderson and Pabis	50	0.1103	–	0.8610	–	–	0.9811	0.00452	0.06720
		60	0.1710	–	0.8441	–	–	0.9799	0.00943	0.09716
		70	0.1029	–	0.7362	–	–	0.9912	0.01432	0.11965
4	Diffusion	50	0.1390	–	1.0000	1.0000	–	0.9789	0.00767	0.08757
		60	0.2183	–	1.0000	1.0000	–	0.9763	0.01301	0.11408
		70	0.1766	–	1.0000	1.0000	–	0.9901	0.02587	0.16084
5	Logarithmic	50	0.0426	–	0.0282	–	0.0187	0.9913	0.00063	0.02517
		60	0.0364	–	0.0158	–	0.0076	0.9932	0.00016	0.01271
		70	0.0775	–	0.0158	–	0.0042	0.9936	0.00008	0.00913

S/N – serial number; *a*, *b*, *c*, *k*, *n* – drying constants; R^2 – coefficient of determination; SSE – sum of square error; RMSE – root mean square error

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Table 3. Non-linear regression analysis of the thin layer drying data for ginger

S/N	Model	Temperature (°C)	Parameters					R^2	SSE	RMSE
			k	*n*	*a*	*b*	*c*			
1	Page	50	0.4023	1.048	–	–	–	0.9993	0.00006	0.00743
		60	0.5030	0.9658	–	–	–	0.9995	0.00004	0.00662
		70	0.7716	0.8894	–	–	–	0.9986	0.00010	0.01018
2	Modified Page	50	0.6507	0.6507	–	–	–	0.9989	0.00008	0.00911
		60	0.6507	0.6507	–	–	–	0.9993	0.00006	0.00772
		70	0.8489	0.8489	–	–	–	0.9974	0.00019	0.01393
3	Henderson and Pabis	50	0.4268	–	1.0008	–	–	0.9991	0.00009	0.00871
		60	0.4837	–	0.9941	–	–	0.9993	0.00006	0.00753
		70	0.7158	–	0.9924	–	–	0.9975	0.00753	0.01377
4	Diffusion	50	0.4235	–	1.0000	1.0000	–	0.9989	0.00008	0.00901
		60	0.4864	–	1.0000	1.0000	–	0.9993	0.00006	0.00772
		70	0.7207	–	1.0000	1.0000	–	0.9974	0.00019	0.01393
5	Logarithmic	50	0.4336	–	1.0006	–	0.0048	0.9991	0.00007	0.00811
		60	0.4835	–	0.9942	–	0.0001	0.9993	0.00006	0.00753
		70	0.7521	–	0.9816	–	0.0146	0.9991	0.00007	0.00838

S/N – serial number; *a*, *b*, *c*, *k*, *n* – drying constants; R^2 – coefficient of determination; SSE – sum of square error; RMSE – root mean square error

Effective diffusivity and activation energy. From Figure 4, the activation energy of the alligator pepper, turmeric and ginger were 22.6, 19.5, and 16.5 kJ·mol^{-1}, respectively. It shows that the activation energy of the alligator pepper was higher than that of turmeric and ginger and this could be attributed to the fact that the seeds were whole and not sliced unlike ginger and turmeric. Slicing exposes a larger surface area of ginger and turmeric to the drying air, thereby making the drying faster.

Table 4. Non-linear regression analysis of the thin layer drying data for turmeric

S/N	Model	Temperature (°C)	Parameters					R^2	SSE	RMSE
			k	*n*	*a*	*b*	*c*			
1	Page	50	0.5240	0.7194	–	–	–	0.9704	0.0019	0.04370
		60	0.6069	0.8236	–	–	–	0.9931	0.00005	0.02220
		70	0.9458	0.5836	–	–	–	0.9939	0.00043	0.02061
2	Modified Page	50	0.6211	0.5178	–	–	–	0.9508	0.00317	0.05634
		60	0.7241	0.7236	–	–	–	0.9883	0.00084	0.02890
		70	0.8523	0.8534	–	–	–	0.9676	0.00226	0.04757
3	Henderson and Pabis	50	0.3718	–	0.9734	–	–	0.9516	0.00312	0.05589
		60	0.5166	–	0.9861	–	–	0.9885	0.00082	0.02853
		70	0.7076	–	0.9743	–	–	0.9683	0.00221	0.04699
4	Diffusion	50	0.3837	–	1.0000	1.0000	–	0.9508	0.00318	0.05635
		60	0.5240	–	1.0000	1.0000	–	0.9883	0.00084	0.02889
		70	0.7274	–	1.0000	1.0000	–	0.9676	0.00226	0.04757
5	Logarithmic	50	0.5124	–	0.9372	–	0.0800	0.9955	0.00029	0.01698
		60	0.5972	–	0.9617	–	0.0400	0.9992	0.00007	0.00748
		70	0.9023	–	0.9324	–	0.0615	0.9980	0.00014	0.01167

S/N – serial number; *a*, *b*, *c*, *k*, *n* – drying constants; R^2 – coefficient of determination; SSE – sum of square error; RMSE – root mean square error

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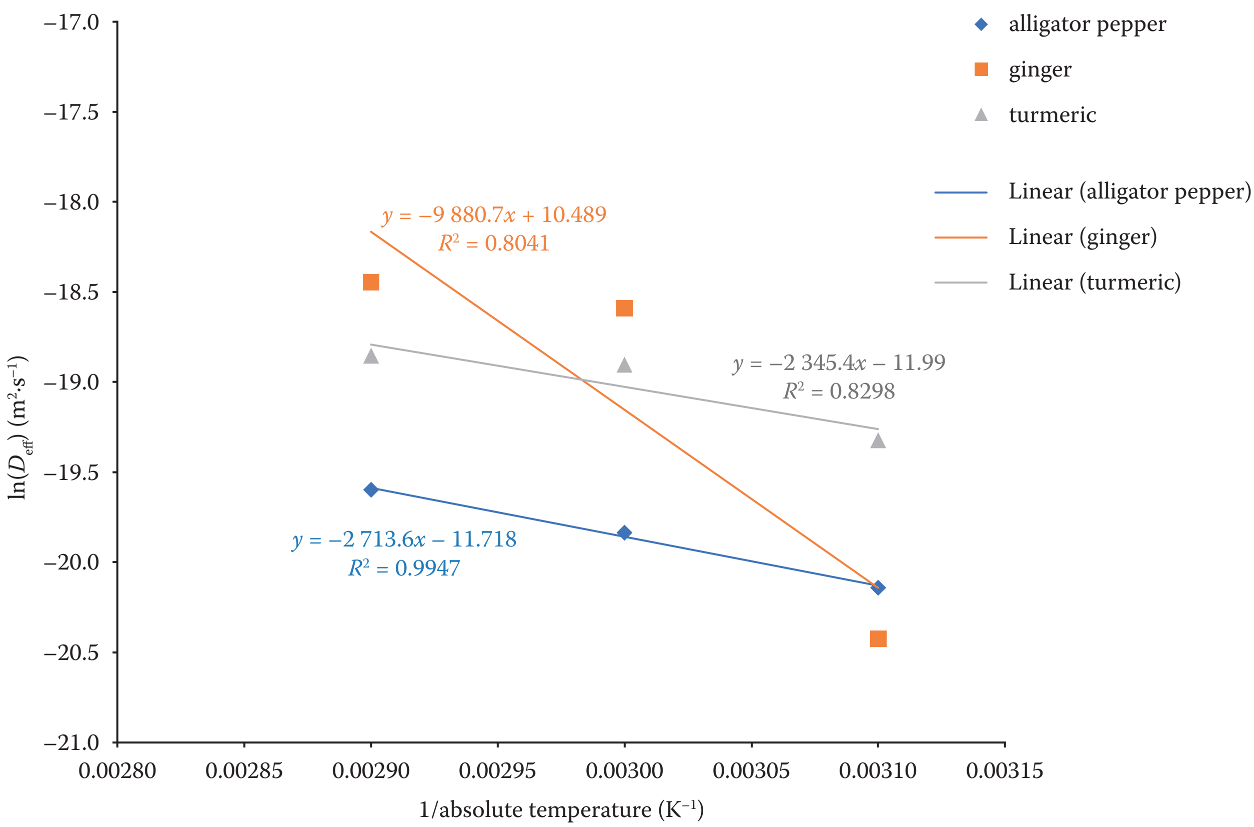

Figure 4. Plot of $\ln(D_{eff})$ against 1/absolute temperature for the alligator pepper, ginger and turmeric

D_{eff} – effective diffusivity

CONCLUSION

Thin layer drying characteristics of the alligator pepper, ginger and turmeric were investigated at three drying temperatures in an air oven. The drying processes were simulated using five semi-empirical models and the following conclusions may be drawn:

(*i*) The thin layer drying of the alligator pepper, ginger, and turmeric took place in the falling rate period. It was observed that the spices dried faster at 70 °C as compared to drying at 50 and 60 °C. The effective moisture diffusivity of the spices increased with an increasing temperature.

(*ii*) The drying characteristics of turmeric and the alligator pepper were best described by the logarithmic model, while that of ginger was best described by the Page model.

(*iii*) Knowledge of drying characteristics of these spices provides information that may assist in the optimisation of the drying parameters to promote adding value and boosting the obtainable income from the spice production and processing.

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