Evaluation of drying rate and quality characteristics of potato slices during drying by infrared radiation heating method under vacuum

Negar Hafezi[*], Mohammad Javad Sheikhdavoodi, Seyed Majid Sajadiye and Mohammad Esmail Khorasani Ferdavani

Department of Mechanics of Agricultural Machinery and Mechanization, Faculty of Agriculture, ShahidChamran University, Ahvaz, Iran.

ABSTRACT

The effect of drying behavior on drying rate and quality characteristics of potato slices in a vacuum- infrared drying system was studied. In this work, the effect of the infrared radiation powers (100, 150 and 200 W) and vacuum levels (20, 80, 140 mm [Hg] and atmosphere pressure) at different thickness (1, 2 and 3 mm) on drying rate, shrinkage percentage and rehydration capacity were investigated. From the study, it was concluded that IR power level has significant effects to processing time and drying rate.The processing time reduced,while drying rates were higher with increased in IR power. Drying rate curve of potato slices at initially time of drying because of surface moisture evaporation in the ascending phase and afterward due to the start of influence of water from within of material to surface descending phase occurs. Also shrinkage percentage increased with increase of sample thickness. In other words, shrinkage was decreased at different thickness with increase of infrared radiation power and vacuum level. It was found that the long period of drying and increase of sample thickness may have contributed to a decrease in rehydration capacity. However, rehydration capacity at temperature 100°C for 3 min was more than temperature 25°C in duration 12 min.

Introduction

Processed foods are normally changed in numerous ways from their fresh counterparts with regard to appearance, flavor, texture, nutrient content and microbiota. Consumers demand high quality and convenient products with natural flavor and taste and greatly appreciate the fresh appearance of minimally processed food (Anjum et al., 2006).Fruits and vegetables are agricultural products that are known for their rich vitamins, high concentration of moisture and low fats. They are highly perishable due to excess moisture present in them especially at harvest. Fruits and vegetables are seasonal crops and are mostly available during the production season. Potatoes are members of the Solanaceae family. Of the many tuber- forming Solarium species, the onethat is most widely cultivated is Solarium tuberosum. In 2007 total world production of potatoes wasmore than 320 million tonnes, and about 66% were consumed by people as food. The other 34%production is used as animal feed, and as potato starch in pharmaceuticals, textiles, adhesives industries.In industry, the drying technologies have been widely used for processing food products. Potato is rich in carbohydrates, proteins, phosphorus, calcium, vitamin C, β-carotene and has high protein calorie ratio. Amongst the world's important food crops, Potato is the fourth important food crop after wheat, rice and maize because of its' great yield potential and high nutritive value. The ratio of protein to carbohydrate is higher in potato than in many cereals and other tuber crops (Marwaha et al., 1999). It constitutes nearly half of the world's annual output of all root and tuber crops and has always remained in the top ten since last twenty years. India ranks fourth in area with 14 lakh hectares and the third largest country in the world in production of potato after China and Russian federation with a production of 294.94 million tonnes and productivity of 17.86 tonnes per hectare (Faisal et al., 2013).

Drying is defined as a process of moisture removal due to simultaneous heat and mass transfer. The moisture can be either transported to the surface of the product and then evaporated, or evaporated internally at a liquid vapour interface and then transported as vapour to the surface (Gogus, 1994). The technique of dehydration is probably the oldest method of food preservation practiced by mankind. The use of artificial drying to preserve agricultural products has expanded widely, creating a need for more rapid drying techniques and methods that reduce the large amount of energy required in drying processes. New and/or innovative techniques that increase drying rates and enhance product quality have achieved considerable attention.

Drying is the most common form of food preservation. This process improves the food stability, since it reduces considerably the water and microbiological activity of the material and minimizes physical and chemical changes during its storage (Hatamipour et al., 2007). Drying of food products has been a very important industrial sector for many years. Drying is the most energy intensive process in food industry. Therefore, new drying techniques and dryers must be designed and studied to minimize the energy cost in drying process (Kocabiyik and Tezer, 2009).

Microbial activities are not active when the moisture content of a product is below 10 %. Hence, harvested vegetables must be stored dry (5% moisture content wet basis) (FAO, 1981) to prevent attack and deterioration by activities of microorganisms and fungi. Considering the fact that the highest energy consumption in agriculture is associated with drying operations, different drying methods can be evaluated to determine and compare the energy requirements for drying a particular product. Dried fruits and vegetables can be produced by a variety of processes. These processes differ primarily by the type of drying method used, which depends on the type of

food and the type of characteristics of the final product (Mujundar, 1987).

The quality evaluation of the dried product was carried out on the basis of response variables viz. Rehydration Ratio, Shrinkage Percentage, Color and the Overall Acceptability. Besides the nutrient contents, most of the previous studies on drying of fruits and vegetables considered the rehydration characteristics of dried samples. The rehydration rate and ratio were obtained by soaking dried samples in water at determined temperature and period of time. Rehydration is a complex process aimed at the restoration of previously dried materials in contact with water. It is generally accepted that the degree of rehydration is dependent on the degree of cellular and structural disruption. During dehydration, irreversible rupture and dislocation occur resulting in loss of integrity and hence a dense structure of collapsed, greatly shrunken capillaries with reduced hydrophilic properties as reflected by the inability to rehydrate fully (Lewicki, 1998). Pre-drying treatments and drying induce changes in structure and composition of plant tissues (Lewicki, 1998), which results in impaired rehydration properties. One of the most important physical changes that the food suffers during drying is the reduction of its external volume. Loss of water and heating cause stresses in the cellular structure of the food leading to change in shape and decrease in dimension. Shrinkage of food materials has a negative consequence on the quality of the dehydrated product. Changes in shape, loss of volume and increased hardness cause in most cases a negative impression in the consumer. There are, on the other hand, some dried products that have had traditionally a shrunken aspect, a requirement for the consumer of raisins, dried plums, peaches or dates Several authors have tried to relate the effect of collapse and porosity with the kinetics and extension of some chemical reactions in foods undergoing drying and further storage (Mayor and Sereno, 2004).

Infrared radiation has significant advantages over conventional drying. Among these advantages are higher drying rates giving significant energy savings, and uniform temperature distribution giving a better quality product. Therefore, it can be used as an energy saving drying method (Mongpraneet et al., 2002). 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 suction device (vacuum pump) 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. Infrared radiation drying has the unique characteristics of energy transfer mechanism. 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. 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., 2011a, b). For drying under vacuum (or vacuum drying), moisture within the product being dried evaporates at lower temperatures (lower than 100°C) giving better product quality, especially in the cases of foods or agricultural products, which are heat-sensitive in nature. When the advantages of the two dying methods are combined, energy efficiency of the drying process is enhanced and degradation of dried product quality is also reduced. Earlier attempts to apply infrared to drying of agricultural materials have been reported in the literatureDoymaz, 2011; Sharma et al., 2005;Abe & Afzal,

1998. Combined infrared radiation and convection or vacuum drying has also been reported as promising (Kouchakzadeh, and Haghighi, 2011; Nimmol, 2010; Swasdisevi et al., 2009). Far infrared drying of potato achieved high drying rates with infrared heaters of high emissive power (Masamura et al., 1988). The drying rate was also reported to be increased when the electric power supplied to the far infrared heater was increased and consequently the temperature of the sample was also observed to be high. Akpinar et al. (2005) found that the potato slices are sufficiently dried in the ranges between 60 and 80℃ and 20%−10% relative humidity at 1and 1.5 m/s. Reyes et al. (2007) found that the type of dryers and the drying temperature had a strong effect on drying rate and on the color and the porosity of the dried potato slices, while the rehydration capacity and the maximum penetration force were not affected. Gowen et al. (2006) studied the rehydration properties of microwave -hot air combination drying of chickpeas and performed an optimization for the process. The report suggested that high levels of microwave power could adversely affect rehydrated product quality. It was found that high power level resulted in low retention of product quality. Pimpaporn et al. (2007) studied the influence of various pretreatments and drying temperature on the low-pressure superheated steam drying kinetics and quality parameters of dried potato chips. Khraisheh et al. (2004) studied the quality and structural changes of potatoes during microwave and convective drying. They reported that air drying led to higher structural changes than in the case of microwave drying. Mongpraneet et al. (2002) examined the drying behavior of the leaf parts of welsh onion undergoing combined far infrared and vacuum drying. The results showed that the radiation intensity levels dramatically influenced the drying rate and the dried product qualities. Singh et al. (2006) found that rehydration rates of sweet potato slices were dependent of drying condition and rehydration temperature. Hernandez et al. (2000) proposed a linear relation for shrinkage of foods as a function of moisture content. Hatamipour and Mowla (2002) reported a linear correlation for volume change and empirical relation for axial contraction of carrots during drying in a fluidized bed dryer with inert particles.
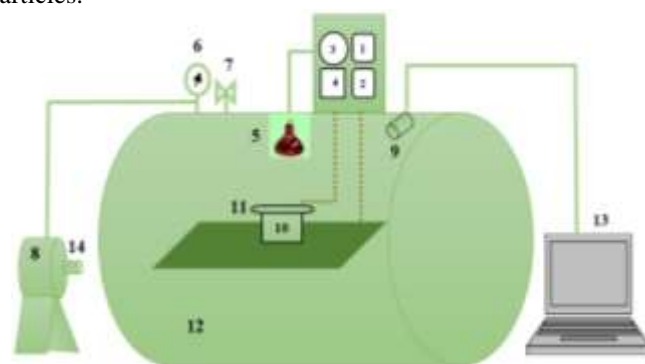
Figure 1. A schematic diagram of a vacuum- infrared drying system: 1) humidity sensor; 2) thermocouples; 3) infrared lamp power controller; 4) voltmeter; 5) infrared lamp; 6) vacuum gauge; 7) vacuum break-up valve; 8) vacuum pump; 9) webcam; 10) electronic balance; 11) sample tray; 12) drying chamber; 13) laptop; 14) air outlet duct.

The objective of this study is to examine the drying behavior of potato slices by drying rate and quality characteristics using combination of infrared radiation heating method with the vacuum operating condition.

Experimental set-up, materials and methods
Experimental set-up

A laboratory scale vacuum- infrared dryer, developed at the Agricultural Machinery and Mechanization Engineering Laboratory, ShahidChamran University (Iran).A schematic diagram of the apparatus for combined vacuum and infrared radiation drying system is shown in Fig. 1. The dryer consists of a stainless steel drying chamber, which is designed to withstand lower level of pressure; a laboratory type piston vacuum pump, which is used to maintain vacuum in the drying chamber; an infrared lamp with power of 250 W (OSRAM, Slovakia), which is used to supply thermal radiation to a drying product; and a control system for the infrared radiator.

Materials and Methods
Sample Preparation

Fresh potatoes were purchased from a local market in Hamadan province (Iran). The samples were stored in refrigerator to prevent undesirable effect at about 5-6oC and relative humidity of about 85%. Potatoes were peeled, washed, and cut into sliced with thickness of 1, 2 and 3 mm by a manual cutter. The samples were blanched in solution containing 2% NaCl for 3 min. The initial moisture content of the fresh samples was 77% (wet basis, wb), which was determined in triplicate by using a convection oven at 70°C for 24 h (AOAC, 1990). Drying experiment potato slices was dried in a vacuum chamber with vacuum levels i.e., 20, 80 and 140 mm [Hg]; IR power of 100, 150 and 200 W. The distance between the infrared lamp and the sample tray was set at 15 cm. The change of the mass of the sample during drying was detected continuously using an electronic balance (Lutron, GM- 1500P, Taiwan) with an accuracy of ±0.05 g. The temperatures of the drying chamber and of the drying sample were measured continuously using thermocouples (SAMWON ENG, SU-105KRR). In start of experiments relative humidity and temperatures of the drying chamber were measured (respectively 35% and 50°C). The drying experiments were performed until the sample moisture content of 6-7% (w.b.) was obtained

Theoretical principle
Modelling of drying kinetics

The moisture content of the samples was found during the drying process at different length of the dryer using equation (1).

$$M_w = \left(\frac{W_w - W_d}{W_w} \right) \times 100$$

(1)

Where: M_w is the moisture content wet basis (%); W_w is the initial weight of potato samples (gr); W_d is the dry weight of potato samples (gr)

Because of the variation in initial moisture content of fresh potato, moisture ratio was used to describe the drying behavior of potato in this study. To calculate the drying rate, an appropriate empirical equation was fitted to the experimental moisture removal data (drying curve) and was then differentiated with respect to time. To find a suitable mathematical model, the moisture content data at different thickness, vacuum levels and infrared power were converted to the moisture ratio (MR, dimension less) expression by using following equation.

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

(2)

Where: MR is the moisture content ratio; M_t is the moisture content at any drying time wet basis (kg water/kg wet material); M_e is the equilibrium moisture content wet basis (kg water/kg

wet material); M_o is the initial moisture content in wet basis (kg water/kg wet material).

Determination ofdrying rate

The drying rate is expressed as the amount of the evaporated moisture over time. The drying rate of potato slices was calculated using the following equation:

$$DR = \frac{MC_{t+dt} - MC_t}{dt}$$

(3)

Where, DR is the drying rate, (kgH$_2$O/kg wet matter. min); MC_{t+dt} is the moisture content at time t+dt, (kgH$_2$O/kg wet material); MC_t is the moisture content at time t (kgH$_2$O/kg wet material) and dt is the time between two sample weighing (min).

Measurements of volume and shrinkage of fresh and dried potato slices

The shrinkage percentage is a drying quality assessing parameter and it must be least for better drying as it directly affects the rehydration quality of the dried product. The shrinkage percentage was calculated after determining the size of the potato slices before and after drying using toluene displacement method (Mohsenin, 1986). For each measurement, three slices were randomly selected. Shrinkage of potato slices at the end of drying process was calculated using the following equation (Koc et al., 2008).

$$\% SKG = \left(1 - \frac{V}{V_0} \right) \times 100$$

(4)

Where V_0 and V denote the initial and dried volume of the same potato slice, respectively.

Measurements of rehydrationcapacity of dried potato slices

The measurement of the water rehydration rate was based on the following procedure. The rehydration tests measured the gain in weight of dehydrated samples (~1 g), dehydrated samples were rehydrated in 200 g of distilled water at 25°C and 100°C for 12 min and 3 min, respectively. 25°C represents the condition of room temperature and 100°C as the temperature at boiling point of water. Samples were withdrawn, drained, wrapped in absorbent tissue to remove surface water and weighed on an analytical balance. Rehydration capacity (R_C) was calculated by Eq (5).

$$R_C = \frac{(M_t - M_r)}{(M_i - M_r)}$$

(5)

The amount of initial M_i and residual moisture content M_r of the samples (w.b.) was determined from the moisture content of fresh and dried potatoes, respectively. The moisture of the rehydrated product M_t was calculated from the sample weight before and after rehydration. The rehydration measurements were made three times for all the samples and average values were reported (Reyes et al., 2007).

Results and discussion
Calculation of drying rate

Figure 2-4. Shows the variations of drying rate with drying time at vacuum level 140 mm [Hg] based on the thickness of potato slices at the various IR power level of 100, 150 and 200 W. Drying rate curve at vacuum levels of 20 and 80 mm Hg and atmosphere pressure was observed such as vacuum level of 140 mm Hg. Drying rate curve of potato slices at initially time of drying because of surface moisture evaporation in the ascending phase and afterward due to the start of influence of water from within of material to surface descending phase occurs.
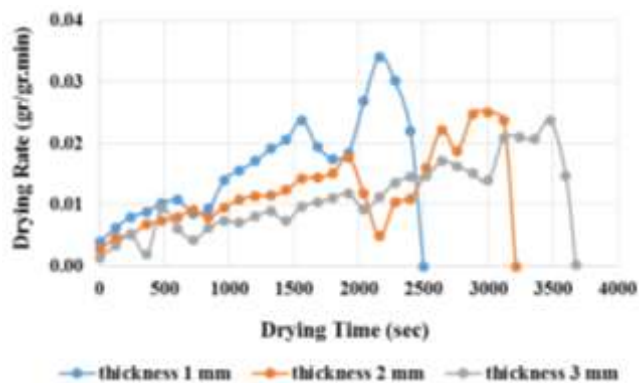
Figure 2. Effect of thickness on drying rate of potato slices at vacuum level of 140 mm Hg and at IR power of 100 W
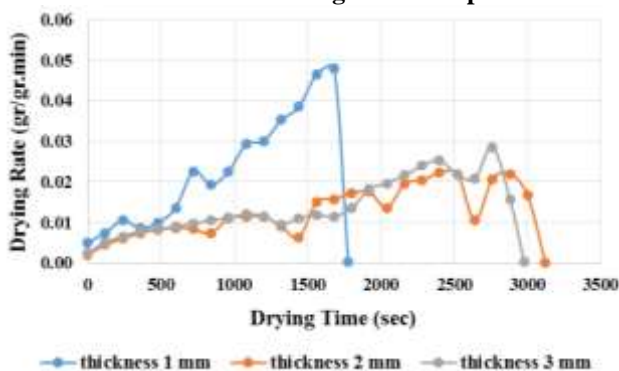

Figure 3. Effect of thickness on drying rate of potato slices at vacuum level of 140 mm Hg and at IR power of 150 W
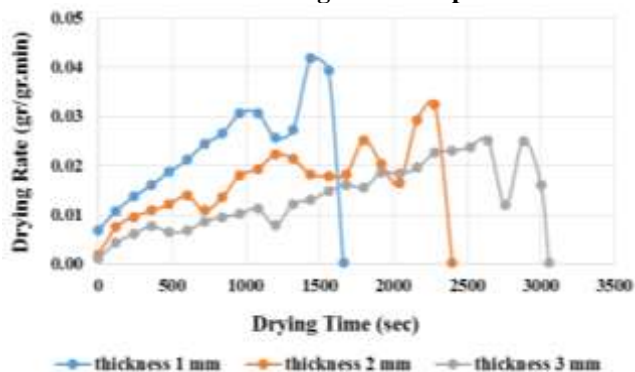

Figure 4. Effect of thickness on drying rate of potato slices at vacuum level of 140 mm Hg and at IR power of 200 W

Calculation of shrinkage percentage

Figure 5. Shows that maximum of shrinkage percentage (85.31%) and minimum of shrinkage percentage (61.79%) was computed at thickness of 3mm and 1 mm, respectively.
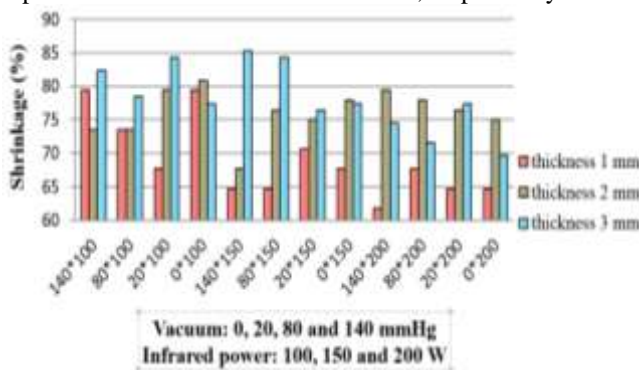

Figure 5. Shrinkage percentage of potato slices in vacuum-infrared drying system

According to Table 1 the factor of thickness has most relationship with volume changes. This coefficient suggests that

direct proportion have to the volume changes. This table display that factors vacuum and IR power have indirect proportion to the volume changes. In other words, shrinkage was decreased at different thickness with increase of infrared radiation power and vacuum level.

Table 1. Correlation coefficients of the ratio of the volume measured by toluene displacement

		Correlations			
		shrinkage	thickness	vacuum	power
Pearson Correlation	shrinkage	1.000	0.622	-0.019	-0.381
	thickness	0.622	1.000	0.000	0.000
	vacuum	-0.019	0.000	1.000	0.000
	power	-0.381	0.000	0.000	1.000

Calculation of rehydration capacity

The long period of drying and increase of sample thickness may have contributed to a decrease in rehydration capacity. Figure 6. Shows that at temperature 25°C for 12 min at the power level of 150 W, vacuum 20 mm [Hg] and thickness of 1 mm, however, fresh-like properties were obtained.
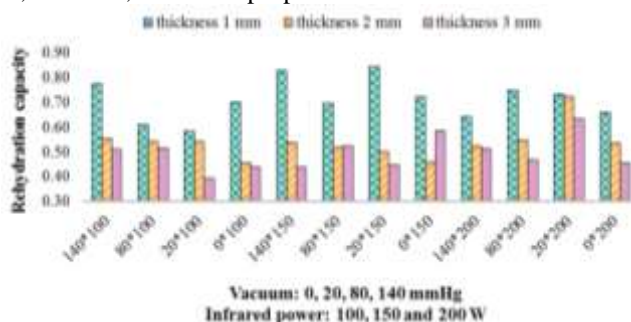

Figure 6. Rehydration capacity of potato slices at temperature 25°C for 12 min in vacuum- infrared drying system

Figure 7. Shows that fresh-like properties were obtained at temperature 100°C for 3 min at the power level of 200 W, vacuum 80 mm [Hg] and thickness of 1 mm. According of results rehydration capacity at temperature 100°C was more than temperature 25°C. In both temperature, value minimum of rehydration was observed at IR power of 100 W and vacuum level of 20 mm [Hg] at thickness of 3 mm.
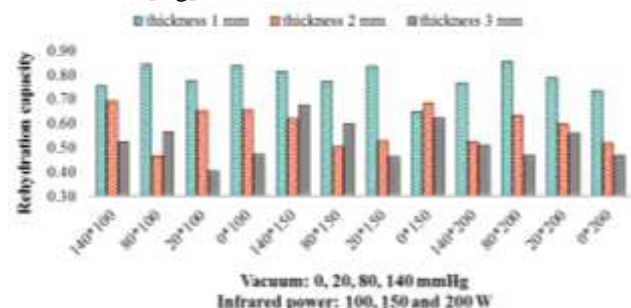

Figure 7. Rehydration capacity of potato slices at temperature 100°C for 3 min in vacuum- infrared drying system

Conclusions

From the study, it was concluded that IR power level has significant effects to processing time and drying rate. The processing time reduced, while drying rates were higher with increased in IR power. Data analysis showed that shrinkage percentage increased with increase of sample thickness. This means that Maximum of shrinkage percentage (85.31%) and minimum of shrinkage percentage (61.79%) was computed at

thickness of 3mm and 1 mm, respectively. The rehydration process at 100ºC yielded the highest rehydration capacity at thepower level of 200 Wvacuum 80 mm [Hg] and thickness of 1 mm.

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