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Effect of Vacuum Drying System on Drying Time and Quality of Banana Slices

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ABSTRACT

Drying is a common method for preserving agric-food products. Banana is one of the popular value-added products. Due to its high nutrition, strong aroma, and the convenience for package, storage, and transportation, dried banana is in a growing demand in local and international market. Conventional drying (hot air) offers dried products that can have a long life over the year. Unfortunately, the dried product quality is significantly reduced in comparison with the original food staff. A relatively novel technique, namely microwave-vacuum drying has received great attention in the last few decades for drying of various fruits and vegetables. Banana slices were dried using microwave-vacuum drying, and the drying characteristics under vacuum drying were examined. During the experimental work four different absolute pressures (1, 4, 7, and 10 kPa), two different thicknesses of banana slices (3, and 4 mm), and constant surface temperatures of banana slices of 70ºC were employed. The quality of the banana slices in terms of Texture profile analysis (TPA) and hardness were also investigated with an aim to produce a fat-free snack-like product. The obtained results show that, drying time decreased at low drying pressure and ranged between 5.25 to 23.25 h. Deff values increased with the vacuum drying processes. The minimum Deff ranged from -0.507 to -0.1104 m^2/s with high coefficients of determination (R^2 = 0.9335 to 0.9457). The drying conditions affected the properties of the TPA of the dried banana in comparison with those of the raw fruits prior to drying. The drying conditions resulting in increased hardness, gumminess, and chewiness, while they reduced the cohesiveness and resilience and no adhesiveness after vacuum drying. The most affected properties were the hardness, and chewiness. The hardness and chewiness of the final product were ranged from 71.19 to 645.24 N, and from 38.67 to 290.99 N, respectively.

INTRODUCTION

Banana is the fruit of many countries. Ripe banana is perishable and deteriorating quickly after harvest; therefore there is a need for the application of appropriate technology to prolong the shelf life of fruit weather in fresh or dried forms. Air drying and solar drying are among the most techniques used to preserve banana fruits. However, there are a lot of thermal energy losses in the convection drying, making it less efficient process. It is also known that air drying leads to a lot of quality deterioration of the product, both in terms of physical properties or food characteristics. Banana is low in sodium, and contains very little fat and free of cholesterol. Therefore, it is useful in patients who suffer from blood pressure and heart disease (Robinson, 2006; Robinson and Sauco, 2010). Banana has the ability to neutralize free hydrochloric acid, which refers to its use in the treatment of peptic ulcer. Fully ripe banana mixed with milk powder is advisable, especially for patients with ulcers. It is a rich source of energy. This is why they are consumed all over the world in one form or another. Ganesapillai et al. (2011) have been focusing on research and interest on banana recently given food and economic importance.

Drying is the removal of moisture from the food in order to reduce microbial activity, damage to the product, and extend the storage life. Knowledge of the kinetics of banana drying is necessary to monitor and improve the banana drying process, and the quality of the final product (Demirel and Turhan, 2003). Modern and previous studies on drying bananas in various forms including fruit entire properties (Queiroz and Nebra, 2001; Dandamrongrak et al., 2002; Sousa and Marsaioli, 2004; Silva et al., 2013), fruit sliced (Demirel and Turhan, 2003; Leite et al., 2007; Abano and Sam-Amoah, 2011; Ganesapillai et al., 2011) and fruit cutting (Garcia et al., 1988). Conventional drying (hot air) offers dried products that can have a long life of the year. Unfortunately, the quality of dried product is significantly reduced from those of the original food staff. The idea of combining the microwave heating and low temperature vacuum proceeded by several researchers. It was found that microwave vacuum considered as an alternative way to improve the quality of the dried product. A comparison between the two processes; hot air and superheated steam to maintain the drying conditions, has been taken into account a number of important drying characteristics such as drying rate, final drying time, and quality of the dried product.

The main purpose of microwave-vacuum drying is to enable dehumidification at a temperature below the boiling point temperature under ambient conditions. Water boiling at 1 bar and 100°C, but if the pressure is reduced to 40 mbar, the boiling temperature is reduced to 28.96 °C (Moran and Shapiro, 1996). An important feature for vacuum drying is the absence of the virtual air during the drying, which makes the process attractive for drying materials that could deteriorate and/or modified chemically as a result of air or high temperature exposure. Vacuum dryer has the lowest maximum temperature drying (Barbosa-Canovas and Vega-Mercado, 1996). All systems that have applied vacuum consist of four main parts: a vacuum chamber, heating and production of vacuum unit (pump) and a water vapor to collect (condensed). Because of the high cost of installation and operation, a vacuum is used only for high-value materials (Somogy and Luh, 1986). Vacuum therapy is also useful in combination with some other processes, such as microwaves and osmotic dehydration (Argaiz et al., 1994), or as a means of finishing drying.

Vacuum drying of banana slices was studied in a domestic microwave oven. The results show that banana temperature rises uniformly and rapidly to the saturation water vapor temperature corresponding to the vacuum then rises slowly until most of the free moisture is lost. The thermal and drying efficiencies were found to drop from almost 100% at the beginning of the drying (high moisture content) to as low as 40 and 30%, respectively, at the end of drying. Both efficiencies were found to increase with the use of vacuum, especially at low moisture content. In this work, the drying characteristics of banana slices undergoing vacuum drying were studied and examined. The qualities of the dried banana slices in terms of texture profile analysis (TPA) and hardness were also investigated with an aim to produce a fat-free snack-like product.

MATERIALS AND METHODS

Materials

The microwave-vacuum dryer used in the present study is shown in Fig. (1). The dryer consists of a stainless steel drying chamber, with inner dimensions of 82 x 80 x 80 cm insulated with packed-rock wool. A heater with rated power of 3 kWh is installed at the bottom of the drying chamber. The distance between the heater and the drying tray, which has dimensions of 80 x 80 cm, is approximately 15 cm. Vacuum drying oven (Model DP810 - SINCE 1889-Yamato Corporation-Japan), has a temperature controller was attached to a vacuum pump 0.75 kWh. Fresh bananas were obtained from a local market. Prior to each experiment, the bananas were peeled and cut into slices 3 and 4 mm thick. The banana slices (about 1.200 -1.300 kg (4 replicates) with initial moisture content of 296.8% db and water activity of 0.961, were placed on the drying tray. The drying chamber was then sealed tightly. The vacuum pump was then switched on to evacuate the drying chamber to the desired operating pressure and the heater switched ON. The experiments were performed at the following conditions: four different absolute pressures of 1, 4, 7, and 10 kPa; two different thicknesses of banana slices 3, and 4 mm, and constant surface temperatures of banana slices of 70ºC. Banana samples were taken before and after the drying process for texture measurements. Samples of raw unprocessed banana and the dried banana were taken to determine moisture content, using the vacuum oven method recommended by AOAC (1995) for foods containing sugar. Samples of banana slices before and after oven drying were weighed. The moisture content was calculated on wet basis (wb) and expressed as follows:

$$\text{Moisture content (w.b)} = \frac{W_1 - W_2}{W_1} \times 100\ ,\ \% \quad (1)$$

Where, W_1 and W_2, respectively, are the sample weight of banana slices before and after oven drying. The moisture content in wet basis was converted into dry basis (db).

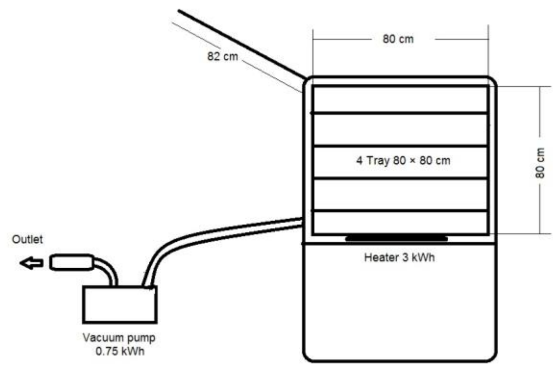

Fig. (1): Schematic diagram of microwave-vacuum dryer employed during the experimental work.

Methods

Modeling of drying data

The banana were dried with different methods and compared with vacuum drying until 6.5% db ± 0.2 moisture content (kg moisture/kg dry matter), and the weight of the banana was measured together tare of the drying tray every 30 min for kinetic modeling. The moisture ratio (MR) value was calculated from the moisture content using Equation (2). It was also used to describe the drying model of banana.

$$MR = \frac{M - M_e}{M_o - M_e} = e^{-k\,t} \quad (2)$$

Where, k, is the drying constant, s^{-1}.

In order to investigate the drying kinetics, the relationship between moisture ratio (MR) and drying time (t) has been previously studied by several researchers as shown in Table (1). In this research work, several classic thin-layer drying models (Erbay and Icier, 2010; Doymaz, 2006; Doymaz et al., 2006; Ceylan et al., 2007) were functioned to fit the experimental data, in which the moisture ration (MR) was expressed as M/M_o instead of $(M - M_e)/(M_o - M_e)$, where, M, M_o, and M_e, refers to the moisture content of banana slices at a certain microwave heating time (t), the initial moisture content, and the equilibrium moisture content, respectively. The reasons for that were based on two aspects; one was that the M_e was unpredictable due to the fluctuation of the relative humidity of air in the desiccator during the drying process (Vadivambal and Jayas, 2010), the other was that the elimination of M_e was acceptable since the value of M_e was quite small (Doymaz, 2004). In respect to the goodness of the fits, the adjusted coefficient of determination (adjusted R^2), the sum of squares due to error (SSE), and the root mean square errors (RMSE) were employed as a criteria to asses the optimal model for the drying procedure.The effective moisture diffusivity was calculated according to the following equation:

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

Where, D_{eff}, is the effective moisture diffusivity in m^2/s, t is the drying time in s, and , L, is the half thickness of the fillets in m.

Texture profile analysis (TPA)

All TPA experiments were performed using a texture analyzer (TA-HDi, Model HD3128, Stable Micro Systems, Surrey, England) equipped with integrated data logging and analysis software (Texture Expert Exceed, version 2.05). A 50-mm diameter compression disk (P50) was employed to exert a two-cycle compression force on the whole banana fruit, and the force–time curve was measured. The crosshead speed was 0.2 mm/s and the fruit was deformed to a depth of 1.5 mm. After completion of the first cycle (first bite), the direction of the plunger was reversed (upward at 1.5 mm/s), and the second cycle was carried out (downward and upward, second bite). Texture profile properties were determined from experimental data with the aid of Texture Expert Exceed.

Table (1): Several thin-layer drying models for the banana drying process

Model name	Model equation	References
Newton	$MR = \exp(-kt)$	Erbay and Icier (2010)
Henderson and Pabis	$MR = a\exp(-kt)$	Kigsly and Singh (2007)
Logarithmic	$MR = a\exp(-kt) + c$	Guine and Barroca (2012)
Page	$MR = \exp(-kt^n)$	Rahman (1995)
Modified Page	$MR = \exp(-kt)^n$	Erbay and Icier (2010)
Two-term exponential	$MR = a\exp(-k_1 t) + b\exp(-k_2 t)$	Erbay and Icier (2010)
Wang and Singh	$MR = 1 + at + bt^2$	Babalis and Belessiotis (2004)
Approximation of diffusion	$MR = a\exp(-kt) + (1-a)\exp(-kbt)$	Erbay and Icier (2010)
Modified Henderson and Pabis	$MR = a\exp(-kt) + b\exp(-gt) + c$	Erbay and Icier (2010)
Midilli and Kucuk	$MR = a\exp(-kt^n) + bt$	Doymaz (2006)

Goodness of fit for the drying models

The values of the constants equation of the examined drying models were determined by fitting the drying models with the experimental data, using a nonlinear least squares procedure (MATLAB Version 8.1.0.604 (R2013b), Math-works, Inc.). The goodness of fit was evaluated by the coefficient of determination (R^2), the sum of squared errors (SSE), and the root mean squared error (RMSE). The expressions for SSE (Xanthopoulos et al., 2007) and RMSE (Kingsly and Singh, 2007) were as follows:

$$\text{SSE} = \sum_{i=1}^{N}\left[\frac{MR_{obsr,i} - MR_{pred,i}}{N - n}\right] \quad (4)$$

$$\text{RMSE} = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{obsr,i} - MR_{pred,i}\right)^2\right]^{1/2} \quad (5)$$

The fitting was considered good when high values of R^2 and low values of SSE and RMSE were obtained. Relative percent errors (PE) below 10% also indicate a good fit (Roberts et al., 2008), where

$$\text{PE} = \frac{100}{N}\sum_{i=1}^{N}\left[\frac{MR_{obsr,i} - MR_{pred,i}}{MR_{obsr,i}}\right] \quad (6)$$

Where, $MR_{obsr,\ i}$, is the moisture ratio observed experimentally for instant i and $MR_{pred,\ i}$, is the predicted moisture ratio for same instant i. The parameters N and n are the number of observations and number of constants, respectively. The experimental data are presented in terms of the mean ±SD. Pairwise LSD tests were used to compare the means. Differences were considered to be significant at $p < 0.05$ (Microsoft Excel, Version 2010). four different absolute pressures of 1, 4, 7, and 10 kPa; two different thicknesses of banana slices 3, and 4 mm, and constant surface temperatures of banana slices of 70ºC.

RESULTS AND DISCUSSION

Drying characteristics of banana fruits

During the experimental drying runs, deviations of the vacuum from their set points were small (Tset - 0.5 kPa). The drying time to reduce the moisture content of banana slices from 294.8 to 5.5 ± 0.5 (dry basis) was in the range of 5.25 – 23.25 h. The drying time was the longest at absolute pressure of 10 kPa, whilst it was the shortest at pressure of 1 kPa. The drying times at different levels of vacuum are shown in Fig. (2). An analysis of variance indicated that the differences in vacuum drying had a significant effect on the drying time. The drying characteristics of banana slices are presented as drying curves. A typical example of the decrease in moisture content with increasing the drying time at different levels of vacuum drying is plotted in Fig. (3). The moisture ratio as a function of drying time is shown in Fig. (4), while the drying rates as a function of time and moisture content are shown in Figs (5) and (6), respectively.

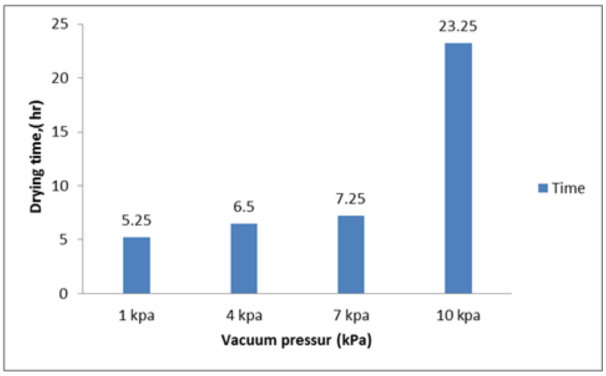

Fig. (2): The drying time required to reduce the moisture content of Banana slices from initial moisture content (298.24 db) to a final moisture content of 5.5 ± 0.5 (dry basis).

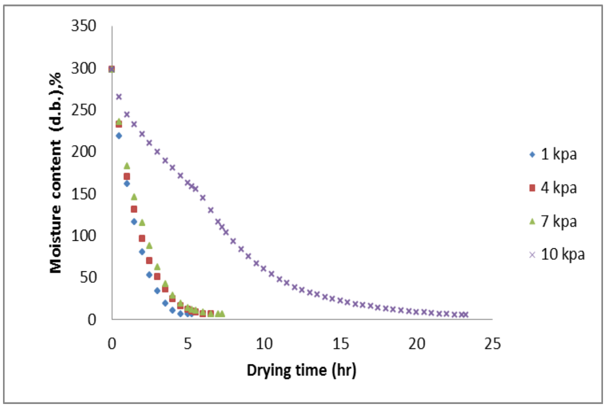

Fig. (3): Moisture content versus drying time at different levels of vacuum drying

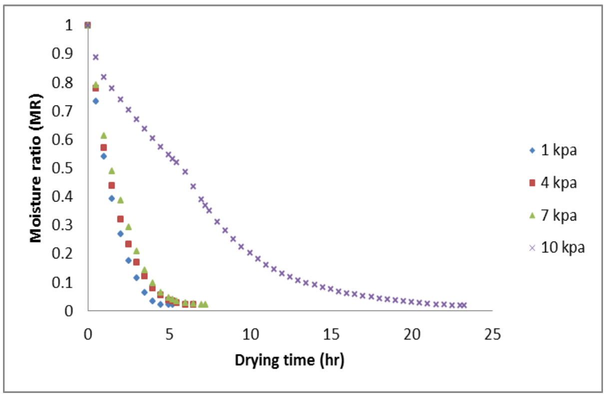

Fig. (4): Moisture ratio versus drying time at different levels of vacuum drying

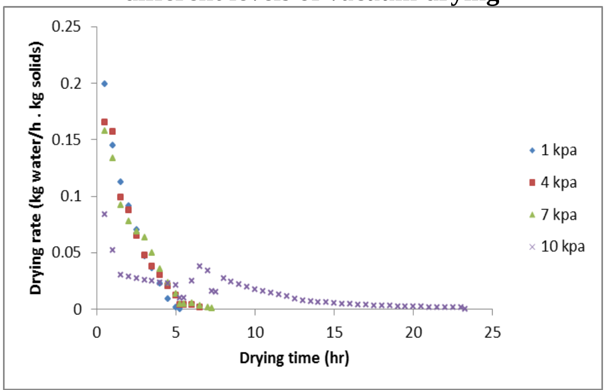

Fig. (5): Drying rate versus drying time at different levels of vacuum drying

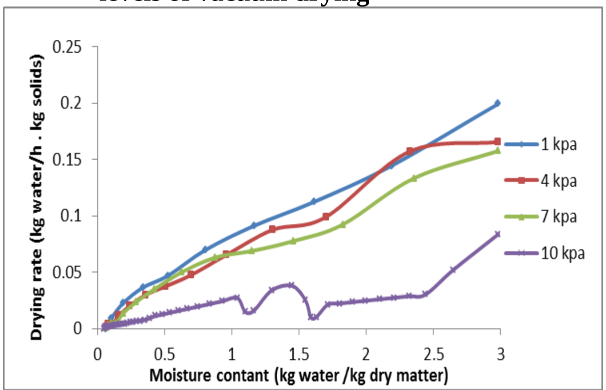

Fig. (6): Drying rate versus moisture content at different levels of vacuum drying

The drying rate always decreased as the drying progressed and never remained constant over an extended period. This indicates that diffusion was the main physical mechanism governing moisture movement, which in agreement with the data published by several researchers (Hassan and Hobani, 2000; Nidbal and Farid, 2002; Falade and Abbo, 2007; Swasdisevi et al., 2007; Karimi, 2010). The drying rate increased by increasing the drying vacuum, while the required drying time decreased. The range of drying rate was smallest at pressure of 10 kPa (0.000145 kg water/h kg solids) and greatest at pressure of 1 kPa (0.199 kg water/h kg solids). Fig. (6) illustrates a typical example of the drying rate plotted as a function of the moisture content at different levels of vacuum drying. Higher vacuum drying promoted faster drying, as indicated by the steeper drying rate curves.

Moisture diffusivity of banana fruits during drying process:

The effective moisture diffusion coefficient (Deff) were determined from the incomplete experimental data relating moisture ratio with drying time and the Arrhenius equation dependence of Deff on the drying vacuum. Deff was ranged from - 0.507 to - 0.1104 m^2/s with high coefficients of determination (R^2 = 0.9335–0.9457). Table (2) shows the values of Deff at different drying vacuum. Increasing the drying vacuum during the experimental work led to increasing the Deff value. A significant effect of drying vacuum on Deff was consistently observed ($p < 0.05$). Thus, the diffusion of water from the banana slices is due mainly to the effect of drying vacuum.

Table (2): Diffusivity of banana slices during the drying process.

The pressure (kPa)	Diffusivity* (Deff, m^2/s) of banana slices
1	- 0.507 ± 0.1179
4	- 0.4379 ± 0.0819
7	- 0.3933 ± 0.0686
10	- 0.1104 ± 0.0098

Drying models

Several drying models were fitted to the experimental drying data to check their validity and performance using nonlinear procedures in standard statistical packages (e.g. MATLAB and Microsoft Excel). Table (3) shows the values of the statistical indicators of the proposed mathematical models for simulating the experimental drying curves at different drying vacuum. In general, all 10 models showed a good fit, with R^2 values higher than 0.9902. Because PE values below 10% indicate good fits, (Roberts et al., 2008). Thus, all models are fitted well with the experimental data considering the average regression coefficient over all experimental variables (R^2 ave. > 0.99 ± 0.006) as the first selection criterion was with the Midilli and Kucuk model, followed by the logarithmic, two-term exponential, and Henderson and Pabis models. Table (4) shows the kinetic and empirical parameters of these models for simulating the experimental drying curves of banana slices dated at different drying vacuum. In all models, the SSE and RMSE were less than 0.063 as shown in Table (4).

Texture profile analysis (TPA)

The effect of vacuum drying method on primary (hardness, cohesiveness, elasticity, and adhesiveness) and derived texture parameters (brittleness, chewiness, and resilience) of the dried banana slices are listed in Table (5). The statistical significance of each property was determined using 10 replicates and all pairwise comparisons were performed by Fisher least significance difference (LSD) with a confidence interval of 95%. The results revealed that all texture properties were affected under certain conditions by the drying vacuum. The drying process increased the hardness, adhesiveness, brittleness, and chewiness; and reduced the cohesiveness, elasticity, and resilience of the dried banana slices as compared with the fresh fruits. The range of the relative change in property (property of dried banana slices/property of fresh banana) was 8.792 to 87.75, 0.02 to - 0.109, 0.145 to – 0.129, 8.396 to 76.406, 7.869 to 65.740, and – 0.166 to – 0.388 for hardness, springiness, cohesiveness, gumminess, chewiness and resilience, respectively. No adhesiveness after undergoing drying, and hardness, gumminess, and chewiness were the most sensitive to the drying conditions. Note that the brittleness at 1 kPa as well as the hardness, and cohesiveness at the same pressure. The primary TPA properties of the banana slices before and after drying are shown in Fig. (7). The range of hardness of the dried fruits was 71.19 to 645.24 N.

Table (3): Values of the statistical indicators (SI) of the examined mathematical models for simulating the experimental drying curves of banana slices.

Model No.	SI	Pressure 1 kPa	4 kPa	7 kPa	10 kPa
1	R^2	0.995100	0.997600	0.994800	0.98350
	SSE	0.005642	0.003157	0.007649	0.06385
	RMSE	0.022650	0.015020	0.021860	0.03610
	PE	1.765000	1.119000	1.778000	3.07400
2	R^2	0.995700	0.998100	0.995200	0.984000
	SSE	0.005001	0.002478	0.006692	0.06197
	RMSE	0.022360	0.013810	0.021120	0.03593
	PE	1.716000	1.041000	1.619000	2.12178
3	R^2	0.998500	0.999200	0.997600	0.99020
	SSE	0.001729	0.001085	0.003518	0.03802
	RMSE	0.013860	0.009509	0.015850	0.02844
	PE	0.971000	0.649000	1.175000	2.29600
4	R^2	0.998800	0.999700	0.998300	0.990400
	SSE	0.001388	0.000450	0.002544	0.037010
	RMSE	0.011780	0.005880	0.013020	0.027770
	PE	0.763000	0.420000	0.978000	1.829000
5	R^2	0.995100	0.997600	0.994800	0.983500
	SSE	0.005642	0.003157	0.007649	0.063850
	RMSE	0.023750	0.015580	0.022580	0.036470
	PE	1.765000	1.121000	1.739000	3.074000
6	R^2	0.999000	0.998800	0.997900	0.984100
	SSE	0.001160	0.001606	0.003133	0.061360
	RMSE	0.012040	0.012080	0.015520	0.036520
	PE	0.730000	0.799000	1.080000	2.950000
7	R^2	0.992000	0.982900	0.986800	0.988500
	SSE	0.009235	0.022560	0.019360	0.044330
	RMSE	0.030390	0.041660	0.035920	0.030390
	PE	2.192000	3.110000	2.681000	2.358000
8	R^2	0.998600	0.999400	0.998500	0.991200
	SSE	0.001574	0.000832	0.002149	0.033950
	RMSE	0.013230	0.008325	0.012390	0.026870
	PE	0.923000	0,501000	0.908000	2.107000
9	R^2	0.990000	0.998200	0.998200	0.98910
	SSE	0.011470	0.002322	0.002608	0.04232
	RMSE	0.043720	0.016060	0.015400	0.03101
	PE	2.365000	1.008000	0.914000	2.45200
10	R^2	0.999100	0.999700	0.998400	0.99440
	SSE	0.001052	0.000423	0.002318	0.02164
	RMSE	0.011470	0.006203	0.013350	0.02169
	PE	0.767000	0.405000	0.991000	1.40800

Table (4): Means (and standard deviations) of the kinetic and empirical parameters of the proposed mathematical models for simulating the experimental drying curves of banana slices.

Model name	SI	Pressure 1 kPa	4 kPa	7 kPa	10 kPa
Lewis	k	0.6719 (0.0391)	0.5809 (0.0201)	0.5197 (0.0243)	0.1477 (0.0057)
Henderson and Pabis	k	0.6852 (0.0484)	0.5924 (0.0233)	0.5313 (0.03)	0.1508 (0.0080)
	a	1.022 (0.0435)	1.021 (0.0244)	1.025 (0.0368)	1.022 (0.0375)
Logarithmic	k	0.608 (0.0295)	0.5522 (0.0273)	0.4811 (0.023855)	0.1256 (0.0112)
	a	1.52 (0.0759)	1.036 (0.019)	1.045 ((0.05125)	1.06 (0.031)
	c	- 0.04383 (0.00217)	- 0.02362 (0.00391)	- 0.03376 (0.001687)	- 0.06867 (0.00338)
Page	k	0.6171 (0.083)	0.5391 (0.0026)	0.4637 (0.0250)	0.1038 (0.01319)
	n	1.136 (0.058)	1.096 (0.025)	1.126 (0.052)	1.168 (0.060)
Modified Page	k	0.7593 (0.3787)	0.8351 (0.04083)	1.506 (0.0752)	0.7642 (0.03791)
	n	0.8847 (0.0441)	0.6954 (0.0333)	0.345 0.003706)	0.1933 (0.009281)
Two-term exponential	k_1	0.4455 (0.0222)	0.4816 (0.02405)	0.3706 (0.018417)	45.09 (2.2534)
	k_2	0.389 (0.01905)	0.5031 (0.025054)	0.3911 (0.01955)	0.1518 (0.00758)
	a	3.901 (0.1941)	- 0.3698 (0.01775)	- 5.454 (0.2726)	- 0.02872 (0.001425)
	b	- 2.899 (0.1448)	4.717 (0.2348)	6.46 (0.322)	1.029 (0.05045)
Wang and Singh	a	- 0.4679 (0.02337)	- 0.3963 (0.019775)	- 0.3529 ((0.01763)	- 0.1061 (0.005301)
	b	0.05484 (0.002741)	0.03934 ((0.001966)	0.03104 (0.001547)	0.002844 (0.0001442)
Approximation of diffusion	k	0.4582 ((0.02287)	0.4349 (0.02154)	0.7695 (0.03487)	0.09061 (0.00449)
	a	- 32.39 (1.608)	2.8 (0.14)	- 22.34 (1.092)	7.323 (0.351)
	b	1.011 (0.05053)	0.8593 (0.0427)	0.9807 (0.0453)	0.9271 (0.0448)
Modified Henderson and Pabis	k	0.3563 (0.01771)	0.5507 (0.02739)	0.2928 (0.01444)	0.07822 (0.00383)
	h	0.3626 (0.0174)	0.2056 (0.01019)	0.6776 (0.03367)	0.07306 (0.003584)
	g	2.225 (0.09912)	0.1982 (0.00981)	0.6628 (0.03302)	1.247 (0.0598)
	a	- 39.05 (1.891)	0.8137 (0.0397)	- 0.06853 (0.003424)	9.011 (0.4405)
	b	- 0.1475 (0.007227)	- 5.808 (0.2891)	16.43 (0.8112)	0.09311 (0.004555)
	c	40.14 (2.0028)	5.987 (0.2973)	- 15.36 (0.757)	-8.066 (0.3877)
Midili and Kucuk	k	0.6091 (0.030336)	0.539 (0.02684)	0.4554 (0.02265)	0.06193 (0.00307)
	a	0.995 (0.04766)	0.9997 (0.04984)	0.991 (0.04883)	0.9123 (0.0455)
	b	- 0.002685 (0.0001312)	-0.00059 (0.0000294)	- 0.000921 (0.00004571)	0.0002368 (0.00001178)
	n	1.11 (0.05527)	1.087 (0.05413)	1.123 ((0.05585)	1.37 (0.06827)

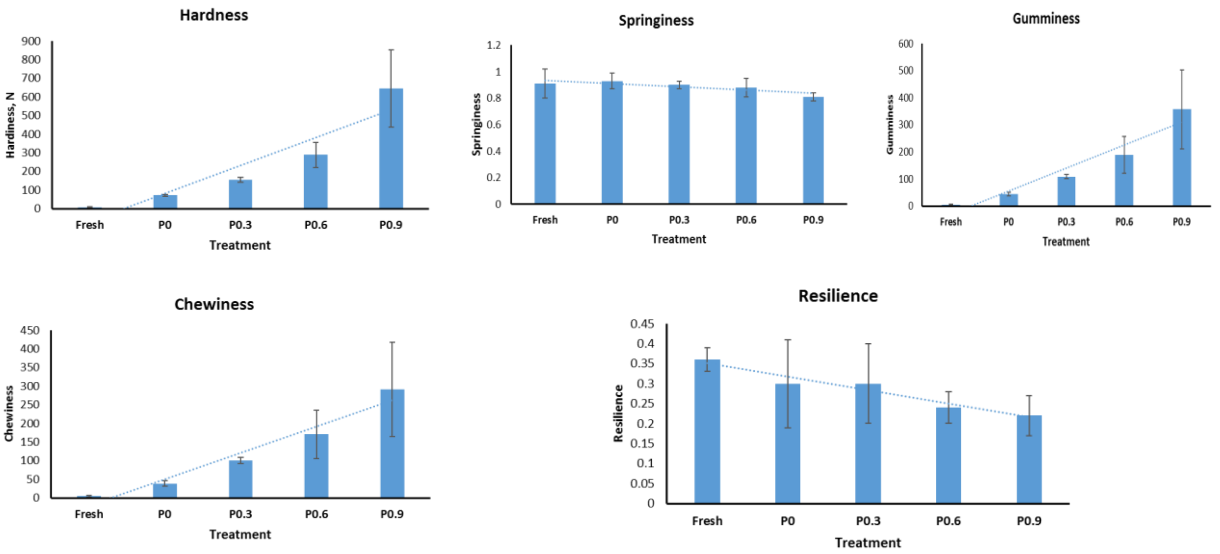

Fig. (7): Primary TPA properties of fresh banana, and dried banana slices at different vacuum drying, l error bars represent 95% confidence intervals.

Table (5): Effect of vacuum drying on texture profile properties of dried banana slices

Property	Sample				
	Fresh	**1 kPa**	**4 kPa**	**7 kPa**	**10 kPa**
Hardness	7.27^{e} ± 2.87	645.24^{a} ± 207.31	288.45^{b} ± 66.82	153.34^{c} ± 13.09	71.19^{d} ± 5.69
Adhesiveness	- 0.42 ± 0.23	-	-	-	-
Springiness	0.91^{b} ± 0.11	0.81^{d} ± 0.03	0.88^{c} ± 0.07	0.90^{b} ± 0.03	0.93^{a} ± 0.06
Cohesiveness	0.62^{c} ± 0.05	0.54^{e} ± 0.07	0.61^{d} ± 0.07	0.64^{b} ± 0.13	0.71^{a} ± 0.09
Gumminess	4.62^{d} ± 2.09	357.62^{a} ± 145.84	188.77^{ab} ± 67.6	108.23^{b} ± 7.92	43.41^{c} ± 6.68
Chewiness	4.36^{d} ± 2.19	290.99^{a} ± 126.29	170.87^{ab} ± 65.28	100.4^{b} ± 7.98	38.67^{c} ± 8.1
Resilience	0.36^{a} ± 0.03	0.22^{b} ± 0.05	0.24^{b} ± 0.04	0.30^{a} ± 0.10	0.30^{a} ± 0.11

CONCLUSION

Drying time of banana slices decreased at low drying pressure. The drying time range was 5.25 to 23.25 h. Deff values increased as the drying temperature and air velocity increased. The minimum Deff ranged from - 0.507 to -0.1104 m^2/s with high coefficients of determination (R^2 = 0.9335 to 0.9457). The drying conditions affected the properties of the TPA of the dried banana slices as compared with the fresh banana slices prior to drying. The drying process increased hardness, gumminess, and chewiness, while they reduced the cohesiveness and resilience and no adhesiveness after vacuum drying. The most affected properties were the hardness, and chewiness, whose ranges were 71.19 to645.24 (N), and 38.67to 290.99 (N), respectively.

REFERENCES

Abano, E. E.; Sam-Amoah, L. K. (2011) "Effects of different pretreatments on drying characteristics of banana slices". *ARPN J. Eng. Appl. Sci. 6*(3): 121–129.

AOAC (1995) Official methods of analysis, 16th ed. Washington, DC USA

Argaiz, A.; Lopez-Malo, A.; Palou, E. and Welti, J. (1994) "Osmotic Dehydration of Papaya with Corn Syrup Solids"Drying Technology, 12(7): 1709–1725.

Babalis; S. J.; Belessiotis, V. G. (2004) " Influence of drying conditions on the drying constants and moisture diffusivity during the thin-layer drying of figs" Journal of Food Engineering, 65: 449–458.

Barbosa-Canovas, G. V.; and Vega-Mercado, H. (1996) "Dehydration of foods" Chapman and Hall, New York, 330p

Ceylan, I.; Aktas, M.; and Dogˇan, H. (2007) "Mathematical modeling of drying characteristics of tropical fruits" Appl Therm Eng, 27: 1931–36.

Dandamrongrak, R.; Young, G.; and Mason, R. (2002) "Evaluation of various pre-treatments for the dehydration of banana and selection of suitable drying models" Journal of Food Engineering, 55: 139–146

Demirel, D.; and Turhan, M. (2003) "Air-drying behavior of Dwarf Cavendish and Gros Michel banana slices" Journal of Food Engineering, 59: 1–11

Doymaz, I. (2004) "Effect of pre-treatments using potassium metabisulphide and alkaline ethyl oleat on the drying kinetics of apricots" Biosystem Engineering, 89(3): 281–287.

Doymaz, I. (2006) "Drying kinetics of black grapes treated with different solutions" Journal of Food Engineering, 76: 212–217.

Doymaz, I.; Tugrul, N.; and Pala, M. (2006) "Drying characteristics of dill and parsley leaves" Journal of Food Engineering, 77: 559–565

Erbay, Z.; and Icier, F. (2010) "A review of thin layer drying of foods: theory, modeling, and experimental results" Crit Rev., Food Sci. Nutr., 50: 441–464.

Falade, K. O.; and Abbo, E. S. (2007) "Air-drying and dehydration characteristics of date palm (Phoenix dactylifera L.) fruits" Journal of Food Engineering, 79: 724–730.

Ganesapillai, M., Regupathi, I.; and Murugesan, T. (2011) "Modeling of thin layer drying of banana (Nendran spp.) under microwave, convective and combined microwave-convective processes" Chem. Prod. Proc. Modell, 6: 1−10.

Garcia, R.; Leal, F.; and Rolz, C. (1988) "Drying of bananas using microwave and air ovens" . *Int. J. Food Sci. Technol. 23*: 73−80.

Guine R; and Barroca, M. J. (2012) "Effect of drying treatments on texture and color of vegetables (pumpkin and green pepper)" Food Bio-production Process, 90: 58–63.

Hassan, B. H.; and Hobani, A. I. (2000) "Thin layer drying of dates" Journal of Food Process Engineering, 23: 177–189.

Karimi, F. (2010) "Properties of the drying of agricultural products in microwave vacuum: A review article" Journal of Agricultural Technology 6(2): 269−287.

Kingsly, A. R. P.; and Singh, D. B. (2007) "Drying kinetics of pomegranate arils" Journal of Food Engineering, 79: 741–744.

Leite, J. B.; Mancini, M. C.; and Borges, S. V. (2007) "Effect of drying temperature on the quality of dried bananas cv". *prata and d'agua*. *LWT-Food Sci. Technol. 40*: 319−323.

Moran, M. J.; and Shapiro, H. N.(1996) "Fundamentals of Engineering Thermodynamics" 3rd edition, Chapter 8. John Wiley and Sons, Inc., New York, NY, 859pp

Nidbal, M.; and Farid, M. (2002) "Microwave vacuum drying of banana slices" Article in Drying Technology · January 2002, https://www. researchgate. net/publication/233091761

Queiroz, M. R.; and Nebra, S. N. (2001) "Theoretical and experimental analysis of the drying kinetics of bananas" Journal of Food Engineering, *47*: 127−132

Rahman, M. S. (1995) "Food properties handbook" Boca Raton, FL, CRC Press: 191–196.

Roberts J. S.; Kidd, D. R.; Padilla-Zakour, O. (2008) "Drying kinetics of grape seeds" Journal of Food Engineering, 89: 460–465.

Robinson, J. C. (2006) "Present and future situation of banana production in the subtropics" In Soprano E, Tcacenco FA, Lichtemberg LA, Silva MC (Eds) Banana: A Sustainable Business, Proc. XVII ASCORBAT Int. Meet. (15-20/10). ASCORBAT/ACAFRUTA. Joinville, Brasil pp. 255–267

Robinson, J. C.; Sauco, V. G. (2010) "Bananas and Plantains" CABI, London, UK pp. 266−269

Silva, W. P.; Silva, C.; Sousa J. A. R.; and Farias, V. S. O.(2013) "Empirical and diffusion models to describe water transport into chickpea (*Cicer arietinum* L.)" *Int. J. Food Sci. Technol.*, *48*: 267−273.

Somogyi, L. P.; and Luh, B. S. (1986) "Dehydration of Fruits" Commercial Fruit Processing, Edited by J.G. Woodroof, and B.H. Luh, A VI Publishing Company Inc. Westport, CT. 678pp.

Sousa, W. A.; and Marsaioli, A. (2004) "Drying of bananas assisted by microwave energy" *Proc. 14th Int., Drying Symp.* (22-25/08) Sao Paulo, Brazil. Vol. C., pp. 1946-1954.

Swasdisevi, T., Devahastin, S., Ngamchum, R. and Soponronnarit, S (2007) ."Optimization of a drying process using infrared-vacuum drying of Cavendish banana slices Songklanakarin J. Sci. Technol., 2007, 29(3) : 809 −816

Vadivambal, R.; and Jayas, D. S. (2010) "Non-uniform temperature distribution during microwave heating of food materials-A review" Food and Bioprocess Technology, 3(2): 161–171.

Xanthopoulos, G.; Oikonomou, N.; Lambrinos, G. (2007) "Applicability of a single-layer drying model to predict the drying rate of whole figs" Journal of Food Engineering, 81: 553–559.

تأثير نظام التجفيف تحت تفريغ على زمن التجفيف وجودة شرائح الموز

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يعتبر التجفيف من أقدم عمليات حفظ الأغية . ومن طرق التجفيف استخدام التجفيف بالهواء الساخن وهذه الطريقة تعرض بعض المنتجات وخصوصا التي تحتوي على نسبة سكريات عالية لفقد مواصفاتها الطبيعية وتغير لونها مما يؤثر على جودةالمنتج. ولذا لجأ الباحثون لإستخدام طرق تكنولوجية جديدة مثل التجفيف باستخدام التفريغ والتفريغ مع نظام التجفيف بالميكروويف، وينبغي أن التأكد من مزايا التجفيف بالتفريغ في مجال التصنيع الغذائى. وفي هذا البحث تم دراسة وتحليل خصائص التجفيف لشرائح الموز باستخدام فرن التجفيف بالميكروويف تحت التفريغ لدراسة معدل التفريغ على خصائص الموز وزمن التفريغ . وقد تم التحقيق من صفات شرائح الموز من حيث تحليل الشخصية الملمس (TPA) والصلابة أيضا، وذلك بهدف إنتاج منتج يمثل وجبة خفيفة خالية من الدهون. وقد انخفض وقت التجفيف مع انخفاض ضغط التجفيف. وكان نطاق وقت التجفيف يتراوح من 5.25 إلى 23.25 ساعة. وكان الحد الأدني للانتشارية الحد الأدنى تراوحت من – 0.507 إلى -0.1104 م2 / ثانية مع معامل تحديد R^2 مرتفع ومعامل إرتباط عالى (r = 0.9335 to 0.9457). وقد تم مقارنة خصائص (TPA) للموزالمجفف مع الطازج واظهرت النتائج زيادة الصلابة وانخفاض التماسك وانعدام الالتصاق للفاكهة المجففة وتراوحت الصلابة بين 71.19 إلى 645.24 نيوتن.