

The Effect of Drying Kinetic on Shrinkage and Colour of Potato Slices in the Vacuum- Infrared Drying Method

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Abstract

The influence of drying conditions on the shrinkage and colour distribution 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 thickness (1, 2 and 3 mm) on bulk volumetric shrinkage were investigated. Colour changes were evaluated by image analysis. 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. It was found that either thickness or IR power had any significant effects ($p < 0.01$) on shrinkage of potato slices in this drying system. Maximum colour changes (44.31%) and minimum colour changes (6.86%) were obtained at thickness of 3 mm and 1 mm, respectively. Also, results imply that neither IR power nor air vacuum had any significant effects ($p < 0.01$) on colour changes of potato slices.

Keywords: *Potato, Drying, Vacuum, Infrared Radiation, Shrinkage, Image Analysis*

1. Introduction

The potato (*Solanum tuberosum* L.) is one of the most unique crops due its potential for high productivity and ability to supplement major food requirements in the world. It 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). It constitutes nearly half of the world's annual output of all root and tuber crops and has remained in the top ten over the last twenty years. India ranks fourth in area with 14 lakh hectares and is the third largest country in the world in potato production after China and Russia with a pro-

duction of 294.94 million tonnes and productivity of 17.86 tonnes per hectare.

As a high moisture food, potato is rich in enzymes, namely peroxidases, and cannot be sun-dried, as traditional sun drying is a slow process and makes such food materials susceptible to fungal growth. It may also result in the loss of product quality from colour degradation, microbial growth, poor rehydration, etc. Therefore, the drying process must be undertaken in a closed dryer.

Today, exports of dried fruits are of paramount importance. Inappropriate distribution of food industries and various types of agricultural products and seasonal and regional production of many products in the world are the main reasons for drying fruits. There is also a dire need in some

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countries due to their climatic and food conditions, the high transportation cost of fresh fruits and vegetables, and limitation of their storage time.

Drying is one of the oldest and best-known methods of preserving fruits and vegetables. In a drying operation, the possibility of microbial corruption and velocity of other detrimental reactions is lessened to a great extent due to the reduction of moisture. Moreover, preserving products through drying reduces volume and weight of product. Drying is generally carried out for two main reasons. The first is to reduce the water activity, which eventually increases the shelf life of food. The second is to reduce the weight and bulk of food for cheaper transport and storage. Drying methods can be broadly classified into solar drying and mechanical drying. One method of mechanical drying is infrared drying under vacuum conditions. In infrared 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 the humidity released by the matter from its vicinity in order for it to face less resistance while avoiding material surface saturation moisture. In vacuum conditions, due to a lack of oxygen in dryer ambiance and unwanted reduction of reactions in food, the quality of dried food is higher in this method than the others (Motevali et al., 2011 a, b). Applying vacuum in food drying also causes expansion of air and vapour and creates a puff state in the matter.

The quality evaluation of the dried product was carried out on the basis of response variables viz. rehydration ratio, shrinkage percentage, colour, and the overall acceptability.

Using dried fruit chips has been highly developed in recent years. Chips of fruits and vegetables, which are classified in the group of dried fruits and nuts and consumed as refreshments, have nutritional value. In drying fruits and vegetables chips, the colour, size, and tissue of materials will undergo noticeable change due to the exit of moisture. This change in size and product shrinkage has a major effect on the marketability and desirability of the product.

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 usually leave a negative impression on the consumer. On the other hand, some dried products have traditionally had a shrunken aspect i.e., 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). The removal of water during drying of biological products leads to cellular structural modifications due to reduced tension inside the cells. This phenomenon causes alterations in the shape and dimension of products. Such changes, according to Yan et al. (2007), affect the physical properties of products (including volume shrinkage rate) and modify the final texture and transport properties of dry foods. Shrinkage during dehydration of fruits and vegetables occurs when the viscoelastic matrix contracts into the space previously occupied by the water removed from the cells (Aguilera, 2003). Shrinkage has been studied by direct measurements with a calliper or micrometre or by changes in related parameters, such as porosity and density. Park (1998) and 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.

In food engineering research, it is often necessary to analyze the surface colour of food samples both qualitatively and quantitatively. Qualitative analysis may involve visual inspection and comparison of the food samples. Quantitative analysis may involve obtaining colour distribution and averages. An attempt may also be made to correlate colour distribution with other data such as temperature and moisture content distributions (Yam and Papadakis, 2004). Colour development only begins when a sufficient amount of drying has occurred in potato slices, and it depends also on the drying rate. Colour is considered one of the most important parameters in the definition of quality of dried potatoes.

In university research laboratories, computer vision systems have been developed for product quality inspection and grading. Studies were carried out to analyze visual characteristics of products ranging from fruits and vegetables such as colour inspection of apples and potatoes (Tao et al., 1995) and sorting of bell peppers based on colour (Shearer and Payne, 1990).

Computer vision (CV) is a technology used for acquiring and analyzing an image of a real scene by computers to obtain information or to control processes (Brosnan and Sun, 2004). Digital image processing is the core of CV with numerous algorithms and methods capable of objectively measuring and assessing the appearance quality of several agricultural products (Mery and Pedreschi, 2005). Computer vision was used to analyze the effect of drying on the shrinkage, colour, and image texture of apple discs (Fernandez et al., 2005) and potato slices (Yadollahinia and Jahangiri, 2009).

The objectives of this research were to conduct an experimental study of drying kinetics, considering the shrinkage and colour distribution of potato slices in a vacuum- infrared dryer.

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 a 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.

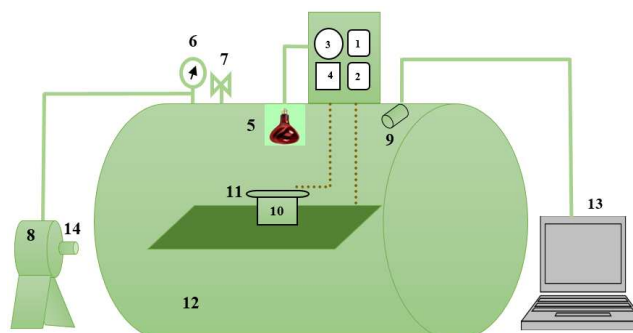


Figure 1: A schematic diagram of a vacuum-infrared drying system: 1) humidity sensor, 2) thermocouples, 3) infrared lamp power controller, 4) voltmeter, 5) infrared lamp, 6) vacuum gauge, 7) vacuum break-up valve, 8) vacuum pump, 9) camera, 10) electronic weight scale, 11) sample tray, 12) drying chamber, 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 to prevent an undesirable effect at about 5-6°C and relative humidity of about 85%. 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 in triplicate by using a convection oven at 70°C for 24 hours (AOAC, 1990). The 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). In the 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.

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).

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

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, the 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.

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

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 Measurements of Volume and Shrinkage of Fresh and Dried Potato Slices

The shrinkage percentage is a drying quality assessing parameter that 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 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).

$$\%SKG = \left(1 - \frac{V}{V_o} \right) \times 100 \quad [3]$$

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

3.3 Colour Measurement

Colour is defined as the visible electromagnetic spectrum reflected by an object that is perceivable by a sensor within its detection range and is one of the most important attributes of objects' appearance. In the last few years, the need to numerically define colour by its coordinates in n-dimensional space has increased strongly (Mendoza and et al., 2006). Generally, the colour spaces applied in product classification are the standard RGB (sRGB; red, green, blue) and $L^*a^*b^*$. sRGB can be easily obtained using computer vision systems. Outputs signals are generated by the camera sensors (e.g., CCD or CMOS), but the rendering is device-dependent, since the range of colours varies according to the display device specifications (Cubero and et al., 2011). The colour of potatoes was measured on 5 slices selected randomly and was described by three coordinates in the sRGB colour space using computer vision. The percentage of colour changes (ΔRGB) and Ash level (ΔL) were calculated using the following equation.

$$\Delta R = \frac{R_1 - R_2}{R_1} \times 100 \quad [4]$$

$$\Delta G = \frac{G_1 - G_2}{G_1} \times 100 \quad [5]$$

$$\Delta B = \frac{B_1 - B_2}{B_1} \times 100 \quad [6]$$

$$\Delta L = \frac{\Delta R + \Delta G + \Delta B}{3} \quad [7]$$

Where ΔR is the percentage of red colour changes, R_1 is value red colour change before drying of sample, R_2 is value red colour change after drying of sample, ΔG is the percentage of green colour changes, G_1 is the value green colour change before drying of sample, G_2 is the value green colour change after drying of sample, ΔB is the percentage of blue colour changes, B_1 is the value blue colour change before drying of sample, B_2 is the value blue colour change after drying of sample, and ΔL is the average of RGB changes. MATLAB software was used to analyze the colour of samples.

Table 1

Regression coefficients of the shrinkage by liquid displacement

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1 (Constant)	73.810	3.472		21.260	0.000
Thickness	4.696	0.913	0.622	5.145	0.000
Vacuum	-0.002	0.014	-0.019	-0.160	0.874
Power	-0.058	0.018	-0.381	-3.154	0.003

Dependent Variable: Shrinkage

4. Results and Discussion

4.1 The Regression Equation of Shrinkage

Linear regression is an approach used to model the relationship between a scalar dependent variable Y and one or more explanatory variables denoted X. Table 1 shows linear regression model to determine an empirical relationship between the measured shrinkage using the liquid displacement method and the variable factors obtained. The regression model is three-variable, linear, and the coefficient of determination is 0.532 and implies that the model can explain 53.2 % of the shrinkage changes.

4.2 The Correlation Coefficient of Shrinkage

The Pearson correlation coefficient is a measure of the linear correlation (dependence) between two variables X and Y, giving a value between +1 and -1 where 1 is total positive correlation, 0 is no correlation, and -1 is total negative correlation. It is widely used in the sciences as a measure of the degree of linear dependence between two variables.

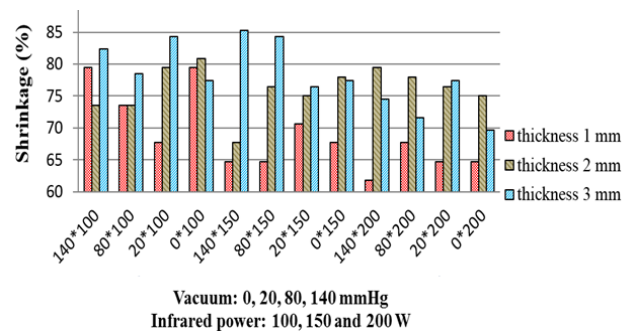
According to Table 2, the factor of thickness (0.622) is related to changes in volume ratio (shrinkage). This coefficient shows that the thickness is directly related to increasing shrinkage of the potato slices. Also this table shows that vacuum and IR power are inversely related to shrinkage changes.

Figure 2 shows the maximum of shrinkage percentage (85.31%) and minimum of shrinkage percentage (61.79%) was computed at thickness of 3 mm and 1 mm, respectively.

Table 2

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

**Figure 2:** Shrinkage percentage of potato slices in vacuum- infrared drying method

4.3 The Regression Equation of Colour Measurement

Table 3 shows the linear regression model used to determine an empirical relationship between the colour measurement using computer vision technique and variable factors obtained. The regression model is a three-variable, linear, and the coefficient of determination is 0.817 and implies that the model can explain 81.7 % of the colour changes.

Table 3

Regression coefficients of the colour measurement using computer vision technique

Model		Unstandardized Coefficients		Standardized Coefficients Beta	t	Sig.
		B	Std. Error			
1	(Constant)	3.013	3.748		0.804	0.034
	Thickness	11.577	0.985	0.887	11.748	0.000
	Vacuum	-0.028	0.015	-0.146	-1.927	0.063
	Power	-0.025	0.020	-0.095	-1.255	0.218

Dependent Variable: Colour

4.4 The Correlation Coefficient of Colour Measurement

According to Table 4, the factor of thickness (0.887) provides the most effect on colour changes. This coefficient shows that the thickness is directly related to increasing the colour changes. So that with increasing the thickness, the gray level (ΔL) which represents a significant colour change in the before and after drying of sample is increased.

(6.86%) obtained at thickness of 3 mm and 1 mm, respectively.

Table 4

Correlation coefficients of the colour measurement using computer vision technique

Pearson Correlation	Colour	Correlations		
		Thickness	Vacuum	Power
Colour	1.000	0.887	-0.146	-0.095
Thickness	0.887	1.000	0.000	0.000
Vacuum	-0.146	0.000	1.000	0.000
Power	-0.095	0.000	0.000	1.000

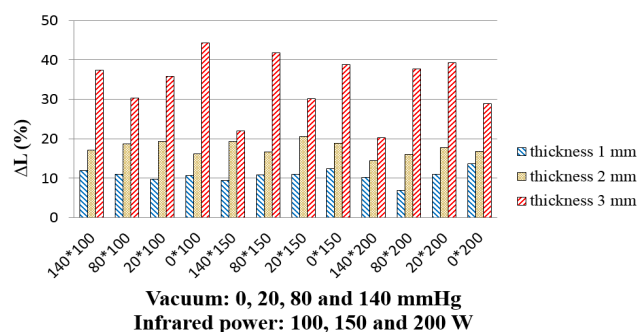


Figure 3: Percentage of colour distribution of potato slices in vacuum- infrared drying method
Figure 3 shows the maximum colour distribution (44.31%) and minimum colour distribution

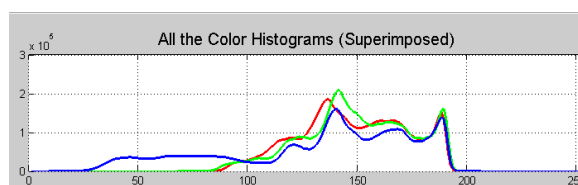


Figure 4: Histogram of colour distribution of potato slice (thickness of 1 mm after drying)

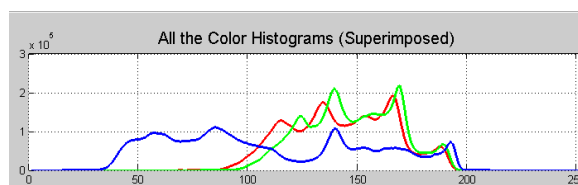


Figure 5: Histogram of colour distribution of potato slice (thickness of 1 mm before drying)

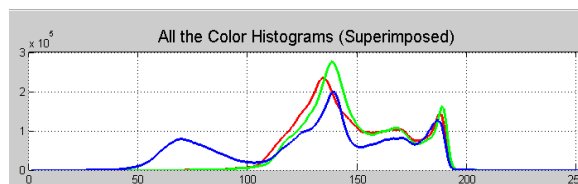


Figure 6: Histogram of colour distribution of potato slice (thickness of 2 mm after drying)

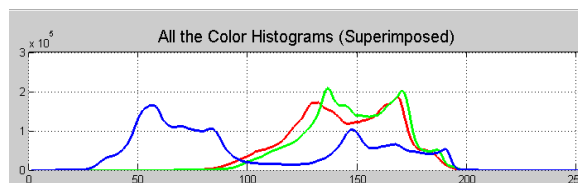


Figure 7: Histogram of colour distribution of potato slice (thickness of 2 mm before drying)

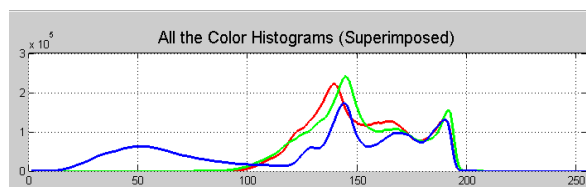


Figure 8: Histogram of colour distribution of potato slice (thickness of 3 mm after drying)

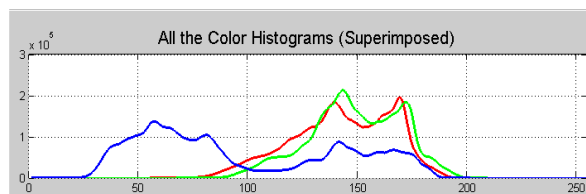


Figure 9: Histogram of colour distribution of potato slice (thickness of 3 mm before drying)

Figures 4-9 show histograms of colour distribution for example in the vacuum of 80 mmHg and infrared radiation power of 150 W in the before

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and after drying of potato slices. The horizontal axis displays the tone values from darkest to brightest tone, and the vertical axis indicates the number of pixels.

5. Conclusions

It was found that both thickness and IR power had significant effects ($p < 0.01$) on shrinkage of potato slices in this drying system. The results also imply that neither IR power nor vacuum had any significant effects ($p < 0.01$) on colour distribution of potato slices.

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