

Evaluation of Quality Characteristics of Potato Slices during Drying by Infrared Radiation Heating Method under Vacuum

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Abstract

The effect of drying behaviour on the 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 mmHg and atmosphere pressure) at different slice thickness (1, 2 and 3 mm) on drying rate and shrinkage percentage and rehydration capacity were investigated. From the study, it was concluded that IR power level has a significant effect on processing time and drying rate. With increasing radiation power, time drying is reduced and consequently drying rate is increased. The drying rate curve of potato slices at initial drying time is in the ascending phase because of surface moisture evaporation and after this phase 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 an increase of infrared radiation power and vacuum level. It was discovered that the long period of drying and increase of sample thickness may have contributed to a decrease in rehydration capacity. Because of porous texture of potato, as soon put in boiling water for 3 minutes, the water absorption process quickly started and before the insert damage to product tissues, to maximum amount of water absorption will reach. The results also showed that with increasing shrinkage, rehydration capacity was decreased.

Keywords: *Potato, Drying rate, Vacuum, Infrared Radiation, Shrinkage, Rehydration*

1. Introduction

Processed foods are different from their fresh counterparts in numerous ways, including their appearance, flavour, texture, nutrient content, and micro biota. Consumers demand high quality and convenient products with natural flavour 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 fat content. 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, Solarium tuberosum is the most widely cultivated. In 2007, total world production of potatoes was more than 320 million tonnes and people consumed about 66% as food. The other 34% production was 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, and β -carotene and has a high protein-

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calorie ratio. Potato is the fourth most 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).

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 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 food stability since it considerably reduces 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 the food industry. Therefore, new drying techniques and dryers must be designed and studied to minimize the energy cost in the drying process (Kocabiyik and Tezer, 2009).

Microbial activities are not active when the moisture content of a product is below 10%. Therefore, harvested vegetables must be stored dry (5% moisture content wet basis) (FAO, 1981) to prevent attack and deterioration due to 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 content, 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 a 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. This is reflected by the inability of rehydrated samples 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 stress in the cellular structure of the food, leading to changes 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 usually cause a negative impression in the consumer. On the other hand, there are some dried products that have traditionally had a shrunken aspect, which the consumer expects, such as raisins, dried plums (prunes), dried peaches, and 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 that give significant energy savings and uniform temperature distribution that yields 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 so that it faces less resistance while avoiding material surface saturation with moisture. Infrared radiation drying has the unique characteristics of an energy transfer mechanism. In the vacuum drying method, the quality of dried food is higher than that of others methods due to a lack of oxygen in dryer ambience and unwanted reduction of reactions in food (Motevali et al., 2011 a, b). Also, applying vacuum in food drying causes the expansion of air and vapour and creates a 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 vacuum drying, the 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 drying methods are combined, the energy efficiency of the drying process is enhanced, and the degradation of dried product quality is also reduced. Earlier attempts to apply infrared radiation to drying of agricultural materials have been reported in the literature Doymaz, 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 reportedly 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. Akpınar et al. (2005) found that the potato slices are sufficiently dried in the ranges between 60 and 80°C and 20%–10% relative humidity at 1 and 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 colour 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 a high power level resulted in low retention of product quality. Pimpaporn et al. (2007) studied the influence of various pre-treatments 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 behaviour 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 on 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. The objective of this study is to examine the drying behaviour of potato slices by drying rate and quality characteristics using a combination of the infrared radiation heating method with the vacuum operating condition.

2. Experimental Set-up, Materials and Methods

2.1 Experimental Set-up

A laboratory scale vacuum-infrared dryer was developed at the Agricultural Machinery and Mechanization Engineering Laboratory of Shahid Chamran University of Ahwaz (Iran). A schematic diagram of the apparatus for the combined vacuum and infrared radiation drying system is shown in Figure 1. The dryer consists of a stainless steel drying chamber, which is designed to withstand a lower level of pressure, a laboratory type piston vacuum pump, which is used to maintain a 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.

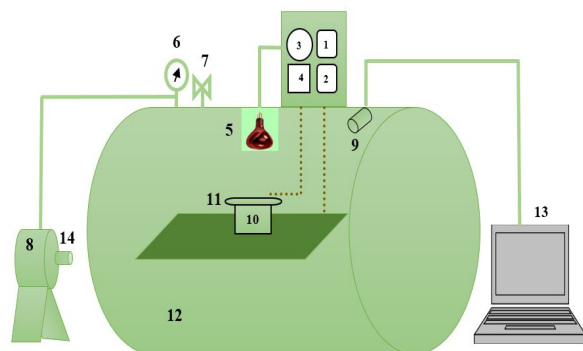


Figure 1: A schematic diagram of a vacuum-infrared drying system: 1) humidity sensor, 2) thermocouples, 3) infrared lamp power controller, 4) voltmeter, 5) infrared lamp, 6) vacuum gauge, 7) vacuum break-up valve, 8) vacuum pump, 9) camera, 10) electronic weight scale, 11) sample tray, 12) drying chamber, 13) laptop and 14) air outlet duct.

2.2 Materials and Methods

2.2.1 Sample Preparation

Fresh potatoes were purchased from a local market in Hamadan province (Iran). The samples were stored in a refrigerator at about 5-6°C and relative humidity of about 85% to prevent undesirable effects. The potatoes were peeled, washed, and cut into slices with thickness of 1, 2, and 3 mm by a manual cutter. 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 were dried in a vacuum chamber with various vacuum levels of 20, 80, and 140 mmHg; 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 gr. The temperatures of the drying chamber and of the drying sample were measured continuously using thermocouples (SAMWON ENG, SU-105KRR). At the start of the experiments, relative humidity and the 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.

3. Theoretical Principle

3.1 Modelling of Drying Kinetics

The moisture content of the samples was measured real time during drying process using equation [1].

$$M_w = \left(\frac{W_w - W_d}{W_w} \right) \times 100 \quad [1]$$

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 potatoes, moisture ratio was used to describe the drying behaviour 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 the following equation.

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad [2]$$

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).

3.2 Determination of Drying 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:

$$DR = \frac{MC_{t+dt} - MC_t}{dt} \quad [3]$$

Where: DR is the drying rate, (kgH₂O/kg wet matter. min); MC_{t+dt} is the moisture content at time t+dt, (kgH₂O/kg wet material); MC_t is the moisture

content at time t ($\text{kgH}_2\text{O/kg}$ wet material), and dt is the time between two sample weighing (min).

3.3 Measurement of Shrinkage of Fresh and Dried Potato Slices

The shrinkage percentage is a drying quality assessing parameter, and it must be as low as possible 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 the liquid displacement method (Mohsenin, 1986). For each measurement, three slices were randomly selected. Shrinkage of potato slices at the end of the drying process was calculated using the following equation (Koc et al., 2008):

$$\%SKG = \left(1 - \frac{V}{V_0}\right) \times 100 \quad [4]$$

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

3.4 Measurements of Rehydration Capacity 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 room temperature and 100°C represents the 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 Equation [5].

$$R_C = \frac{(M_t - M_r)}{(M_i - M_r)} \quad [5]$$

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).

4. Results and Discussion

4.1 Calculation of Drying Rate

Figure 2-4 shows the variations of drying rate with drying time at vacuum level 140 mmHg based on the thickness of potato slices at the various IR power levels of 100, 150, and 200 W. The drying rate curve at vacuum levels of 20 and 80 mmHg and atmosphere pressure was observed such as vacuum level of 140 mmHg. The drying rate of potato slices at first step has been rising and then gradually decreases. The reason for this is that at the beginning of the drying time due to the high moisture content of the product, the drying rate increases, but then to reduce the moisture content and the surface shrinkage of potato slices during drying process makes the descending phase.

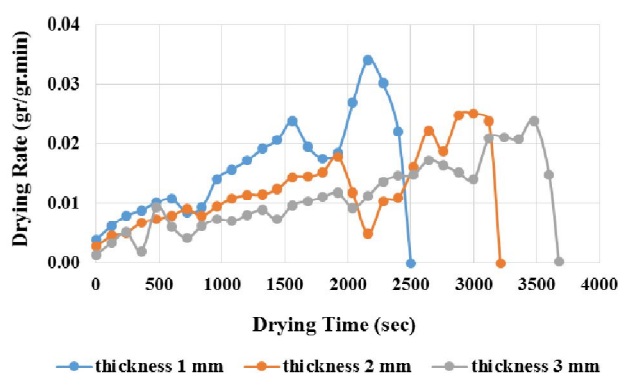


Figure 2: Effect of thickness on drying rate of potato slices at vacuum level of 140 mmHg and at IR power of 100 W

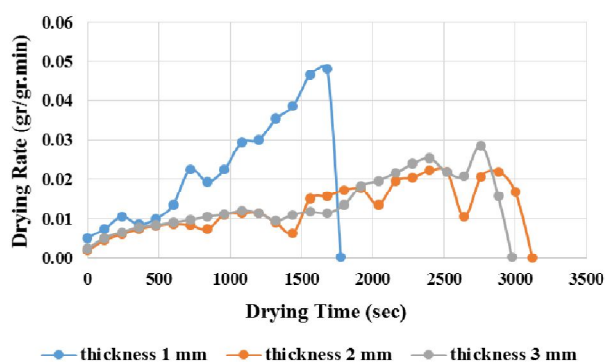


Figure 3: Effect of thickness on drying rate of potato slices at vacuum level of 140 mmHg and at IR power of 150 W

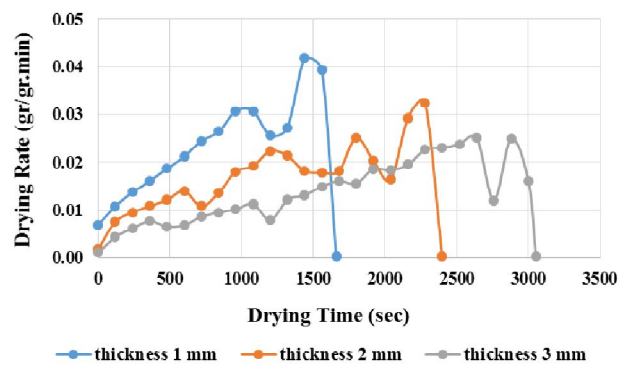


Figure 4: Effect of thickness on drying rate of potato slices at vacuum level of 140 mmHg and at IR power of 200 W

4.2 Calculation of Shrinkage Percentage

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

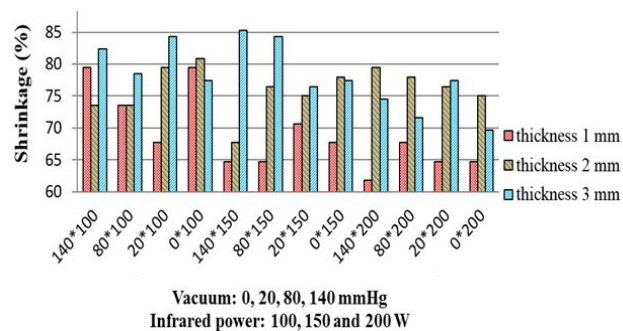


Figure 5: Shrinkage percentage of potato slices in vacuum- infrared drying method

Table 1

Correlation coefficients of the shrinkage by liquid displacement

Pearson Correlation	Correlations			
	Shrinkage	Thickness	Vacuum	Power
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

According to Table 1, the factor of thickness has the most relationship with volume changes (shrinkage). This coefficient suggests that a

directly proportional relationship between the two variable. This table show the factors vacuum and IR power have indirectly proportional relationships to the volume changes. In other words, shrinkage was decreased at different thickness with an increase of infrared radiation power and vacuum level.

4.3 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 mmHg and thickness of 1 mm. Figure 7 shows that maximum of rehydration rate was obtained at temperature 100°C for 3 minutes at the power level of 200 W, vacuum 80 mmHg, and thickness of 1 mm. According to the results, rehydration capacity at temperature 100°C was more than that at temperature 25°C. At both temperatures, the value minimum of rehydration was observed at IR power of 100 W and vacuum level of 20 mmHg at thickness of 3 mm.

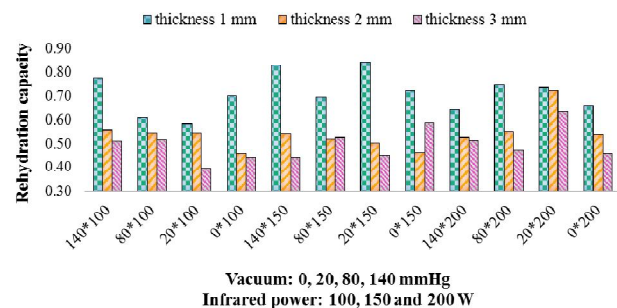


Figure 6: Rehydration capacity of potato slices at temperature 25°C for 12 min in vacuum- infrared drying method

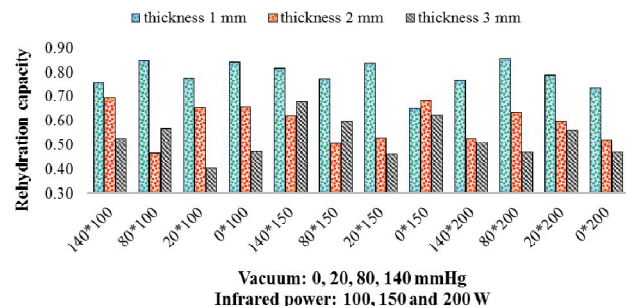


Figure 7: Rehydration capacity of potato slices at temperature 100°C for 3 min in vacuum- infrared drying method

According to the above picture results shows that in the vacuum- infrared method due to porous texture of potato, as soon put in boiling water (100°C) for 3 minutes, the water absorption quickly started and before the insert damage to product tissues, to maximum amount of water absorption will reach.

5. Conclusions

From the study, it was concluded that IR power level has significant effects on processing time and

drying rate. The drying time decreased, while drying rates increased with infrared radiation power increase. 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%) were computed at thickness of 3mm and 1 mm, respectively. The rehydration process at 100°C yielded the highest rehydration capacity at the power level of 200 W, vacuum 80 mmHg and thickness of 1 mm.

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