Assessment of some physical properties of dried potatoes

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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 research, 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. It was concluded that infrared radiation power amount has a significant effect on processing time and drying rate. With increasing radiation power, drying time 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 the material to surface descending phase occurs. Also, the statistical results indicated that thickness at error level of 1% had statistically significant effect on shrinkage and rehydration capacity values of dried potatoes. Shrinkage percentage increased with increasing of samples thickness. In other words, shrinkage was decreased at different thickness with increasing of infrared radiation power and vacuum level. It was concluded that the long period of drying and increasing of sample thickness may have contributed to a decrease in rehydration capacity. Potato slices at thickness of 1 mm put in boiling water for three minutes, the most amount of water absorption ratio that it was able to absorb was the value of 86% the initial moisture. The results also showed that with increasing shrinkage, rehydration capacity was decreased.

Keywords: potato, drying rate, vacuum, infrared radiation, shrinkage, rehydration

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1 Introduction

Processed foods are different from their fresh counterparts in numerous ways, including their appearance, flavour, texture, nutrient content, and microbiota. 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 (Bacelos and Almeida, 2011). The other 34% production was used as animal feed and as potato starch in pharmaceuticals, textiles, adhesives industries (Bacelos and Almeida, 2011). 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-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

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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, 2006). 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. 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 caused stress in the cellular structure of the food, has been 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).

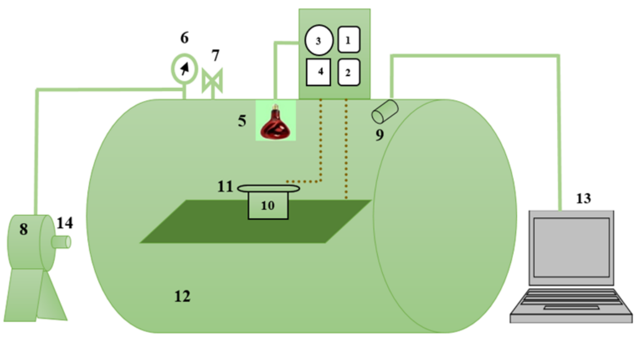
Infrared radiation (IR) has significant advantages over conventional drying. Among these advantages are higher drying rates that give significant energy savings and uniform temperature distribution that yields a better quality product. Therefore, it can be used as an energy saving drying method (Mongpraneet 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 other methods due to a lack of oxygen in dryer ambiance and unwanted reduction of reactions in food (Motevali et al., 2011a; 2011b). 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; 2011b). For vacuum drying, the moisture within the product being dried evaporates at lower temperatures (lower than 100℃), 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 researches of Doymaz, 2011; Sharma et al., 2005; Abe and Afzal, 1998. Combined infrared radiation and 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. 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. 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 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). The 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.



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.

Figure 1 Schematic diagram of a vacuum-infrared drying system

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°C-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, w.b.), which was determined with three replications using a convection oven at 70°C for 24 h (AOAC, 1990). Drying experiment potato slices with three replications 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 mounting height lamp up sample tray in a series of pre-trials determined and fixed on 15 cm to avoid burning samples. As stop time depends on prolonging drying process of potatoes, hence 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, K(CA)). At the start of the experiments, relative humidity and the temperatures of the drying chamber were measured (35% and 50°C, respectively). The drying experiments were performed until the sample moisture content of 6%-7% (w.b.) was obtained (Lisinsca and Leszezyenski, 1989). The potato amount in each experiment includes six slices that were put on the sample tray. Therefore, depending on the slice thickness, the weight of potatoes in each experiment was between 13-22 g.

3 Theoretical principle

3.1. Modeling of drying kinetics

The moisture content of the samples was measured real time during drying process using Equation 1(Anonymous, 2001).

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

Where: M_w is the moisture content wet basis, %; W_w is the initial weight (total material) of potato samples, g; W_d is the dry weight of potato samples, g. Total material includes water and dry material of sliced potatoes.

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 using the following Equation 2 (Anonymous, 2006).

$$MR = \frac{M_t - M_e}{M_o - M_e} \qquad (2)$$

Where: MR is the moisture ratio; M_t is the moisture content at any drying time, kg $_{water}$/kg $_{total\ material}$; M_e is the equilibrium moisture content, kg $_{water}$/kg $_{total\ material}$; M_o is the initial moisture content, kg $_{water}$/kg $_{total\ material}$.

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 3 (Doymaz, 2011):

$$DR = \frac{MC_{t+dt} - MC_t}{dt} \qquad (3)$$

Where: DR is the drying rate, kg$_{H2O}$/kg $_{total\ material}$. min; MC_{t+dt} is the moisture content at time t+dt, kg$_{H2O}$/kg $_{total\ material}$; MC_t is the moisture content at time t,kg$_{H2O}$/kg $_{total\ material}$; 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 4 (Koc et al., 2008):

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

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 (Reyes et al., 2007).

$$R_C = \frac{(M_t - M_r)}{(M_i - M_r)} \qquad (5)$$

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.

For statistical analysis, a factorial experiment based on completely randomized design with three replications was used. Statistical analyses were performed using MSTATC and SPSS16 so the differences between the means were compared by Duncan's test (ANOVA, and post-hoc Duncan).

4 Results and discussion

4.1 Calculation of drying rate

Figure 2 shows the variations of drying rate with drying time at the infrared power level of 200 W based on the thickness of potato slices. The results showed that increasing the slice thickness in a constant radiation intensity is caused to create a hard layer on the surface of the potato and consequently the drying time in any thickness compared to the previous thickness is increased approximately 45%. On the other hand, the drying rate is reduced about 42%.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. The results of drying rate in two other radiations have been as much as 200 W. This means that by increasing the drying time has been slower drying speed.

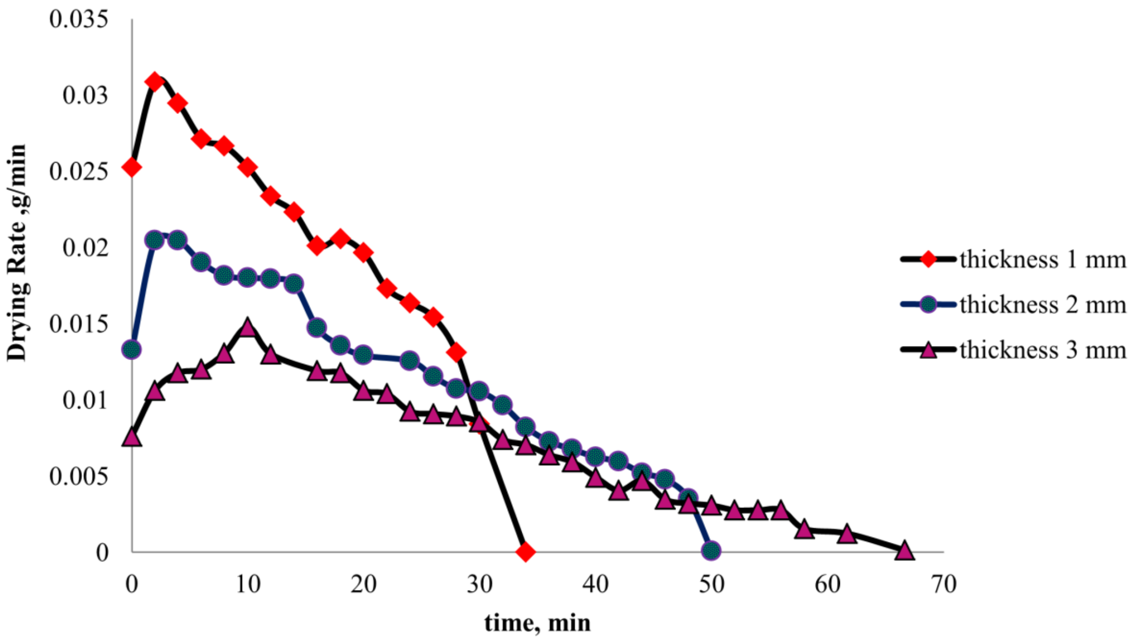


Figure 2 Effect of thickness on drying rate of potato slices at IR power level of 200 W

4.2 Calculation of shrinkage and rehydration capacity

Results of the shrinkage and rehydration capacity measurement of dried potato slices are shown in Table 1. Statistical analysis indicated that thickness at error level of 1% had statistically significant influence on shrinkage and rehydration capacity values of dried potatoes. Also interaction between thickness and infrared power at error level of 5% has statistically significant effect on the shrinkage rate.

Table 1 Analysis of variance of the effect of three main factors on the amount of shrinkage and rehydration capacity in drying process

Source	Degree of freedom	Shrinkage (value of F)	Rehydration at temperature 25 °C (value of F)	Rehydration at temperature 100 °C (value of F)
Thickness, mm	2	63.546**	5.093**	3.725**
Vacuum, mmHg	3	2.387n.s	0.206n.s	0.035n.s
Infrared power, W	2	0.987n.s	2.415n.s	0.213n.s
Thickness × Vacuum	6	2.018n.s	0.226n.s	0.414n.s
Thickness × Infrared power	4	4.550*	0.744n.s	0.414n.s
Vacuum × Infrared power	6	1.149n.s	0.819n.s	0.319n.s
Thickness × Vacuum × Infrared power	12	2.181n.s	0.397n.s	0.424n.s
Error	72			
Total	107			

Note: ** Significant at the 1% level, * Significant at 5% and n.s No significant differences C.V= 4.73%

Figure 3 shows that maximum shrinkage percentage (85.31%) and minimum shrinkage percentage (61.79%) were computed at thickness of 3mm and 1 mm, respectively. Swasdisevi et al. (2009) due to a study was done on banana concluded that with the increasing intensity of infrared radiation, shrinkage is decreased and with increasing the thickness of the slice, the shrinkage is increased. It can be said that his results are consistent with findings from this research.

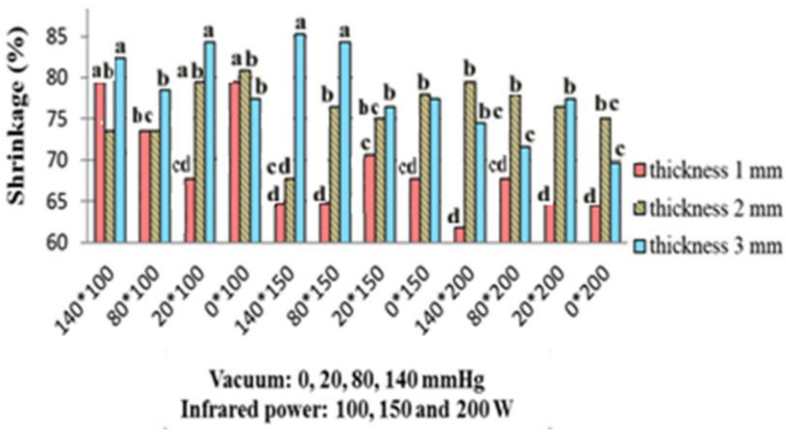


Figure 3 Shrinkage percentage of potato slices in vacuum- infrared drying method

The long period of drying and increase of sample thickness may have contributed to a decrease in rehydration capacity. Figure 4shows that maximum of rehydration rate was obtained at temperature of 25°C for 12 min at the power level of 150 W, vacuum 20 mmHg and thickness of 1 mm. On other hand, Figure 5 shows that maximum of rehydration rate was obtained at temperature 100°C for three 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 of 25°C. At both temperatures, the minimum value of rehydration was observed at IR power of 100 W and vacuum level of 20 mmHg at thickness of 3 mm. Doymaz (2011) investigated the effect of different levels of infrared radiation on the kinetics of drying and rehydration examined slices of sweet potatoes. He observed that with the increasing intensity of infrared radiation, rehydration rate is increased. The maximum of rehydration rate was obtained at the radiated power of 146 W and then with increasing of the infrared radiation intensity, rehydration rate was decreased. Lin et al (2006) on a research studied color and rehydration changes of dried sweet potatoes in an infrared-freeze combination dryer. They observed that the rate of water absorption with reducing the thickness of the potato slice had been related. So that the maximum of rehydration capacity at minimum of thickness of potato slice was obtained.

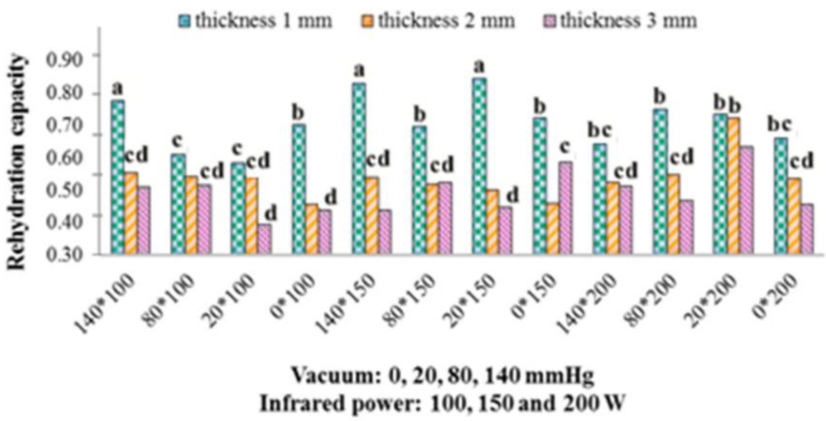


Figure 4 Rehydration capacity of potato slices at temperature 25°C for 12 min in vacuum- infrared drying method

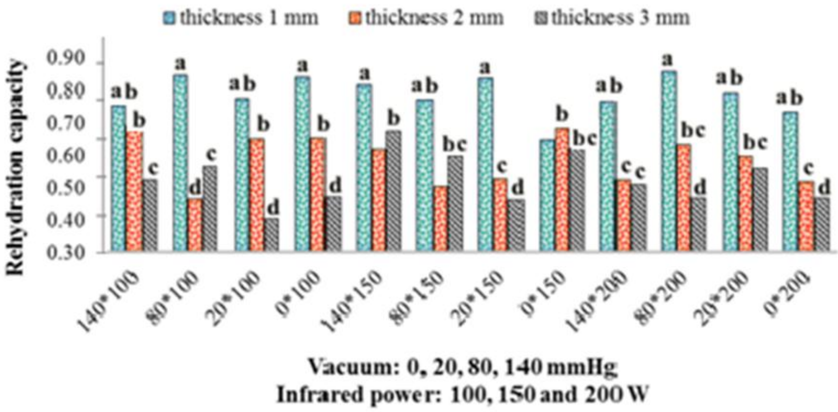


Figure 5 Rehydration capacity of potato slices at temperature 100 °C for 3 min in vacuum- infrared drying method

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

4 Conclusions

In this research, it was concluded that infrared radiation power amount has significant effects on drying time and rate. With the increasing of drying time, the drying rate is decreased about 42%. Data analysis showed that shrinkage percentage increased with the increasing of samples thickness. This means that maximum of shrinkage percentage (85.31%) and minimum of shrinkage percentage (61.79%) were computed at thickness of 3 mm and 1 mm, respectively. The rehydration process at 100 °C yielded the highest rehydration capacity at the power level of 200 W, vacuum level of 80 mmHg and thickness of 1 mm.

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