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Investigation of Thermal Utilization Efficiency in Different Drying Methods of Pomegranate Arils

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Abstract

In this study, thermal utilization efficiency for drying of pomegranate arils was evaluated using various drying methods including hot air, microwave and vacuum, infrared. Results from data analysis showed that the lowest and highest thermal utilization efficiency levels in drying pomegranate arils were associated with vacuum drying and microwave dryers, respectively. Based on the results of data analysis in vacuum dryer, thermal utilization efficiency increased with increasing drying temperature. Thermal utilization efficiency in convective dryer decreased with increasing temperature in such a way that the highest thermal utilization efficiency occurred at 70 °C and the lowest efficiency occurred at 40 °C. Furthermore thermal utilization efficiency increased by applying microwave pretreatment in hot air convection method. Thermal utilization efficiency in IR dryer increased with increasing IR radiation.

Keywords: Drying methods; Infra-red radiation; pomegranate; Thermal utilization efficiency; Microwave drying

Introduction

The pomegranate scientific name Malus granatum, with the meaning of high grain apple, is from the Punicaceae tribe. Pomegranates according to their tastes can be divided to two groups of sour and sweat. It's main matrix is the Near East, specially Iran so it's sour kind exists abundantly in wild form in Iran north jungles. Pomegranates are popularly consumed as fresh fruit, beverages (juice and wine) and other food products (jams and jellies).

Drying is known as the best method to preserve fruits and vegetables. Water removal during drying prevents microorganism evolution and harmful chemical reactions leading to longer storage time (Barbosa-Canovas and Vega-Mercado, 1996).

Different methods are used to pomegranate preservation, like drying which is cheaper than other ways.

Drying makes the pomegranate able to be preserved for longer time. (Walde et al., 2007). One of the most common methods in farm products drying is hot air convection method. This method has some drawbacks like low energy efficiency, low quality of dried products and longer period of drying time. These drawbacks led to use of some new techniques in agricultural and food products drying (Boudhrioua et al., 2003; Wang and Sheng 2006). Infra-red radiation (IR) is an electromagnetic kind of radiation which its absorption causes thermal vibration in product or food. IR drying specially is appropriate for thin layers of farm crops or foods which are in radiation exposure (Motevali et al., 2011a, b). In IR drying, special infrared lamps are used to extract moisture from the material being dried. In this method, the air surrounding wet matter flows using a ventilator or suction device to remove humidity released by the matter from its vicinity in order for it to face less resistance while avoiding material surface saturation with dump. Drying of chemicals, pharmaceuticals and foodstuff in industry and performing laboratory tests to determine drying characteristics of different materials are among applications of IR drying (Nonhebel G, 1973). Infra-red ray can heat the crop and extract humidity of it by penetration, but its penetration power is limited. Other drawbacks of using IR-drying are high operation expenses and drying thin layers of materials like outer layers and food coatings. By combining IR drying method with hot air convection, this problem is almost solved (Dostie et al, 1989).

In normal thermal processing (hot air drying, IR drying and combination of hot air and IR drying), energy can be transmitted to the crop by transmission, conduction and radiation. Due to food thermal conductivity reduction in period of descending drying process with hot air drying, IR drying and combination of hot air and IR drying, velocity of heat transfer to the interior parts of crop decreases (Feng and Tang, 1998; Adu and Otten, 1996). In order to resolve these problems and prevention of significant deterioration of product quality and also to achieve efficient and rapid heat transfer process, using microwave for drying crops has developed.

Microwave drying in comparison with normal hot air drying and IR drying takes less time and drying process in this method is done by using lower energy consumption (Yongsawatdigul &Gunasekaran, 1996a; Drouzasm & Dchubert, 1996). Despite conventional heating systems, in microwave drying, due to waves penetration into the crop, heat is spread throughout of the food and energy transfer by conduction barriers, particularly in the viscous materials is not influenced (Krulis et al., 2005; Mertens and Knorr, 1992; Abbasi and Rahimi, 2007). That's why the heat transfer rate in the microwave method is faster than other methods.

In vacuum drying method due to lack of oxygen in dryer ambiance and unwanted reduction of reactions in food, the quality of dried food in this method is higher than the others (Motevali et al., 2011 a, b). Also applying vacuum in food drying causes expansion of air and vapor and creates puff state in the matter. This factor leads to swelling of foodstuff and because of increase in area and volume, greater amount of heat transfers between drying matter and hot air (Kompany et al., 1993; Jaya and Das, 2003). One of drawbacks of vacuum drying method is high energy consumption in farm products and foods drying. Due to the high energy consumption in this method, vacuum drying can be used for highly sensitive and high value-added products (Motevali et al., 2011 a, b).

Although several studies have been carried out to investigate convective, IR, IR-convective, vacuum, Microwave and Microwave-vacuum drying characteristics of various agriculture products and food materials such as eggplants (Wu et al., 2007), white radish (Lee and Kim, 2009), Pomegranate arils (Motevali et al., 2011a), Date Paste (Ashraf et al., 2012), Salicornia herbacea L. (2012), Black Mulberry (Esmaeili Adabi et al., 2013), mint (2007), spinach (2007), sardine fish (Darvishi et al., 2012), peach (Wang and Sheng, 2006), mushroom (Lombraña et al. 2010, Ghaderi et al., 2012, Motevali et al., 2011b), garlic (Figiel, 2009), beet roots (Figiel, 2010), Grape (Caglar, 2009; Ruiz Celma et al.,, 2009), olive husk (Ruiz Celma et al., 2008) and etc, no investigation on the comparison of thermal utilization efficiency in different methods of drying.

Thermal utilization efficiency is defined as the ratio of latent moisture evaporation heat of sample to the amount of energy required to evaporate moisture from free water (Umesh Hebbar et al., 2004). Considering that the highest energy consumption in agriculture is related to drying the product, different drying methods can be evaluated to calculate and compare the energy requirements for drying a particular with each product.

The study objectives include comparing the thermal utilization efficiency during drying of the mushroom slices using six drying methods including 1. Hot air 2. Infrared 3. Hot air –infrared 4. Microwave 5. Vacuum, 6. microwave-vacuum.

Materials and Methods

Fresh sour pomegranate was purchased from Juybar city of Mazandaran province and kept in refrigerator at 5°C. Initial pomegranate moisture content was determined gravimetrically and was found to be % 73.1 wet bases (Motevali et al., 2010). After drier preparation and its adjustment for desired conditions according to the experiment plant, pomegranate arils were placed in the drying chamber in baskets. Various experiments were performed with the following treatment. 1- hot air drying: six temperature levels of 45, 50, 55, 60, 65 and 70°C, three air velocity levels of 0.5, 1 and 1.5 m/s. 2- hot air drying with microwave pretreatment: 100 W microwave pretreatment for 20 minutes and 200 W microwave pretreatment for 10 minutes. 3- Microwave drying using a Samsung model M945 microwave oven at 100, 200 and 300 W power levels. 4- Vacuum drying at 250 kPa in a vs-1202 v5, (Korea) vacuum dryer. The vacuum pump was a Serno 26431801, (Germany) diaphragm vacuum pump.

This experimental was conducted at five temperature levels of 50, 60, 70, 80 and 90°C. 5- The drying process in IR dryer was performed at illumination levels of 0.22, 0.31 and 0.49 w/cm^2 and four air velocity levels of 0.3, 0.5, 0.7 and 1 m/s at 25° C.

Thermal Utilization Efficiency

This efficiency is defined as the ratio of latent moisture evaporation heat of sample to the amount of energy required to evaporate moisture from the free water. Eq. (1) is used to determine thermal utilization efficiency (Umesh Hebbar *et al.,* 2004):

$$T.U.E = LA_d l_h(M_i - M_o)/3600Pt(100 - M_0) \qquad (1)$$

where L is weight density of pomegranate arils (kg/m^2), A_d, total product area (m^2), l_h, latent heat of vaporization (kJ/kg), M_i, Initial moisture content (wb%), M_o, final moisture content (w.b.%), P, heat capacity of the heat source (kW) and t operation time of the heat source (h). Initial moisture content of samples (M_i) was on the average 73 (w.b. %) and was dried to a final moisture content (M_o) of 7 (w.b. %). Since water makes up more than 93% (w.b. %) of pomegranate arils, the latent heat of vaporization the samples was considered equal to the latent heat in the ambient pressure for hot air, microwave, infrared and hot air -infrared combination dryers. The latent heat of evaporation in the different levels of the experiment was also considered equal to for vacuum and microwave-vacuum dryers.

Results and Discussion

Convective Drying

Results obtained from calculating thermal utilization efficiency of the dryer show that this result for drying pomegranate slices varies in different drying methods. In IR drying, it ranged from 27% to 67% and in hot air drying from 18% to 53% and hot air drying with microwave pretreatment from 22% to 68%. Since in each drying experiment, latent heat of vaporization (λ), initial moisture content (M_i) and final moisture content (M_o) are constant for given values of applied heat capacity (Q) and initial sample weight, the thermal utilization efficiency of the device is solely dependent upon performance of the heat sources (electric heaters, IR lamps and microwave radiation).

The highest efficiency in hot air drying was at 70°C and air velocity of 0.5 m/s because of the low performance of heaters resulting in low temperature and air flow rate. This is because control of the air passing the heater chamber was designed such that heaters could only turn on when the air temperature was lower than the desired temperature. The lowest efficiency in drying using hot air convection method was obtained at 45°C where heaters had the highest performance time (Table 1, 2 and 3).

Using multiple regression analysis, a relationship was established between thermal efficiency utilization, temperature and air velocity in the hot air dryer (Fig. 1, 2 and 3). The equation and the associated coefficient of determination (R^2) are given below the figure.

IR Drying

In IR drying, infrared lamps are continuously on during the experiment, and increase in drying temperature (through decreased the distance between infrared lamp and sample) reduces sample drying time resulting in decreased energy consumption and consequently increased drying efficiency. In the IR method, drying time is decreased through reduction in air flow rate and thus thermal utilization efficiency is increased. Therefore, a combination of 49 W/cm^2 power and 0.5 m/s air velocity with thermal utilization efficiency of 68% is recommended (table 4).

Using multiple regression analysis, a relationship was established between thermal efficiency utilization, IR radiation and air velocity in the IR dryer (Fig. 4). The equation and the associated coefficient of determination (R^2) are given below the figure.

Microwave and Vacuum Drying

In the microwave dryer, the highest efficiency was 84% achieved at 130 W power, while the lowest was 67% at 480 W (table 5). The reason for decreased efficiency at higher power levels can be further waste of microwaves. Thermal utilization efficiency of this dryer is higher than the other dryers.

In figure 5 using multivariable regression analysis a relationship have been established between thermal efficiency utilization and microwave power. Respective equations and R^2 for each figure has been given inside it. Using the equation, the thermal efficiency utilization can be calculated for microwave power changes. Using such equations obviates the need for performing experiments in various microwave power levels.

While in the vacuum dryer, thermal efficiency is decreased due to high energy consumption and high latent heat of evaporation at low absolute pressures. The lowest thermal efficiency is 29% obtained 40°C and the highest efficiency was 49% at 90°C. However, the problem of prolonged drying time at lower temperatures makes these temperatures undesirable. Therefore, it is not recommended to dry mushroom slice, at 40°C (Table 4). By comparing the amount of energy consumed and thermal efficiency, 80 and 90°C temperatures can be suggested.

In figure 6 using multivariable regression analysis a relationship have been established between thermal efficiency utilization and air temperature. Respective equations and R^2 for each figure has been given inside it.

Conclusions

In this study, thermal efficiency utilization in four different methods of drying button mushroom slices was studied. Comparison of four drying methods, shows that maximum thermal efficiency utilization was calculate in the microwave dryer and minimum thermal efficiency utilization in vacuum drying with 78 and 12%, respectively. Also results show that power increasing shows an increasing process in both microwave drying and vacuum drying methods. The best drying method in terms of thermal efficiency is the microwave drying.

Table 1: Thermal utilization efficiency in convective drying method (control treatment)

Drying Method	Pretreatment	Temperature (°C)	Air Velocity (m/s)	T.U.E (%)
	Control Treatment	45	0.5	28
		50	0.5	34
		55	0.5	39
		60	0.5	44
		65	0.5	47
		70	0.5	53
		45	1	24
		50	1	29
		55	1	36
		60	1	42
		65	1	45
		70	1	49
		45	1.5	18
		50	1.5	22
		55	1.5	27
		60	1.5	32
		65	1.5	38
		70	1.5	43

Table 2: Thermal utilization efficiency in convective drying method (Microwave pretreatment 100W)

Drying Method	Pretreatment	Temperature (°C)	Air Velocity (m/s)	T.U.E (%)
	Microwave pretreatment (100W)	45	0.5	35
		50	0.5	39
		55	0.5	42
		60	0.5	45
		65	0.5	51
		70	0.5	58
		45	1	29
		50	1	31
		55	1	38
		60	1	40
		65	1	46
		70	1	52
		45	1.5	22
		50	1.5	25
		55	1.5	31
		60	1.5	36
		65	1.5	38
		70	1.5	43

Table 3: Thermal utilization efficiency in convective drying method (Microwave pretreatment 200W)

Drying Method	Pretreatment	Temperature (°C)	Air Velocity (m/s)	T.U.E (%)
	Microwave pretreatment (200W)	45	0.5	39
		50	0.5	43
		55	0.5	49
		60	0.5	53
		65	0.5	59
		70	0.5	68
		45	1	32
		50	1	36
		55	1	44
		60	1	47
		65	1	53
		70	1	57
		45	1.5	26
		50	1.5	33
		55	1.5	40
		60	1.5	44
		65	1.5	52
		70	1.5	58

Table 3: Thermal utilization efficiency of infrared radiation drying method

Drying Method	Air Velocity (m/s)	IR Radiation (W/cm^2)	T.U.E (%)
IR Drying	0.3	0.22	58
		0.31	67
		0.49	64
	0.5	0.22	47
		0.31	53
		0.49	50
	0.7	0.22	41
		0.31	46
		0.49	40
	1	0.22	27
		0.31	39
		0.49	37

Table 4: Thermal utilization efficiency of the microwave dryer

Drying Method	Microwave Power (W)	T.U.E (%)
Microwave Drying	130	54
	260	78
	450	74

Table 5: Thermal utilization efficiency of the vacuum dryer

Drying Method	Temperature (°C)	T.U.E (%)
Vacuum Drying	40	12
	60	21
	70	27
	80	33
	90	37

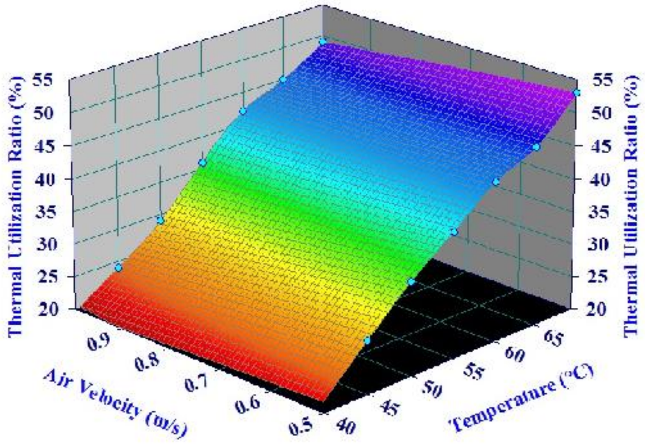

Fig.1. Effect of temperature and air velocity on thermal utilization efficiency during control treatment drying

$TUE = 60.77 + 2.10T - 320.24V - 0.01T^2 + 204.67V^2 + 0.11TV$	$R^2 = 0.986$

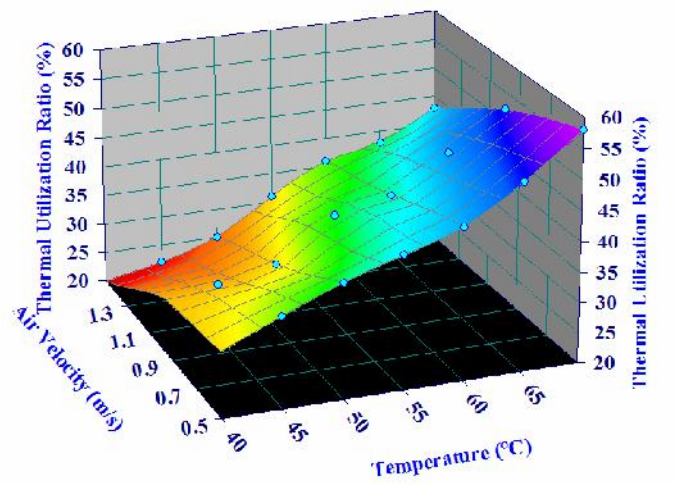

Fig.2. Effect of temperature and air velocity on thermal utilization efficiency during microwave treatment drying (100W)

$TUE = 47.91 - 162.29T + 159.52T^2 - 61.90T^3 + 301.54V - 401.23T^2$	$R^2 = 0.949$

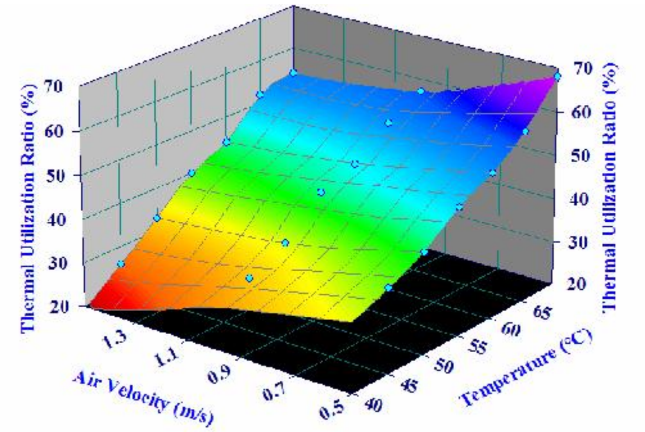

Fig.3. Effect of temperature and air velocity on thermal utilization efficiency during microwave treatment drying (200W)

$TUE=-18.78+3.50T-0.055T^2+0.00037T^3-88.08V+85.21V^2-29.18V^3$	$R^2 = 0.987$

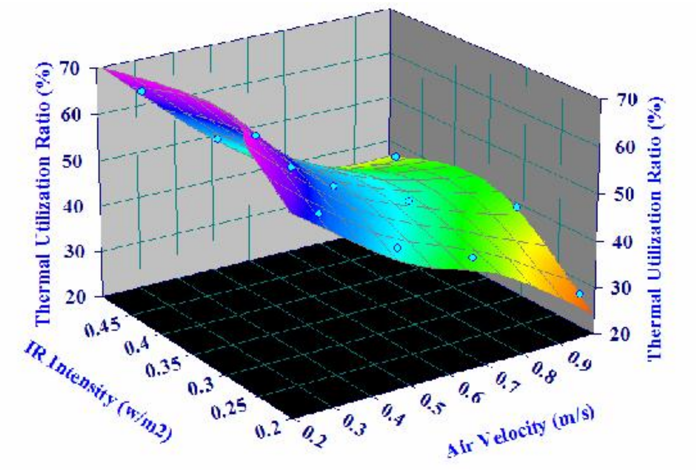

Fig. 4. Effect of IR intensity and air velocity on thermal utilization efficiency for drying of pomegranate arils

TUE=-2.46+1.186V-26.31R-0.00095V^2+7.33R^2+0.023RV	R^2 = 0.984

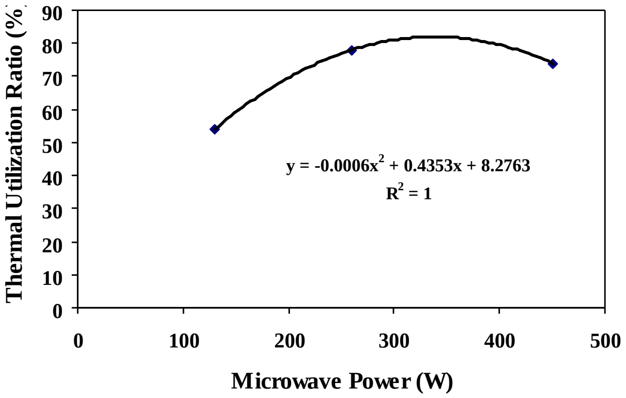

Fig. 6. Effect of microwave power on thermal utilization efficiency in microwave dryer

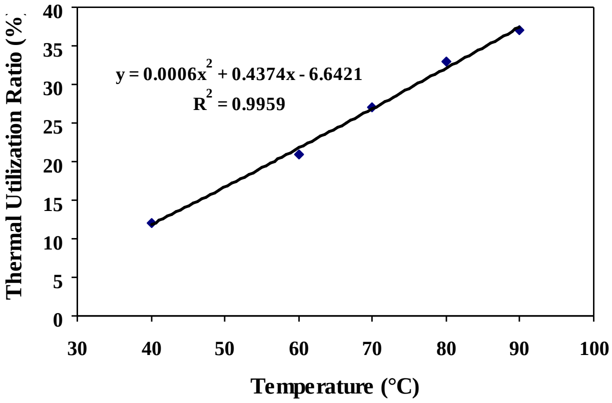

Fig. 6. Effect of temperature on thermal utilization efficiency in vacuum dryer

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