Drying Kinetics Under Different Drying Methods and Quality of Slices Pumpkin

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Abstract

The purpose of this study was to make a comparison drying between low-pressure superheated (LPSS), and vacuum and hot air drying methods for pumpkin slices. The experiments were conducted to examine the drying kinetics and quality of dried products viz. color, shrinkage, rehydration, microstructure, texture (hardness and crispness) and the specific energy consumption (SEC) of the process. Results showed hot air drying would spend least drying time but it have high shrinkage and lowest rehydration when comparing with other method of drying. In aspect of hardness and crispness, LPSS drying would have lower hardness and higher crispness.

Keywords: Energy consumption, Low-pressure superheated steam drying, Pumpkin slice

Introduction

Currently, pumpkin has been processed by various methods due to raise its value and extend its shelf life for a long time such as pumpkin powder manufacturing and pumpkin chip including dried pumpkin in order to take it as breakfast cooking or snack manufacturing. And drying was one of methods regarded as the popular one for a long time. In addition, there were various methods for drying as well which they had their different advantage and disadvantage within themselves. For example, hot air drying was the convenient and fast method and its drying equipments were quite cheap since it used less equipments and technology used by it was not so complicated. But this method also had many disadvantages especially in aspect of nutrient quality of its products after its drying which easily losing when facing the heat and oxygen. It was found that there were many research works identified that hot air drying would cause food getting more damage than other method. But it also had many advantages thus there were many research works, studies and development about pumpkin drying with hot air coming out continuously form past to present such as.

Therdthai and Krajangmathekul et al. (2011) studied the quality of dried pumpkin undergoing drying with hot air and hot air drying combination with microwave and microwave combination with vacuum. The results showed that microwave usage accompanying with hot air drying could reduce more drying time, lightness value, and yellowness value of dried pumpkin. In addition, it was found that hot air drying accompany with microwave at vacuum condition would cause pumpkin's color changing after drying getting least value.

Nawirska et al. (2009) studied pumpkin slices drying with hot air drying, vacuum drying and microwave drying accompanying with vacuum. From the experiment was found to vacuum microwave drying would spend shorter drying time than hot air drying 10 times which all those drying methods could get better result than hot air drying.

Doymaz. (2006) studied pumpkin thin layer drying kinetics with hot air. The results showed that drying ratio was slow when temperature was decreasing and relative humidity was increasing. Moisture ventilation from pumpkin slices could explain with diffusion and there was accuracy of prediction from mathematical model. It could be concluded that logarithmic model and Verma model explained satisfied pumpkin drying characteristic which most closed to experimental result.

Alibas. (2006) studied pumpkin slices drying with 3 drying methods i.e. microwave drying, hot air drying and hot air drying accompanying with microwave. From the study was found to microwave drying accompanying with hot air was the best effected drying method by considering from drying time, color value and energy consumption. Besides hot air drying, which had gained its popularity for a long time from past to present as early mentioned. But it was found that vacuum drying also had gained its popularity by using it for agricultural products since its advantage was usage low drying temperature and there was least oxygen quantity in drying processing. Thus, it could reduce qualities damage in term of color and nutrient which sensitized to heat and oxidation occurrence well. This drying was popularized by using it drying vegetable and fruit products which emphasized special their qualities. But vacuum drying had its disadvantage i.e. its equipment cost was quite expensive and high energy consumption as well. In the past, there were many research works studied on vacuum drying such as:

Junlakan. (2014) study effect of drying kinetics on the quality of vacuum dried banana, pineapple and apple slices. It was found that it would spend shortest drying time period at the highest drying temperature. And in term of qualities was found to the dried fruit had given the highest yellowness value, low shrinkage, huge and numerous air hollow structure, high crispness value and high rehydration ability.

Arevalo-Pinedo et al. (2006) who study the drying kinetics of pumpkin (Cucurbita maxima) in nature and pre–treated by freezing and blanching was studied by using a vacuum dryer. It was observed that the applied pre- treatment influence favorably in the kinetic of drying, however freezing showed greater influence than blanching. It was observed that the best values were obtained for the highest temperature and lowest pressure for the samples pre–treated by freezing.

WuaL. et al. (2007) study the vacuum drying characteristics of eggplant were investigated. The results showed that increasing drying temperature accelerated the vacuum drying process, while drying chamber pressure did not show significant effect on the drying process within the temperature range investigated. Drying shrinkage of the samples was observed to be independent of drying temperature, but increased notably with an increase in drying chamber pressure. and the limitation of vacuum drying was that it still had oxygen coming in drying chamber during its working processing. Thus, it would still cause the problem in term of quality damage from oxidation occurrence. But this problem could be solved by using steam feeding into its system replacing the oxygen which could help to reduce the said problem. And this drying method was low pressure superheated steam drying which would have very similarity to vacuum drying such as:

Elustondo et al. (2001) studied low pressure superheated steam drying using natural materials and food group such as wood slab, shrimp, banana, apple, potato and cassava slices by considering only the drying kinetic by experimental and calculation of the equation by semi –empirical model. It was found that equation that could predict the drying of the sample group was good.

Pimpaporn et al. (2007) studied effects of combined pretreatments on drying kinetics and qualityof potato chips undergoing low– pressure superheated steam drying. It was found that combined blanching and freezing pretreatment were the best methods in aspect of qualities i.e. beautiful color, lower hardness value, more crispness value and without toughness. Recently, there were research study and working development on LPSS drying continuously. There were the different advantage and disadvantage of the said 3 drying methods. In any case, users would consider and select them for their purpose suitably. But there were researchers had studied and compared the 3 drying methods especially comparative studies on vacuum with LPSS drying

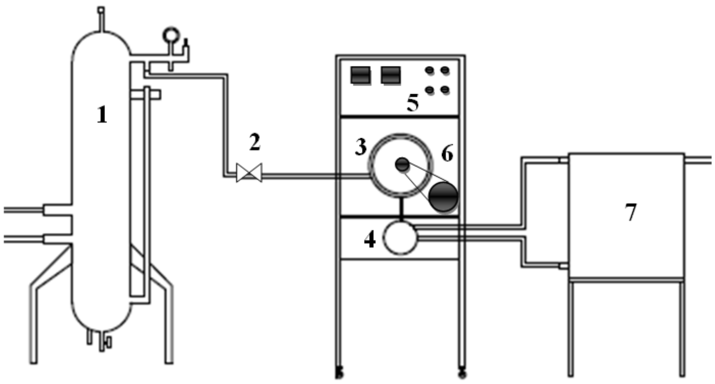
Devahastinet al. (2007) studied compare of low–pressure superheated steam and vacuum drying of a heat–sensitive material on kinetics and quality in term volume, shrinkage apparent density, color, and rehydration behavior which using carrot was experiment material. It was found that the LPSS drying takes over for drying time than vacuum drying but in terms of quality LPSS find a better quality of shrinkage has shaped evenness over and there was higher rehydration rate.

Leeratanarak et al. (2006) studied drying kinetics and quality of potato chips undergoing LPSS drying and hot air drying which quality in term of color, texture, and brown pigment. On their experimental procedure, potato would be taken for blanching in hot water by spending different blanching time. These investigators found that the potato undergoing blanching would get faster dried than without blanching one. And also it was found that LPSS drying was getting slower drying than hot air drying. Its exception was hardness value would decrease when potato was undergoing blanching. But when comparing between LPSS drying and hot air drying, The results showed that there was no difference.

Methakhupet at. (2005) studied effects of drying methods and conditions on drying kinetics and quality of Indian gooseberry flake. They found that vacuum drying spent less time than LPSS drying at every experimental conditions. In term of vitamin C quantity preserving, it was found that the two drying methods had given similar result but total color difference of Indian gooseberry flake that drying with vacuum drying was of more value than LPSS drying.

Thomkapanich. (2005) studied of intermittent low – pressure superheated steam and vacuum drying of banana. Intermittent low pressure superheated steam drying would support Moisturereduction rate of sample. Intermittent vacuum drying would spend longer drying time than regular drying. In term of quality of both low pressure superheated steam drying and vacuum drying, the results showed that the color of product would get more change than regular drying. Especially on long vacuum pump closing time, it would cause product's color getting more changing. However, no data research work which had been taken pumpkin for drying with LPSS drying and experimental comparative study with vacuum drying and hot air drying. Therefore, the objective of this research was to study LPSS drying with vacuum drying and hot air drying on drying kinetics, energy consumption and product quality (in terms of color, shrinkage, rehydration ratio, texture and micro structure).

Experimental set–up, materials and methods



1: boiler

2: steam value

3: drying chamber

4: vacuum pump

5: control system

Figure1. Experimental apparatus of the low-pressure superheated steam drying system.

It can also be seen in Table 1 that lower of drying time were obtained when the absolute pressure of the dryer was decreased. This is because decreasing of an absolute pressure resulted in a lower boiling point of water. The decrease of a boiling point of water resulted in an increase of the driving force for the outward moisture diffusion process. Hence, escaping of water molecules from the drying product became easier and faster. (Methakhup, Chiewchan and Devahastin, 2005)

Experimental set–up

Experimental apparatus of the drying system is illustrated in figure 1 show the details within drying chamber. The drying system was developed in the Department of Mechanical Engineering at Chiang Mai University Thailand. The system mainly consists of a cylindrical drying chamber dimensions of 30 cm in diameter and 40 cm long, made of stainless steel and insulated with elastomers; a 5 kW boiler, which could produce steam up to 8 kg/hr at slightly above atmospheric pressure; a water ring vacuum pump, whichwas creating vacuum pressure in the drying chamber; an 1.5 kW electric heater, which was used to supply thermal steam. An 0.2 kW electric fan was used to disperse the steam throughout the drying chamber. The change of sample mass during drying was recorded using a load cell (Transtronic, capacity 5 kg, China) with an accuracy of ± 0.2 g. The sample holder was hung in the drying chamber by a wire attached to the load cell. Water cooling tank made of polyethylene and capacity 100 liter was used reduce cooling water temperature of water ring vacuum pump to maintain vacuum pressure in the system. The temperatures within the chamber were measured by the type K thermocouplessending the signal to a PID controller. In case of vacuum drying and hot air drying experimental used the same LPSS drying experiment but do not used steam in the drying process.

Materials

Fresh pumpkin fruits (CV.TongAmpai) used in the drying experiments were provided from a provided from a local *market pumpkin in Chiang Rai, Thailand.* Samples were and sliced peeled and sliced to a thickness of 3 ± 0.3 mm using a knife. Then, pumpkin slices were cut into slabs with 30 mm length and 20 mm width. The initial moisture content of pumpkin was in the range of 700 – 900 % d.b., as determined by hot air oven at 103°C for 72 hr.

Methods

In all experimental method used a single experimental apparatus for all and perform a LPSS drying and vacuum drying experimental, the pumpkin slices prepared for each experiment, approximately 20 pieces, were placed in a thin layer on the sample holder. Steam valve was opened to allow the saturated steam from a boiler to flow into the drying chamber. The drying experiments were conducted under sub – atmospheric pressure at the steam temperatures of 80, 90 and 100°C and chamber absolute pressures of 7 and 10 respectively. In part of hot air drying experimental used drying temperatures of 80, 90 and 100°C while the constant inlet air velocity of about 1 m/s. The all experiments were stopped when the pumpkin moisture content of 18% d.b. (Thai community product standard, 2003) Before opening up the door of drying chamber and unloading the samples at the end of the drying process, the vacuum break – up valve was opened to allow the air into the chamber to regain atmospheric pressure. Moisture content of samples were measured and the dried products brought to test the quality in terms of color, shrinkage, rehydration ratio and texture (hardness and crispness)

Drying kinetics of pumpkin

The drying kinetics of pumpkin with initial moisture content of 700 – 900% d.b. The moisture ratio of pumpkin at any time was then calculated by:

$$\text{Moisture ratio (MR)} = \frac{M_t - M_{eq}}{M_i - M_{eq}}$$

where MR is the moisture ratio; M_t is the moisture content at any time (kg/kg.db.) M_i is the initial moisture (kg/kg.db.); $M_{eq}$is the equilibrium moisture content (kg/kg.db.); k is the drying constant (min^{-1}); t is time (min); n is the degree of nonlinearity of the drying curve. In this work, the steam temperature above the normal boiling point was used, so that it might be reasonable to assume the moisture content at equilibrium to be zero

Evaluation of specific energy consumption

In this study, three kilowatt–hour meters were connect to vacuum pump, electric heater and electric fan to measure the energy consumption of each component. The energy efficiency of drying process was evaluated in term of specific energy consumption:

$$\text{SEC} = \frac{(E_{vacuum} + E_{heater} + E_{fan})}{m_{water}}$$

where SEC is the specific energy consumption (kWh/kg $_{water}$), E_{vacuum} is the measured electric energy consumption of vacuum pump (kWh),E_{heater} is the measured electric energy consumption of heater (kWh), E_{fan} is the measured electric energy consumption of fan (kWh) and m_{water} is the amount of water evaporated form dried product (kg).

Color measurement

Color–measurement spectrophotometer (Hunter Association laboratory, Inc., model Mini Scan XE Plus, VA, USA) was used to determine the colors of fresh and dried samples in terms of the L, representing lightness from 0 (black) to 100 (white), a, representing redness(+)/greenness(–) and b, representing yellowness(+)/blueness(–) in Hunter Lab color system. For each during experiment the color measurements were performed on five samples at three different positions. The color changes of the samples were calculated by:

$$\Delta L = \frac{(L - L_o)}{L_o} \quad , \Delta a = \frac{(a - a_o)}{a_o} \quad , \Delta b = \frac{(b - b_o)}{b}$$

where L, a, b represent the lightness, redness and yellowness of the dried samples, respectively, while L_o, a_o, b_o represent the initial values of the lightness, redness and yellowness of the fresh sample, respectively

Shrinkage measurement

The shrinkage of dried pumpkin was measured and analyzed in terms of the percentage change of the volume of the sample, using the volumetric displacement method with vegetable oil as the working liquid. Ten samples were used for a shrinkage measurement for each experimental condition. Shrinkage of the dried pumpkin was expressed in terms of the following formula:

$$\%\ Shrinkage = \frac{V_o - V_f}{V_o} \times 100$$

where V_o and V_f are the initial and final volumes of a pumpkin sample, respectively. All tests were performed in duplicate and the average values were reported.

Rehydration ability

The rehydration ability of dried pumpkin slices was measured in terms of the mass ratio, evaluated by immersing a dried sample into hot water at 90°C for 10 minutes. The dried pumpkin were then taken out and wiped off with paper towel to eliminate excess water on its surface. The masses of the dried and rehydrated samples were measured by an electric balance with an accuracy of ±0.001 g. The rehydration ratio of the sample was then calculated by:

$$\text{Rehydration ratio} = \frac{m_{after}}{m}$$

Where m and m_{after} are the masses of the dried and rehydrated samples, respectively. The average values of for sample were reported. All measurements were performed in duplicate.

Texture analysis

The texture measurements of the sample were carried out using a texture analyzer (Stable Micro System, TA.XT.Plus, UK). The sample was placed on a hollow planar base and the force was then applied to the sample. A 5 mm spherical probe was set to travel at a constant speed of 2 mm/s until the sample was cracked. The maximum force of break and initial slope of deformation were indicated as hardness and crispness of the sample respectively (Aguilera, Castro, &Cadoche, 2004). All tests were performed in duplicate and the average values were reported.

Microstructure analysis

The microstructure of sample was observed by a scanning electron microscope (LEO, Leo 1450 VP, UK) at 190x magnification. The samples were cut and coated with a gold layer using a sputter–coater and the cross–section of dried products was photographed.

Results and discussion

Drying kinetics of pumpkin slices undergoing different drying processes

Fig. 2(a) and 2(b) shows the drying curves of pumpkin slices dried, it was found that LPSS drying spent less drying time than vacuum drying at all pressure and every temperature as well. Since the beginning of drying pumpkin in the boiling water evaporates away, the water moves out faster vacuum drying. But when we compared between LPSS drying and vacuum drying with hot air drying, it was found that hot air was faster drying than the two prior methods at every temperature. This was because hot air drying would use heat from air flow. It would cause simultaneous mass transfer and heat transfer on pumpkin's surface. And when air flow was increasing, it might cause more drying rate. Because of this, hot air drying caused more air speed than LPSS drying and vacuum drying. Due to this, it might definitely make hot air drying having the shortest drying time.

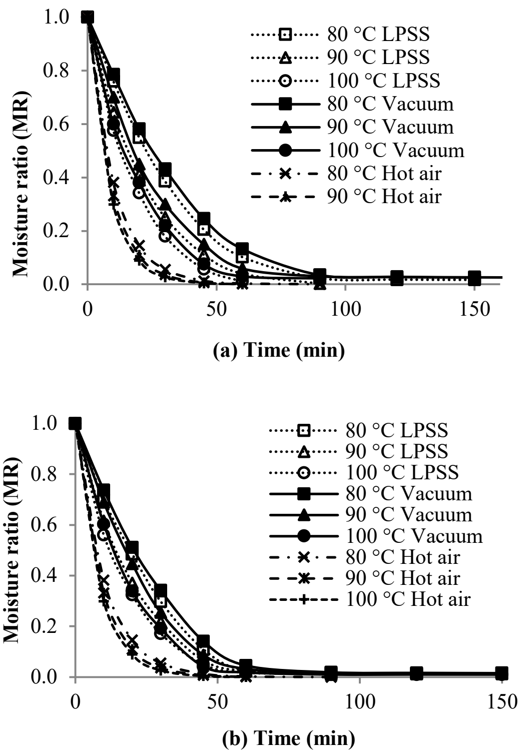


Figure 2. Comparison of drying curves of pumpkin slices undergoing low superheated steam drying and vacuum drying at (a) absolute pressures 7 kPa. (b) absolute pressures 10 kPa.

Evaluation of specific energy consumption

When comparing energy consumption of three drying methods as shown in the Table 1. The results showed that LPSS drying would have less specific energy consumption than vacuum in the pressure period at 7 kPa and 10 kPa because it spent less drying time. And when comparing LPSS drying and vacuum drying with hot air, it was found that hot air had lower SEC value than the prior two methods. This was because it spent less drying time and one more important thing, hot air did not use vacuum pump which consumed very high energy about 85% of the total consumed energy. Due to this, it would cause hot air having lowest SEC value.

Table 1 Specific energy consumption of vacuum drying

Method	Drying pressure (kPa)	Drying Temperature (°C)	Drying time (min)	SEC (kWh/kg water)
LPSS	7	80	70.0	111.36
		90	63.0	100.22
		100	55.0	87.49
	10	80	72.9	115.97
		90	63.5	101.02
		100	58.5	93.07
Vacuum	7	80	180	361.8
		90	150	340.7
		100	86	186.2
	10	80	112	222.4
		90	68	147.6
		100	60	134.8
Hot air		80	37.0	28.78
		90	26.0	26.00
		100	24.0	24.75

In case of redness value, LPSS drying would have more redness changing occurrence than Vacuum. But when comparing with hot air, it was found that redness value was decreasing. These results were similar to those reported by Devahastin et al. (2007) who compared the color values of drying carrot undergoing LPSS drying and vacuum.

Quality of color dried pumpkin slices.

The changes of color parameters of pumpkin undergoing LPSS drying, vacuum drying and hot air drying are listed in Table 2. In case of the lightness value, LPSS drying would have less lightness than vacuum drying in case which the pressure was increasing and it would obviously have more dark color since gelatinization was occurring in said pressure duration which caused pumpkin getting more dark color. But when comparing with hot air drying, it was found that it had more lightness value than the prior two methods since it spent less drying time because of it let hot air flowing through pumpkin surface which caused its surface getting dried so fast.

Table 2. Effects of drying temperature and pressure on the changes of lightness of dried pumpkin slices undergoing different drying methods.

Method	Drying Pressure (kPa)	Drying Temperature (°C)	ΔL	Δa	Δb
LPSSD	7	80	-0.160 ± 0.014[c]	0.500 ± 0.095[g]	-0.129 ± 0.022[ef]
		90	-0.212 ± 0.022[b]	0.508 ± 0.100[g]	-0.174 ± 0.012[d]
		100	-0.289 ± 0.005[a]	0.523 ± 0.093[g]	-0.300 ± 0.019[b]
	10	80	-0.077 ± 0.020[f]	0.461 ± 0.156[g]	-0.100 ± 0.021[f]
		90	-0.121 ± 0.054[de]	0.364 ± 0.145[f]	-0.115 ± 0.066[ef]
		100	-0.156 ± 0.042[c]	0.193 ± 0.060[e]	-0.140 ± 0.067[de]
Vacuum	7	80	-0.128 ± 0.024[f]	-0.247 ± 0.051[b]	-0.247 ± 0.015[c]
		90	-0.164 ± 0.044[c]	-0.138 ± 0.094[c]	-0.267 ± 0.066[c]
		100	-0.165 ± 0.042[c]	-0.130 ± 0.068[c]	-0.305 ± 0.047[b]
	10	80	-0.147 ± 0.017[cd]	0.097 ± 0.013[d]	-0.142 ± 0.026[de]
		90	-0.206 ± 0.054[b]	0.033 ± 0.004[d]	-0.164 ± 0.028[d]
		100	-0.148 ± 0.037[cd]	0.031 ± 0.010[d]	-0.139 ± 0.030[de]
Hot air	atm	80	-0.102 ± 0.033[ef]	-0.327 ± 0.074[b]	-0.111 ±0.039[ef]
		90	-0.080 ± 0.051[f]	-0.410 ± 0.066[a]	-0.109 ±0.050[ef]
		100	-0.089 ± 0.028[f]	-0.436 ± 0.028[a]	-0.376 ± 0.031[a]

Values in the same column with different superscripts mean that the values are significantly different ($p < 0.05$).

It was also found that LPSS drying gave redder and lighter those obtained by vacuum drying but when compare versus hot air found that the redness was reduced. These results were similar to those reported by Leeratanarak et al. (2006) who studied drying kinetics and quality of potato chips undergoing LPSS drying and hot air drying compares the color values which also found that LPSS drying led to smaller increase of a value than hot air drying. In case of yellowness value, it was found that LPSS drying, vacuum drying and hot air drying have nearly same values which were not quite different.

Shrinkage dried pumpkin slices.

Form Table 3. comparing was pumpkin's shrinkage drying with LPSS drying and vacuum drying, it was found that pumpkin drying with LPSS drying was of less shrinkage at every temperature and pressure period used in drying. These results were similar to those reported by Devahastin et al. (2007) who compared the shrinkage values of drying carrot undergoing LPSS drying and vacuum drying. It was also found that both method smaller difference. This was because LPSS drying would cause water inside pumpkin's flesh boiling in the drying moment at boiling point temperature of that pressure. Due to this, it would affect too many porous occurrences and there was very regular distribution. So it was able to reduce better shrinkage than Vacuum drying which there was no the said boiling manner which can see in figure 3 (a) and (b) compare figure 3 (c) and (d). But considering among LPSS drying, vacuum drying and hot air drying, it was found that the temperature period 80°C and 90°C Hot air drying was of the very shrinkage. This was because hot air drying would cause more subsidence of inner structure of pumpkin's flesh at the low temperature which the view from the figure 3 (a), figure 3 (c) and 3 (e) it shown SEM photographs to see that the pumpkin slice using hot air drying would have collapsed and packed with a homogeneous than the other method.

Table 3. Effects of drying temperature and pressure on shrinkage, rehydration ratio, hardness and crispness of dried pumpkin slices.

Mothod	Drying pressure (kPa)	Drying temperature (°C)	Volume shrinkage (%)	Rehydration ratio	Hardness (N)	Crispness (N/mm)
LPSSD	7	80	90.18 ± 0.98^{def}	3.66±0.04^{ef}	14.42 ± 1.56^{ab}	7.43 ± 0.88^{a}
		90	86.95 ± 1.54^{ab}	3.70±0.45^{ef}	14.96 ± 1.77^{ab}	9.01 ± 0.97^{a}
		100	86.92 ± 1.78^{cde}	3.86±0.10^{f}	11.73 ± 1.68^{a}	11.77 ± 1.34^{ab}
	10	80	90.48 ± 1.85^{cdef}	3.33±0.15^{ab}	27.51 ± 0.61^{e}	7.60 ± 0.55^{a}
		90	89.37 ± 0.87^{cd}	3.38±0.10^{abc}	22.7 ± 1.76^{d}	8.69 ± 2.54^{a}
		100	88.92 ± 1.23^{cd}	3.85±0.30^{f}	20.77 ± 0.69^{d}	11.15 ± 1.21^{ab}
Vacuum	7	80	89.60±1.16^{cde}	3.30±0.24^{a}	16.52 ± 0.13^{bc}	7.20 ± 0.99^{a}
		90	89.62±1.34^{cde}	3.55±0.05^{bcde}	15.26 ± 1.68^{bc}	8.11 ± 0.99^{a}
		100	85.88±0.39^{a}	3.56±0.09^{cde}	12.02 ± 3.06^{a}	11.12 ± 0.45^{ab}
	10	80	91.27±0.74^{ef}	3.26±0.06^{a}	28.10 ± 2.72^{e}	7.22 ± 0.64^{a}
		90	88.52±0.97^{bc}	3.36±0.12^{abc}	25.36 ± 2.32^{e}	8.11 ± 2.65^{a}
		100	89.92±0.63^{cde}	3.60±0.05^{de}	21.15 ± 1.79^{d}	10.14 ± 0.49^{ab}
Hot air	atm	80	92.48±1.10^{f}	3.73±0.06^{ef}	31.31 ± 1.62^{f}	4.85 ± 2.68^{ab}
		90	92.34±1.02^{f}	3.67±0.02^{ef}	20.50 ± 1.13^{d}	8.88 ± 2.89^{c}
		100	90.15±1.96^{cdef}	3.40±0.01^{abcd}	18.07 ± 1.70^{cd}	8.91 ± 4.23^{bc}

Values in the same column with different superscripts mean that the values are significantly different ($p < 0.05$).

Rehydration ratio

Form Table 3. when comparing between LPSS drying and vacuum drying, it was found that LPSS drying would have higher rehydration ratio at particular low pressure period i.e. 7 kPa and 10 kPa at the same temperature. These results were similar to those reported by Devahastin et al. (2007) who compared the rehydration values of drying carrot undergoing LPSS drying and vacuum drying.

It was also found that LPSS drying had much better rehydration capability than that vacuum drying. Because of pumpkin drying using LPSS drying will pore over night can suck the water back over the vacuum drying which pumpkin flesh is holding tight layer was spread throughout the pumpkin. Since the pumpkin which dried with LPSS drying would cause more pore. It would be able to reabsorb more water than vacuum drying. And the inside of pumpkin's flesh would have layered solid aggregation spreading in pumpkin's flesh. It could be seen from the picture SEM images figure 3 (a), (b) and figure 3(c), (d) When comparing with pumpkin's flesh drying with vacuum drying, there was more air hollow manner within its inner structure. It was able to reabsorb water more than low pressure period. But when comparing among 3 methods, it was found that pumpkin's flesh drying with hot air would have lowest rehydration since there was more air flowing through it at the pumpkin's surface. It would cause its surface getting dried so fast and cause hard layer obstructing water reabsorption.

Hardness and Crispness

Form the table 3. when comparing LPSS drying, vacuum drying and hot air drying, it was found that LPSS drying would have less hardness value and more crispness all pressure and every temperature period. These results were similar to those reported by Thomkapanich et al. (2006) who studied of intermittent low–pressure superheated steam and vacuum drying of banana. This is because the flesh pumpkin has a total of more porous and evenly distributed. Due to the water in pumpkin boiling to vaporize at low temperatures which there is increasing pressure within the material, thus resulting in a large porous and the number pore over vacuum drying and hot air drying. This similar behavior has also been reported by other workers by Leeratanarak et al. (2006) who studied drying kinetics and quality of potato chips undergoing different drying techniques. It was found that hot air drying has hardness more than LPSS drying. Since there were more air hollows in pumpkin's flesh and they spread themselves constantly

This was because it let water inside the product boiling and became steam at the low temperature and there was more pressure inside the product. Due to this, it would cause pore big size and more pore than vacuum drying and hot air drying.

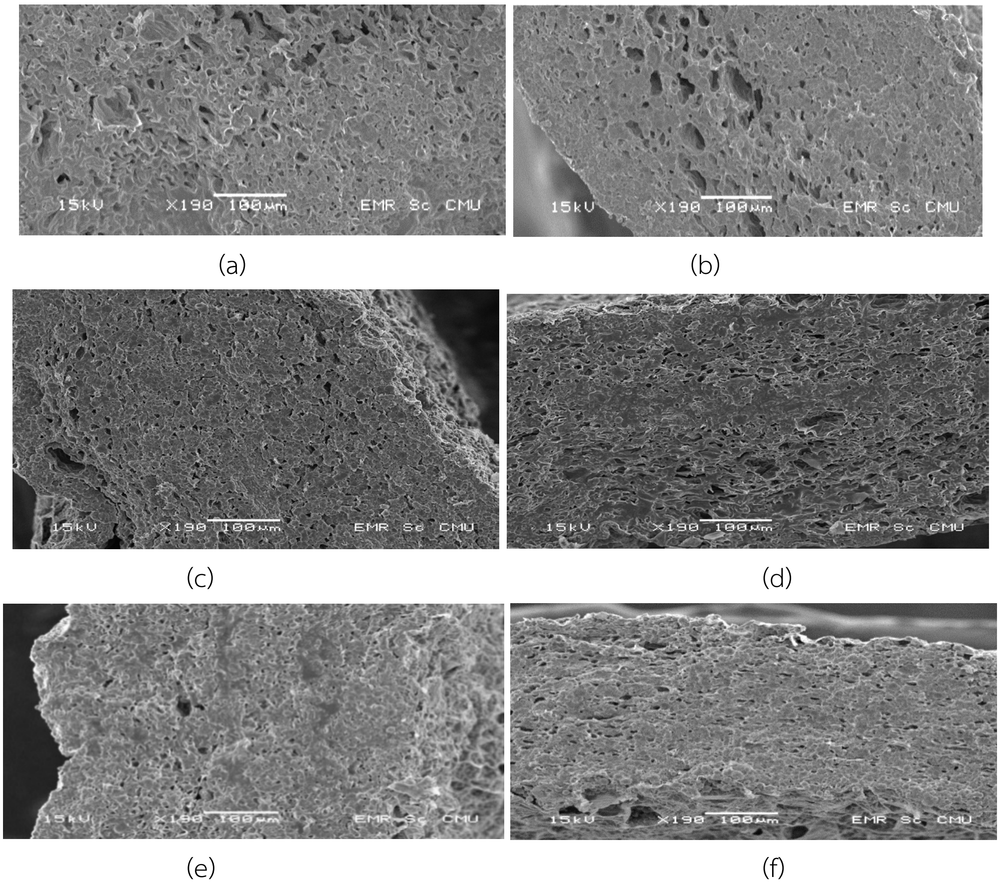


Figure 3. SEM photographs showing cross section of dried pumpkin slices using hot drying underwent different conditions. (a) lpss drying 7 kPa,80°C; (b) lpss drying7 kPa, 100°C; (c) vacuum drying7 kPa, 80°C; (d) vacuum drying7 kPa, 100°C; (e) hot air drying80°C; (f) hot air drying 100°C.

Conclusions

From the study or drying kinetics and quality of pumpkin slices undergoing from different drying methods, it was found that hot air drying would spend least drying time. But when comparing just only between LPSS drying and vacuum drying, it was found that LPSS drying spent less drying time than vacuum drying. In aspect of energy consumption, hot air drying would consume least energy when comparing with LPSS drying and vacuum drying due to it spent shortest drying time and there was no vacuum pump usage. But when comparing just only between LPSS drying and vacuum drying, it was found LPSS drying would spend more energy than vacuum drying.

Hot air drying would give the most lightness. Since it spent short time which let pumpkin slices touching with more heat and white starch granules were occurred on the surface. LPSS drying would have most changing in aspect of redness. In aspect of yellowness, it was found that drying method did not quite affect to its changing.

In aspect of shrinkage and rehydration, hot air drying would have high shrinkage and lowest rehydration when comparing with other type of drying especially at low temperature including high rehydration since its inside had high air hollow which let it have ability to reabsorb water well.

In aspect of hardness and crispness, hot air drying would have more hardness and least crispness. This was because the surface area of pumpkin would become hard layer which caused from hot air including there was less air hollow in pumpkin's inner flesh.

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