Shrinkage characteristic of potato slices based on computer vision

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Abstract: Shrinkage during drying plays an important role in evaluating the quality of the dried product. The aim of this study is to use image processing technique for measuring the variation of potato shape parameters during drying process. A standardized image acquisition system consisting of a digital camera, illumination, computer hardware and software were developed to capture and process images. During drying process, parameters related to shape (surface area of slice) decreased with drying time. The percentage of surface area reduction, which is obtained by measuring potato slices surface area before and after drying, can be used to realize the shrinkage characteristic of potato slices. Results showed that factors such as slice thickness and infrared radiation power ($P<0.01$) had significant effect on shrinkage characteristic of potato slices and also absolute pressure ($P<0.05$) had significant effect on the shrinkage percentages. The values of maximum and minimum of shrinkage percentage were achieved at power level of 100 and 200 W and slice thickness of 1 and 3 mm.

Keywords: potato, drying, vacuum, infrared radiation, shrinkage, computer imaging

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1 Introduction

Potatoes are members of the Solanaceae family. Of the many tuber-forming Solarium species, the one that is most widely cultivated is Solarium tuberosum. Potato is one of the unique and most potential crops having high productivity, supplementing major food requirement in the world (Faisal et al., 2013). It is rich in carbohydrates, proteins, phosphorus, calcium, vitamin C and 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. Higher quality product would have desirable color, texture and flavour as well as shape, and certain functional properties such as rehydration and porosity. If these factors could not be achieved to an acceptable level, then the dried product will be unappealing to the consumer. The following points should be noticed during drying of potatoes:

1）Preserving the cellular structure of potatoes;

2）Preserving the nutritional value of potatoes;

3）Prevention from non-enzymatic browning and oxidation during storage of product.

Drying is one of the oldest and well known methods of preserving fruits and vegetables. In drying operation, possibility of microbial corruption and velocity of other detrimental reactions is lessened to a great extent due to the reduction of moisture. Drying is used as a method of increasing product stability and increasing ease of distribution and storage. Drying of cellular tissues produces several changes of chemical (browning and other reactions) and physical (color, texture, shape,

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porosity and, .. etc.) properties (Yadollahinia et al., 2009).

The knowledge of physicochemical properties of food materials is important for an adequate design of food operations as well as for the control and improvement of the quality of the final product (Rahman, 2005). However, during the drying food materials may undergo undesirable changes such as shrinkage that has a negative effect on the required characteristics of dehydrated product for commercial usage. The analyses of the drying kinetics data permits to understand the moisture transfer inside the foods considering the shrinkage of samples and mechanisms involved. The quality of the dehydrated product depends on the extension of these changes. Regarding to the changes in volume and porosity, high shrinkage and low porosity lead to products with poor rehydration capability (Mayor et al., 2011).

Shrinkage during dehydration of fruits and vegetables and occurs when the viscoelastic matrix contracts into the space previously occupied by the water removed from the cells (Aguilera, 2003). Use of fruit dried chips has been highly developed in recent years.Chip of fruits and vegetables, which are classified at the group of dried fruits and nut and consumed as refreshments, has high nutritional value. In drying fruits and vegetables chips, color, size and tissue of materials will tolerate noticeable change due to the exit of moisture in a way that change in size and type of shrinkage of product leaves high effect on marketability and desirability of the product (Yadollahinia et al., 2009). Shrinkage has been studied by direct measurements with a caliper or micrometre or by changes in related parameters such as porosity and density.

Food stuffs are known to undergo volumetric changes upon water loss which are expressed as shrinkage. Size, which is the first parameter identified with quality, has been estimated using machine vision by measuring either projected area, perimeter or diameter. Size measurement is important for determining produce surface area. The shape is one of the important visual quality parameters of fruits, vegetables, etc. (Mahendran et al., 2011). Such modification, occurring continuously during the drying process, affect the physical properties of the solids and this is essential for design purpose. The effect of air conditions (temperature, relative humidity and velocity) and characteristic sample size on drying kinetics of various plant materials (potato, carrot, pepper, garlic, mushroom, onion, leek, pea, corn, celery, pumpkin and tomato) was examined during air drying by Krokida et al. (2003).

Mayor and Sereno (2004) investigated the changes in volume, density, porosity and shape factors of pumpkin tissue during osmotic dehydration (OD); air drying (AD). Image analysis showed that shrinkage of samples during OD was isotropic. Pumpkin cylinders increased elongation and decreased roundness and compactness during osmotic dehydration. Taiwo and Baik (2007) studied the effects of various pre-treatments (blanching, freezing, air drying, osmotic dehydration and control) on the shrinkage and textural properties of fried sweet potatoes.

Pimpaporn et al. (2007) studied the influences of various pre-treatments and drying temperature on the LPSSD drying kinetics and quality parameters of dried potato chips. Shape is one of the most common object measurements for food quality evaluation. Image processing technique can be easily applied to measurement of the shape of food. Yan et al. (2007) successfully used image analysis to measure the dimensions change of fruits during drying. The changes of surface area, perimeter, equilibrium diameter and shape factor of pineapple, mango and banana were measured by image analysis and correlated them with change in moisture content. Mendiola et al. (2007) measured non-isotropic shrinkage of potato slabs during convective drying with two digital cameras for top and side view. Cellular surface area of potato cells were recorded and related to moisture content by means of an empirical equation with in conjunction with SAFES methodology.

Agriculture with the food sector, has become on the main applications of computational vision, since they require, in the analysis of the product, a reproduction of human perception with regard to the image of the product, involving the analysis of attributes, such as size, shape, texture, brightness, color, and .. etc., which directly influence quality assessment. A computer vision system (CVS) provides an alternative to the manual inspect ion of biological products by integrating an image acquisition device and a computer (Jayas et al., 2000). Digital image processing is the core of CV with numerous algorithms and methods capable objectively of measuring and assessing the appearance quality of several agricultural products (Mery and Pedreschi, 2005).

Fernandez et al. (2005) presented a method based on computer vision was used to analyse the effect of drying on shrinkage, color of apple discs. Ramos et al. (2004) monitored microstructural changes in cells of grape during first stage of convective air drying, under a stereo-microscope. A gradual overall shrinkage of grape cells was observed during the process. The cellular parameters: area, perimeter, major and minor axis length, Feret diameter, elongation, roundness and compactness, were quantified by image analysis. Mulet et al. (2000) investigated the shape changes along the drying process of potato and cauliflower by image analysis and directly with a caliper. The objective of this study was to develop an image processing system to measure shrinkage of potato slices during drying with high precision and to study the effect of infrared radiation powers, absolute pressure levels and various thickness on shrinkage characteristic of potato slices during drying by vacuum-infrared dryer.

2 Materials and methods

2.1 Experimental set-up

A laboratory scale vacuum-infrared dryer, developed in Postharvest Lab. (at Department of Mechanics of Agricultural Machinery and Mechanization, Faculty of Agriculture, Shahid Chamran University of Ahwaz, Ahwaz, Iran) was used. A schematic diagram of the apparatus for 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 lower level of pressure; a laboratory type piston vacuum pump (JY IA-2, China), which was used to maintain vacuum in the drying chamber; an infrared lamp with power of 250 W (OSRAM, Slovakia), which was used to supply thermal radiation to a drying product; and a control system for the infrared radiator.

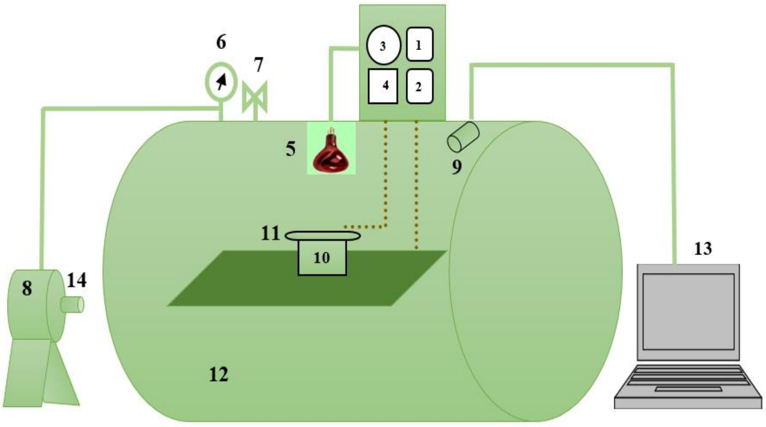


Figure 1 A schematic diagram of a vacuum-infrared drying system: 1) humidity sensor, 2) thermocouples, 3) infrared lamp power controller, 4) voltmeter, 5) infrared lamp, 6) vacuum gauge, 7) vacuum break-up valve, 8) vacuum pump, 9) camera, 10) electronic weight scale, 11) sample tray, 12) drying chamber,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

2.2 Sample preparation

Fresh potatoes amount of 30 kg were purchased from a local market in Hamadan province (Iran). The samples were stored in refrigerator to prevent undesirable effect at about 5°C-6°C 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 slicer. The initial moisture content of the fresh samples was 77% (wet basis), which was determined in triplicate by using a convection oven at 70°C for 24 h (AOAC, 1990). Experiments of drying of potato slices were performed in a vacuum chamber with absolute pressure levels of 20, 80, 140 and 760 mmHg; and infrared power of 100, 150 and 200 W. The distance between the infrared lamp and the sample tray was adjusted to 15 cm. The change of the sample mass during drying was detected continuously using an electronic weight scale (Lutron, GM- 1500P, Taiwan) with the accuracy of ±0.05 g. At beginning of experiments, initial relative humidity and temperatures of the drying chamber were set on35% and 50°C. The temperatures of the drying chamber and samples were monitored continuously using thermocouples (SAMWON ENG, SU-105KRR). After the initial measurements, all potato slices were immediately moved to the tray dryer.The drying experiments were performed until the sample moisture content of 6-7% (w.b.) was obtained.

2.3 Modelling of drying kinetics

The moisture content of the samples was measured real time during the process time of the dryer using equation (1).

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

Where, M_t is the moisture content at any drying time (kg $_{\text{water mass}}$kg^{-1}$_{\text{total mass}}$);W_w is the initial weight of potato samples (kg $_{\text{total mass}}$) and W_d is the dry weight of potato samples (kg $_{\text{dry mass}}$). Total mass includes water and dry material of sliced potatoes.

To find a suitable mathematical model, the moisture content data at different thickness, absolute pressure levels and infrared power were converted to the dimensionless mass losses (MR) of potato slices during drying experiments were calculated by using the following equation (2).

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

Where, MR is the dimensionless mass losses; M_t is the moisture content at any drying time (kg $_{\text{water mass}}$kg^{-1}$_{\text{total mass}}$); M_e is the equilibrium moisture content (kg $_{\text{water mass}}$kg^{-1}$_{\text{total mass}}$); M_o is the initial moisture content (kg $_{\text{water mass}}$kg^{-1}$_{\text{total mass}}$).

2.4 Image processing methods

Images processing included extracting the intensity plane from the image, applying a threshold to identify the potato slices from the image background and filtering the image to remove small objects compared to the potato slices. The system mainly consists of digital camera (SAMSUNG, ES55), four fluorescent lamps (Philips, 23W) and a Plexiglas plate with black background. The angle between the axis of the camera lens and the lighting source axis was 45° to capture the diffuse reflection responsible for the color, which occurs at that angle from the incident light. Image of potato slices were captured directly from the black background using the digital camera. Parameters of the acquisition were 1/2 second shutter speed, macro focusing mode, F 3.2 aperture stop and ISO 200 sensitivity. Images consisted of 3648×2736 pixels with the resolution of 96 dot per inch (dpi) were saved in JPEG format. The axis of the digital camera formed an angle of 90° with the plane of the sample and the lens was 12 cm above the sample. The digital data generated were transferred to a PC via USB interface. Image processing and analysis were performed using macros written in MATLAB 8.3 version 2014 (MathWorks, Inc.). The flowchart in Figure2shows the algorithm developed in this study to segment the images and extract the desired features. Image segmentation is the first step of image analysis. Optimal threshold value was applied to grey-scaled images to subtract the background from the images and obtain the binary image. After removing all undesirable objects from the background and filling the unwanted noisy holes (based on the 30 images investigated in this section, the surface area of noisy holes was 4.782 ± 0.102% of the region of interest in binary image) within the object, the final binary image was ready for extracting quantitative morphological data.To remove the effects of the background pixel values from the color and texture data, logical and operator was applied to superimpose the original RGB images of the samples on the binary images gained from the last steps. Figure 3 shows one of preprocessed potato slice image as well as its original image. The image analysis program calculated the surface area of each potatoslice.Thesurface area of each potato slice as key characteristic value was calculated according to the number of image pixels points and area of each pixel point. Then the total surface area of sample measured can be obtained by summing image area of each potato slice in square millimeter.

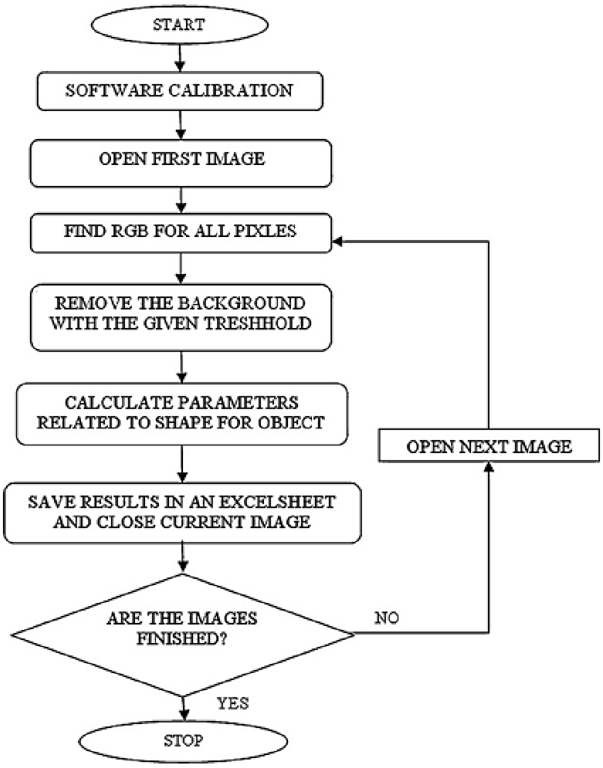
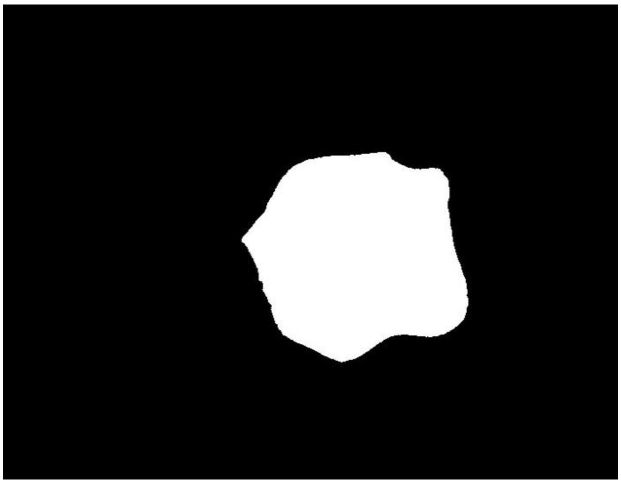


Figure 2 Flowchart of image processing software showing measurement process

(a) Original image



(b) Preprocessed image

Figure 3 Original and preprocessed images of potato slice

2.5 Evaluation of shrinkage characteristic

Total surface area of sample before and after drying was measured respectively according to the above image processing methods. The percentage reduction of potato slice surface area (shrinkage) was calculated by the following equation (3), which can be used to reflect the shrinkage characteristic of potato slice during drying.

$$SKG=\left(1-\frac{A}{A_0}\right)\times 100 \tag{3}$$

Where, SKG is the shrinkage percentage of potato slice (%), A is the sample surface area at the drying time (mm^2) and A_0 is the initial sample surface area (mm^2).

For statistical analysis, a factorial experiment based on completely randomized designwith three replications was used. Statistical analysis was performed using

MSTATC so the difference between the means was compared by Duncan's test.

3 Results and discussion

Variations of the moisture ratio with drying time at infrared power levels 100, 150 and 200 Watts are given in Figure 4. As was expected, drying of the potatoes at infrared powers resulted in shorter drying times, which indicated that thermal had a direct effect on the moisture variations and drying time.

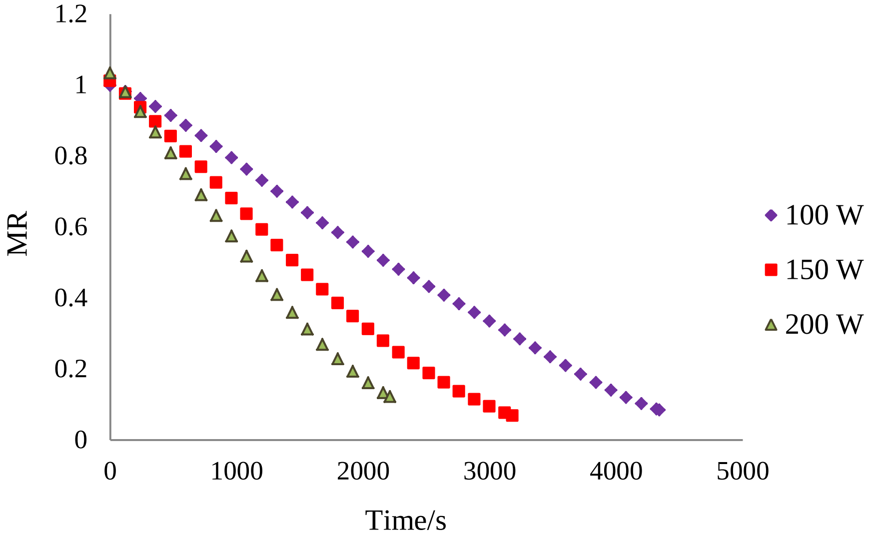


Figure 4 Effect of infrared power on MR vs. time at thickness of 1 mm and 80 mmHg absolute pressure

Temperature increase by infrared radiation caused increased release and remove moisture from the potato tissue and the obtained curve from moisture changes over drying time have a significant decreasing trend.

The effect of absolute pressure on the moisture ratio is demonstrated in Figure 5. It shows that absolute pressure decreased drying time but its effect on the drying rate was less than the infrared power effect.

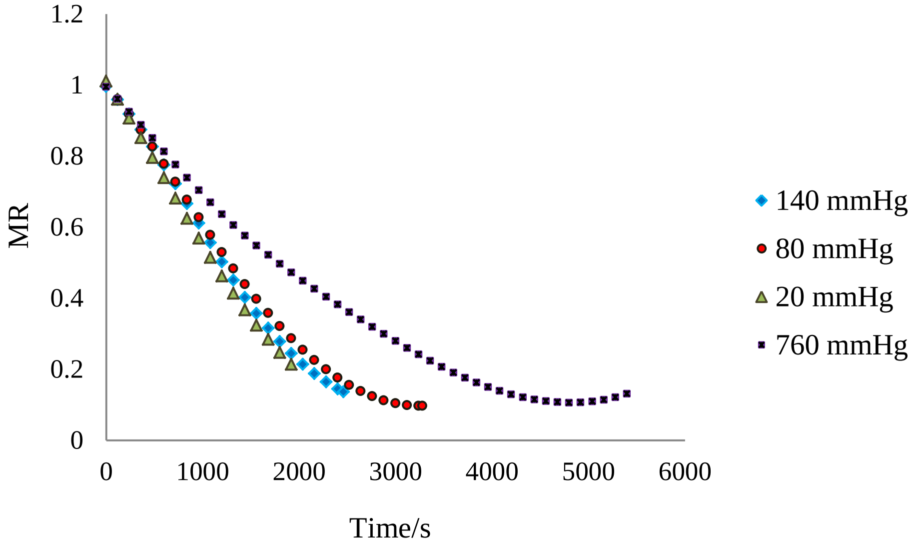


Figure 5 Effect of absolute pressure on MR vs. drying time at thickness of 1 mm and 150 W infrared power

In order to investigate the method accuracy for shrinkage rate measurement by computer vision, the repeated experiments were carried at different thickness levels of potato slices.

Results of the shrinkage measurement of dried potato slices are shown in Table 1. Statistical analysis (ANOVA, and post-hoc Duncan) showed that thickness, absolute pressureandinfrared power parameters respectively at error level of 1%, 5% and 1%had statistically significant influence on shrinkage values of dried potato slices.

Table 1 Analysis of variance of the effect of slice thickness, absolute pressure and the infrared power on the rate of shrinkage

Source	**Sum of Squares**	**df**	**Mean Square**	**F**
Thickness, mm	2299.873	2	1149.936	187.850 **
Absolute pressure, mmHg	187.825	3	62.608	10.227 *
Infrared power, W	698.646	2	349.323	57.064 **
Thickness × Absolute pressure	59.673	6	9.946	1.625 n.s
Thickness × Infrared power	52.637	4	13.159	2.150 n.s
Absolute pressure × Infrared power	91.971	6	15.328	2.504 n.s
Thickness × Absolute pressure × Infrared power	100.886	12	8.407	1.373 n.s
Error	440.754	72	6.112	
Total	3932.264	107		

** Significant at the 1% level, *Significant at 5% and n.s No significant differences

According to Figures from6 to 8, results show that byincreases of slice thickness and radiation power factors and also decrease of absolute pressure (acts of vacuum in the dryer chamber), theshrinkage percentage is reduced.

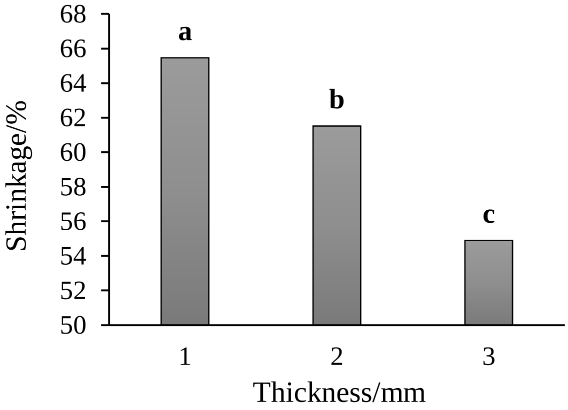


Figure 6 The mean comparison of slice thickness on the shrinkage using Duncan test

At Figure 6, the effect of slice thickness on the samples shrinkage was seen clearly. Asthat be seen in Figures 7 and 8, the leastshrinkage value has obtained at the absolute pressure of 80 mmHg and heating power of 200 watts.

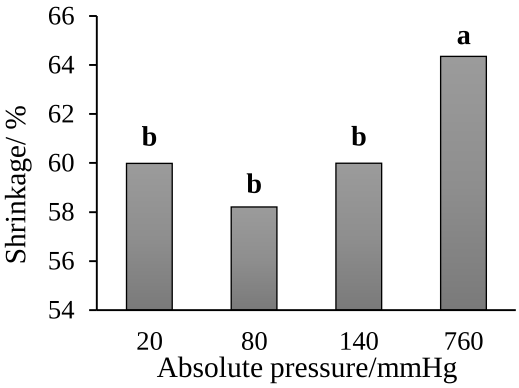


Figure 7 The mean comparison of absolute pressure on the shrinkage using Duncan test

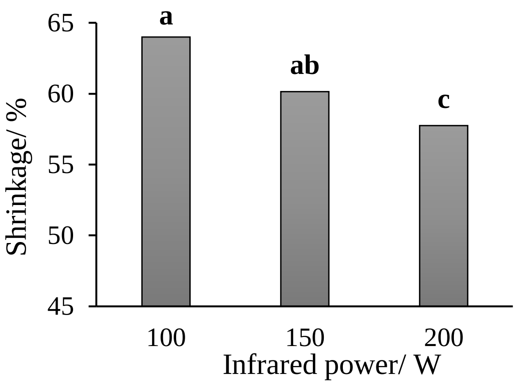


Figure 8 The mean comparison of infrared power on the shrinkage using Duncan test

The results showed that surface area reduction most was affected by the thickness of potato slice and infrared heating. The mean final shrinkage at the infrared powers, absolute pressures and thickness various of the samples and in the final moisture content of 6 (wet basis) to 60.63% was observed.

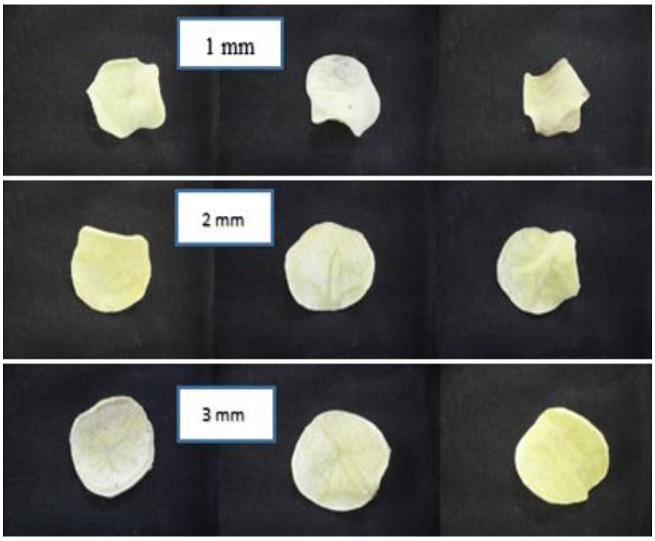


Figure 9 Images of dried potato slices at various thickness

Figure 9 shows the images of dried potato slices at absolute pressure level of 80 mmHg and various infrared radiation power of 100, 150 and 200 W at the different slice thickness. As is shown in the abovepicture, shrinkage changes was reduced in the more thickness. Such that the thicker slice could almost preserve its circle-shape mode up to the process end. Yadollahinia and Jahangiri (2009) investigated the shape changes along the drying process of potato and found that Shrinkage showed almost linear relation with moisture content. Also it was found that air flow direction had significant effect on shrinkage of parallel and perpendicular diameters in 60°C and 70°C and no significant effect at 80°C. Slices dried in 80°C showed more circularity than slices dried in 60°C and 70°C.

4 Conclusions

Data analysis showed that either slice thickness or infrared power had any significant effects (at significant level of $P<0.01$) and also absolute pressure had significant effects (at significant level of $P<0.05$) on shrinkage of potato slices in this drying system. From the study it was found that during drying process parameter related to shape (slice surface area) decreased with drying time. The results show that percentage reduction of surface area, which is obtained by measuring potato slices surface area before and after drying, can be used to reflect the shrinkage characteristic of surface of area potato slices. Also was found the drying time decreased with increase in infrared power and reduce in absolute pressure at a given thickness. On the other hand, the deformation is seen more in the product surface.

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