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Investigation of banana slices shrinkage using image processing technique

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Abstract

The aim of this study is to use image processing technique for measuring the variation of banana shape parameters during drying process. Roundness, elongation, area, thickness, perimeter, density ratio, and foam stability of banana slices were measured during drying time to describe the shrinkage kinetics. Therefore, a thin-layer experimental dryer was made based on a computer vision system. The experiments were performed at five levels of air temperature (50, 60, 70, 80 and 90 °C), three levels of thickness (3, 5 and 7 mm) at a fix level of air velocity 0.5 m/s. The results of image processing technique showed the capability of this method for online measuring of the samples shape parameters. Roundness of samples decreased and elongation increased with decreasing of moisture content ratio. Relations of area, thickness, density, and perimeter variations, and MR had a linear form.. A linear model described the samples shrinkage as a function of MR due to suitable coefficient of determination. Finally, it is concluded that the method of this study is useful for design of a machine vision system for controlling the shape variations of products during drying time at the online form. Being online and automatic are two important and effective properties in reducing of the measurement's errors, sampling time and reducing the standstill at the experiments.

Keywords: Computer Vision System; Image Processing; Shrinkage; Banana.

Abbreviations:

A	Local sample area (mm^2)	**SD**	Shortest diameter of slice(mm)
A_0	Initial sample area (mm^2)	**t**	Time(min)
E	Elongation (dimensionless)	**V**	Local sample volume (mm^3)
LD	Longest diameter of slice(mm)	**V_0**	Initial sample volume (mm^3)
m_d	Mass of dry material (g)	**X**	Moisture content, dry basis (kg_{H2O} . kg -1 dry material)
m_w	Mass of water(g)	**X_0**	Initial moisture content, dry basis (kg_{H2O} . kg -1 dry material)
MR	Moisture content ratio (X/X_0)	**ρ**	Local density of samples (kg/m^3)
P	Perimeter (mm))	**ρ_0**	Initial density of samples (kg/m^3)
R	Roundness (dimensionless	**λ**	Sample thickness at the drying time (mm)
R^2	Coefficient of determination	**λ_0**	Initial sample thickness (mm)
S_b	Shrinkage (dimensionless)	**a,b**	constants in the mathematical model

Introduction

World production of banana has been increased from 22 million tons in1961 to 96 million tons in 2009 (FAO, 2009). Protection of this massive production is an important problem. Drying is one of the oldest methods to protect food and agricultural products. Drying is used as a means of increasing product stability and ease of distribution and storage (McLaughlin and Magee, 1998). It is also used to generate new products such as puree, essence, chips and etc. Decreasing of moisture content during drying was found to make a non-isotropic change in the volume of the sample which is (expressed as shrinkage (Sjoholm and Gekas, 1995; Hatamipour and Mowla, 2002; Yadollahinia and Jahangiri, 2009). Shrinkage occurs during dehydration of fruits and vegetables when the viscoelastic matrix contracts into the space previously occupied by the water removed from the cells (Aguilera, 2003). Shrinkage is measured directly with a caliper or micrometer or indirectly by measuring changes in related parameters such as thickness, area, perimeter, porosity, density, etc (Hatamipour and Mowla, 2002; Mayor and Sereno, 2004; Guine et al., 2006; Kingsly et al., 2007; Martynenko, 2008; Yadollahinia and Jahangiri, 2009). There are several methods for measureing the shrinkage of banana and other fruits during drying process. In one of them, the sample volume is measured using water or gas displacement (Yan et al. 2008), though it is not accurate and reliable. At the present, many researchers use a new method, which is image-processing method, to measure the shape parameters (Fernandez et al., 2005; Mendiola et al., 2007; Yadollahinia et al., 2009). Using of image processing is a general method for measuring the rate of shrinkage in the products especially in the fruits (Yadollahinia and Jahangiri, 2009). In this method, a machine vision system is used to take the pictures of the dried product, and then the pictures are processed by an special computer software. In addition, this method is performed fast, continual and automatic. Image processing involves changing the nature of an image in order to either: Improve its pictorial information for human interpretation; Render it more suitable for autonomous machine perception

Table 1. the coefficients of the model in all conditions (**a** is a representative of the variations rate).

Temperature (°C)	Thickness(mm)	R^2	a	b
90	3	0.977	0.266	0.737
	5	0.963	0.355	0.571
	7	0.994	0.543	0.450
80	3	0.866	0.281	0.661
	5	0.925	0.399	0.536
	7	0.948	0.493	0.422
70	3	0.994	0.313	0.684
	5	0.938	0.418	0.616
	7	0.976	0.479	0.460
60	3	0.960	0.334	0.592
	5	0.986	0.458	0.496
	7	0.923	0.382	0.532
50	3	0.989	0.351	0.630
	5	0.993	0.387	0.611
	7	0.946	0.444	0.462

$$\frac{V}{V_0} = a \times \frac{X}{X_0} + b$$

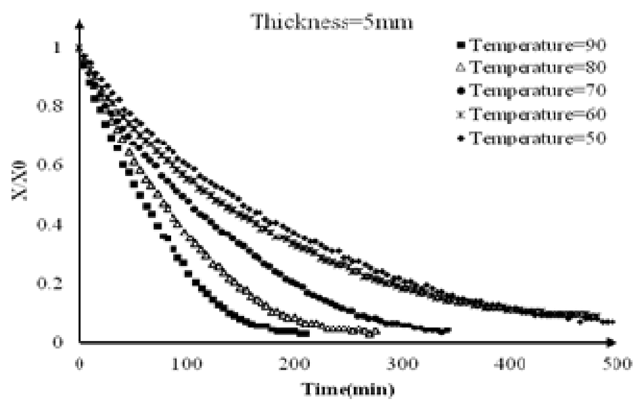

Fig 1. Kinetics of banana drying.

(McAndrew, 2004). Therefore, image processing is a start point to design a machine to control drying process automatically. Hatamipour and Mowla (2002) did a study about shrinkage of carrots during drying in an inert medium fluidized bed. They found that the shrinkage of root vegetables during drying in a fluidized bed could be well correlated with moisture content of the sample. They reported that air velocity, temperature, and presence of inert medium fluidized bed did not show any clear effects on shrinkage in their system. They found a linear relationship between shrinkage and moisture content. Mendiola et al. (2007) measured a Non-isotropic shrinkage of potato slabs during convective drying using two digital cameras at top and side views. They used the taken pictures to measure the lateral projected area and also fractal dimension of samples. Yan et al. (2008) used image analysis to measure the dimensional change of pineapple, mango, and banana during air-drying. Yadollahinia et al. (2009) measured the shrinkage of potato during drying. They used a machine vision system and its image processing software in order to measure variation of area, perimeter, major and minor diameters, diameters parallel and perpendicular to airflow, roundness and elongation to define the shrinkage kinetics of the potato slices. Their photography was done at two dimensions. Therefore, they could not measure the changes in volume, density and foam stability of the slices. Sjoholm & Gekas (1995), McLaughlin & Magee (1998) and Dissa et al. (2008) some studies concerning to about shrinkage of apple, potato spheres, and mango, respectively during drying processes. Also Ratti (1993), Mayor and Sereno (2004), Fernandez et al (2005), Guine et al (2006), Batista et al (2007), Hassini et al

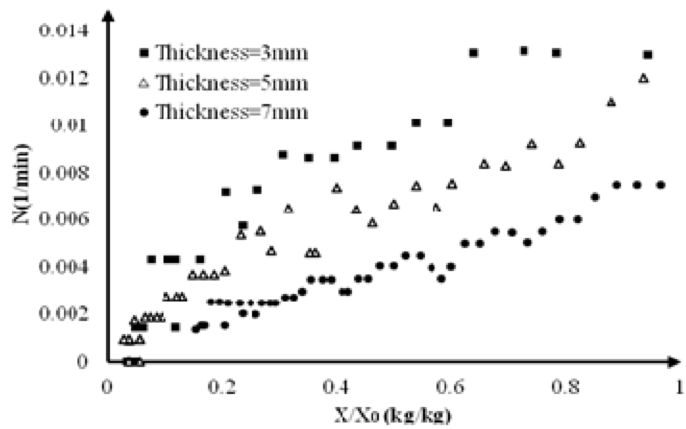

Fig 2. Drying rate of banana slices for different slice thicknesses (Air temperature= 90 ˚C).

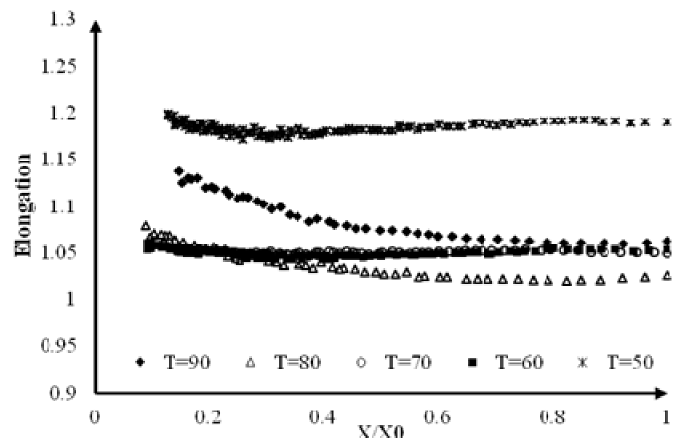

Fig 3. The effect of moisture content on the elongation of the samples (Air velocity=0.5m/s, Thickness=7mm).

(2007), and Kingsly et al (2007) studied the shrinkage characteristics of different materials during drying process. There are many scientific researches about drying and specially about shrinkage, however, there are a few researches about the shrinkage using image-processing technique . Therefore, the major aim of this study is to use image processing technique in order to measure the variation of banana shape parameters during drying process.

Results and Discussions

Fig.1 shows an exponential relation between moisture content ratio (MR) and drying time and thus, the rate of dehydration decreased during drying time. The effect of drying temperature on the rate of dehydration is clear. This means that by increasing the drying temperature, the drying rate decreases . The changes of moisture content ratio versus drying rate for different thicknesses are shown in Fig.2. In addition, Fig.2 represents the effect of the slices thicknesses on the drying rate. According to the figure, increasing of the slice thicknesses was found to the increasing the drying rate (Sankat and Castaigne, 2004; Ceylan et al., 2007; Yadollahinia and Jahangiri, 2009). Drying rate of banana slices for different slice thicknesses (Air temperature= 90 ˚C)

Roundness and elongation of samples at different experiments were determined. The results are shown in Figs.4 and 5 (for thickness of 7 mm). The other results had the same trends. Elongation of samples increased with decreasing of the moisture contents. Thesenon-isotropic changes resulted in deformation of the samples shape that redused Roundness. Yadollahinia and Jahangiri (2009) showed similar results for potato slices. . The effect of temperatures and slices thickness on roundness and elongation were not clear. Fig. 6 represents the dimensionless variations of area and perimeter of the banana slices versus moisture content ratio and also the effect of the slice thickness on the rate of variations. Because of dehydration and mass transfer process during drying period, the slice area and the perimeter increased with decreasing of moisture content. Relation between moisture content ratio and the slice area (and the slice perimeter), due to suitable coefficient of determination parameter, was found linear. Dissa et al. 2008; Yadollahinia and Jahangiri, 2009; reported similar results for amelie mango and potato slice, respectively. However, the effect of air temperature was not clear (Fig.8), increasing the slice thickness from 3 to 7mm was found to decrease the variations rate. Average percent of reduction was calculated as 20% for the slice area and 10% for the slice perimeter. Therefore, the variations rate of the slice area has been more

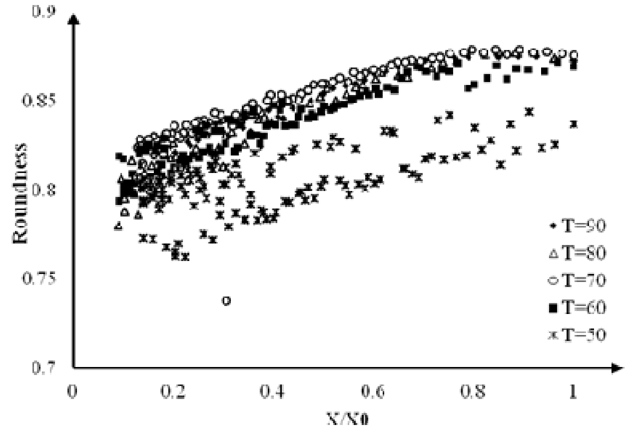

Fig 4. The effect of moisture content on the roundness of the samples (Air velocity=0.5m/s, Thickness=7mm).

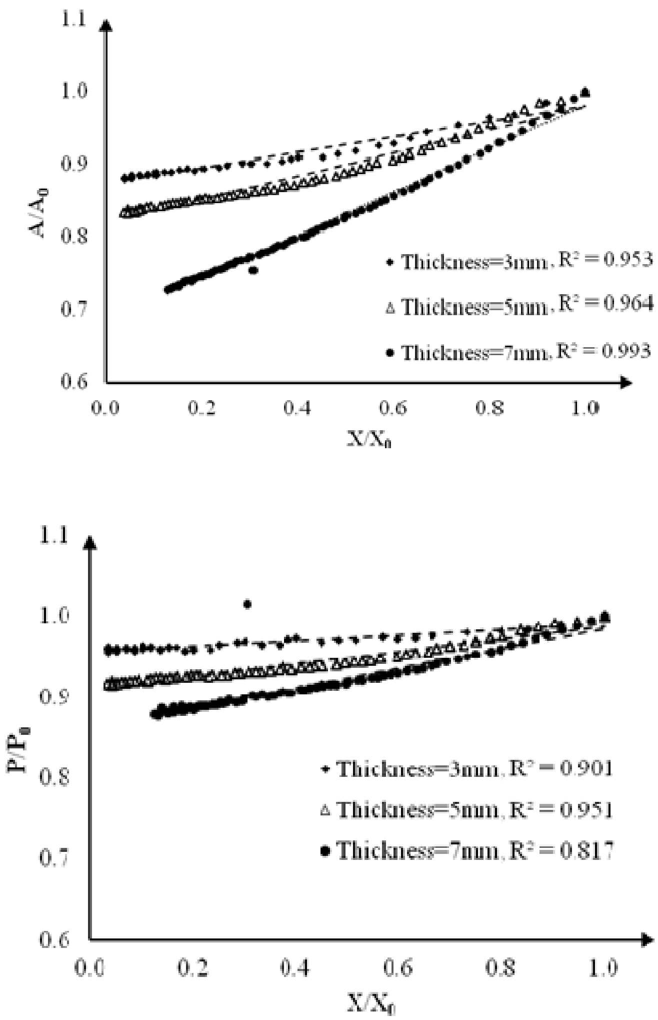

Fig 5. Dimensionless variation of sample area and sample perimeter as a function of moisture content ratio.

than that of the slice perimeter. Determination of variation of the sample thickness is necessary to measure the volume variation of the samples. Fig.9 represents dimensionless variation of sample thickness as a function of moisture content ratio (Sjoholm and Gekas, 1995; Hatamipour and Mowla, 2002; Hassini et al., 2007; Dissa et al., 2008). The ratio between the volume of the samples after drying and during drying period was used to express the kinetics of the samples shrinkage (Yan et al., 2008). Similar to area and perimeter, the effect of slice thickness on the samples shrinkage was clear completely (Fig.10). Average percent of the variation of the samples shrinkage was calculated as 40% during drying period. The modeling of the samples shrinkage as a linear function of moisture content was used to describe the rate of variations (Madamba et al., 1996). The results of modeling of shrinkage are shown in table.1. According to the results, it is clear that the rate of shrinkage increased with increasing the thickness of the samples. In addition, in the thicknesses of 3 and 5 mm, increasing of air temperature resulted in decreasing of the shrinkage rate (Sjoholm and Gekas, 1995; Hatamipour and Mowla, 2002; Sankat and Castaigne, 2004; Hassini et al., 2007; Ceylan et al., 2007; Dissa et al., 2008).

Materials and methods

Sample preparation

Fresh bananas were supplied from a local market and then, the bananas transferred to the laboratory of the Research and Development of Department of Agricultural Machinery Engineering, University of Tehran. In order to calculate the initial moisture content, some of banana slices were dried in an oven at 110 °C for 24h. Average moisture content was found to be 75% (Wet basis). For starting each experiment, a banana was peeled and sliced into layers of 3, 5 or 7 mm (referring to the experiment conditions) in thickness by a meat slicer. Then, the samples were arranged upon a rectangular tray (20 cm in length and 15 cm in width)and after that, the tray was placed into an experimental dryer at a pre set conditions. After finishing of each experiment, the samples were placed into oven to remove their remaining moisture.

In this study, the slices were dried at temperatures of 50, 60, 70, 80, 90 °C, and thicknesses of 3, 5, 7 mm at a constant air velocity of 0.5 m/s.

Dryer Machine

A thin-layer dryer was made based on a computer vision system to measure the effects of drying on change of visual properties of products and to find a relation between these properties and moisture content of products (Fig.10). The dryer consisted of a centrifugal fan (Damandeh, BEF-25/25F4T, 6300 m3/hr), air duct, four electrical heating elements (a 750W element in the centrifugal fan for preheating the airflow and 3×2000W elements in the air duct for heating the airflow), straightener, control unit, illumination and imaging chamber, a single point load cell, measurement sensors and drying chamber with one layer tray. Whole body of the dryer was thermally insulated with glass wools. The control unit consisted of a programmable logic controller (PLC, FATEK, Fbs-20MA), an analogue to digital converter (FATEK, Fbs-6AD), a digital to analogue converter (FATEK, Fbs-4AD), a 12V DC power supply (Acro, AD1048-24FS), Load cell transmitter (ESiTT, TR-3,turkey),

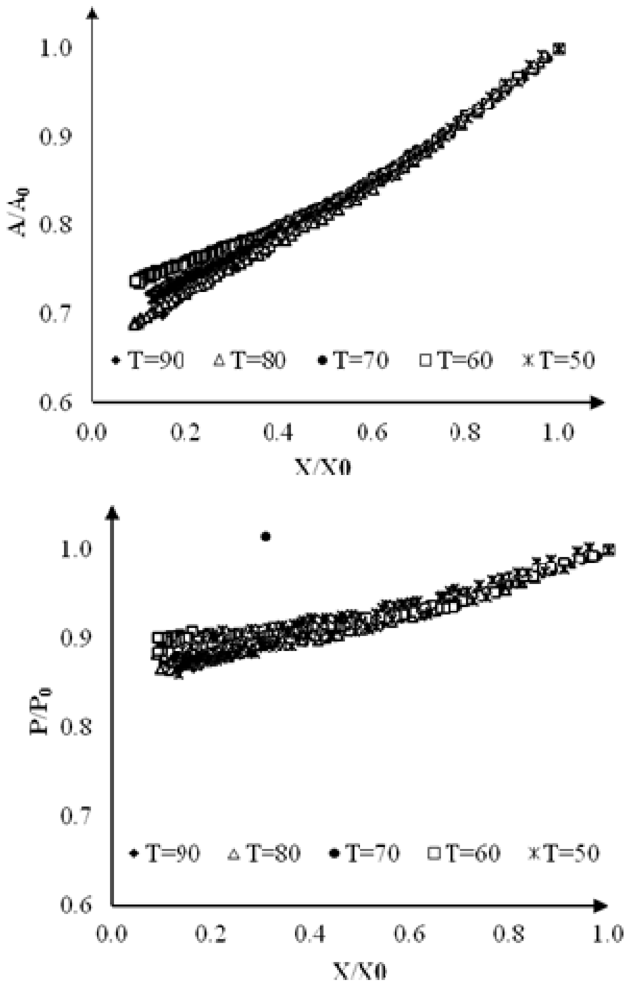

Fig 6. Effect of air temperature on the variation rate of the slice area and perimeter (thickness of 7mm)

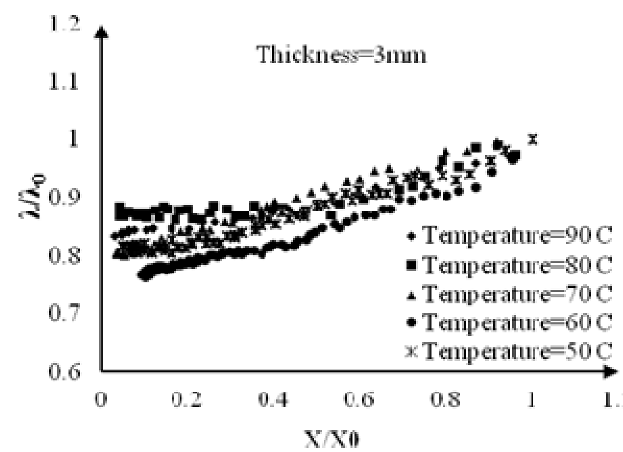

Fig 7. Dimensionless variation of sample thickness as function of moisture content ratio.

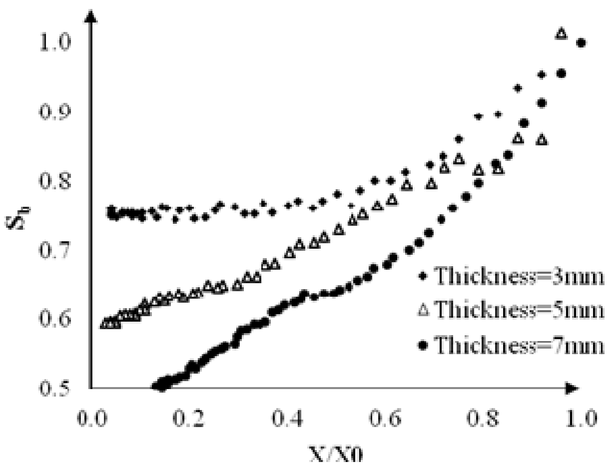

Fig 8. kinetics of shrinkage as a function of moisture content ratio.

an inverter to control speed of the fan (Rhymebus, RM5E-2002), a power controller (Autonics, SPCI-35) to control voltage of the elements and relative humidity and temperature sensors boards. The temperature of the airflow was controlled within ±1ºC with the use of a PLC, a power controller and two PT-100 temperature sensors (before and after the samples tray). Outside air temperature was measured using a temperature sensor (LM35, NSC, USA). Relative humidity of the airflow was measured by means of a high-temperature relative humidity sensor (EE99-03-FP6AD 802, E+E Elektronik). Weight loss and moisture of samples during drying was measured by means of a high precision aluminum single point load cell (Tedea, Huntleigh, model 1004) with an accuracy of 0.001g,. The air velocity was measured by an anemometer (Lutron, AM-4201, Taiwan) and controlled using the inverter. The PLC was interfaced to a PC (Intel-Pentium 4, 3.06 GHz, 512MB RAM, 200GB hard disk) via RS-232 port. All measured data (temperatures, relative humidity, air velocity, weight of samples and time) were transferred and saved to the PC via the PLC and a written program in MATLAB environment. A human machine interface (HMI, FV035ST-C10) was used to enter set- points, to communicate with the dryer, digital camera, fluorescent lamps, and the load cell, and to determine the paths in which measured data should be saved and to view the dryer performance graphically.

The position of the cameras and image processing

In this study, the photography was done at three-dimension type. Therefore, two cameras were used to take picture from the samples during drying time. One of them was fixed along top, and another one was fixed alongside of samples. The images of the upper camera were used to calculate surface properties and the side one to calculate the thickness variations. A computer program was developed in MATLAB environment to process the taken images. The program had several steps parts. In the first step, the images were called to the MATLAB environment.

In the second step, the images were isolated from background. In the third part, the images were changed from their format to binary, and in finally the images area, volume,

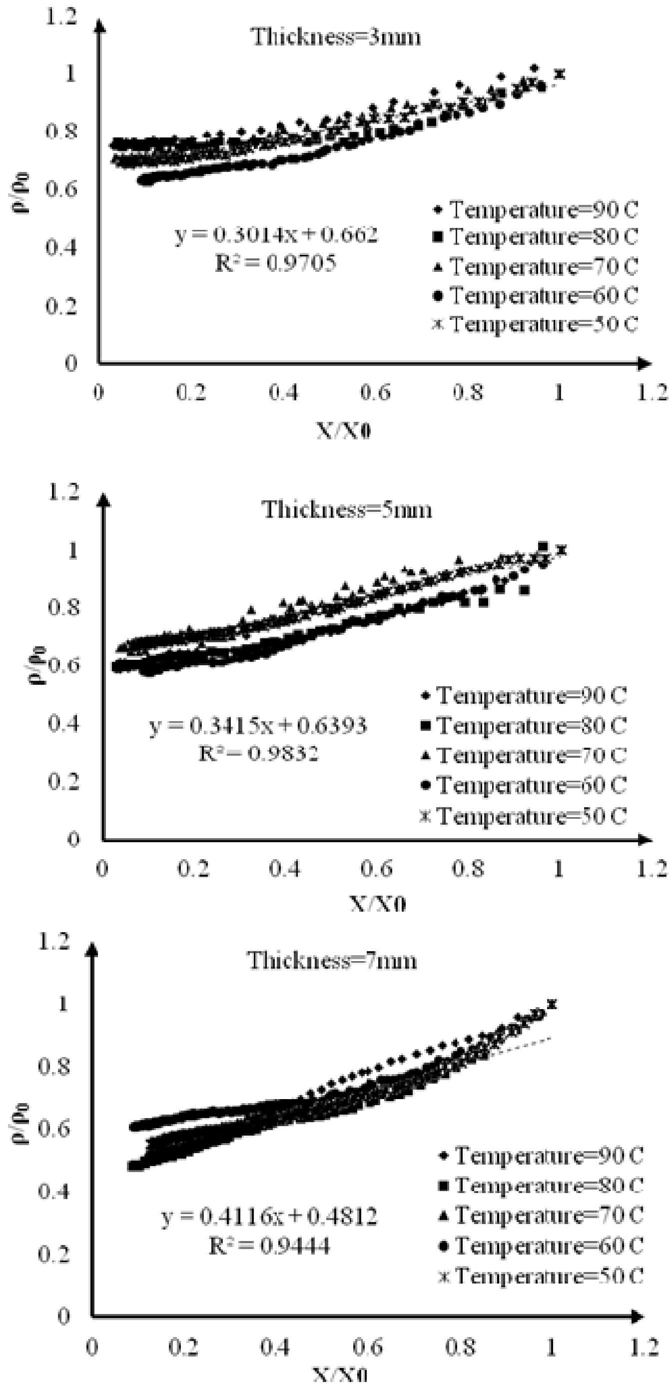

Fig 9. Dimensionless variation of sample density at different slice thickness.

perimeter, longest and shortest diameter, thickness and density of slice were calculated. The details of this program are shown as a flowchart in Fig.11. According to the flowchart, the calculations are done for all pictures automatically and its output will be a matrix with N (number of pictures) rows and 7 columns consisted of A, P, LD, SD, V, Density and stability of the slices. The ratio of the

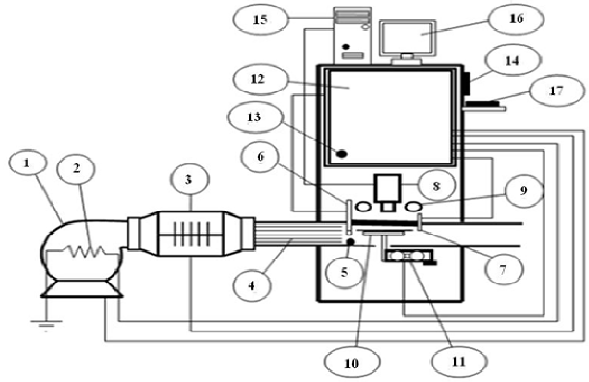

Fig 10. Experimental dryer: 1.fan; 2.preheating element; 3.heating elements; 4.straightener; 5.air velocity sensor; 6.relative humidity and temperature sensor; 7.temperature sensor; 8.digital color camera; 9.fluorescent lamps; 10.platform; 11.load cell; 12.control unit; 13.outside temperature sensor; 14.HMI; 15.computer; 16.monitor; 17.keyboard.

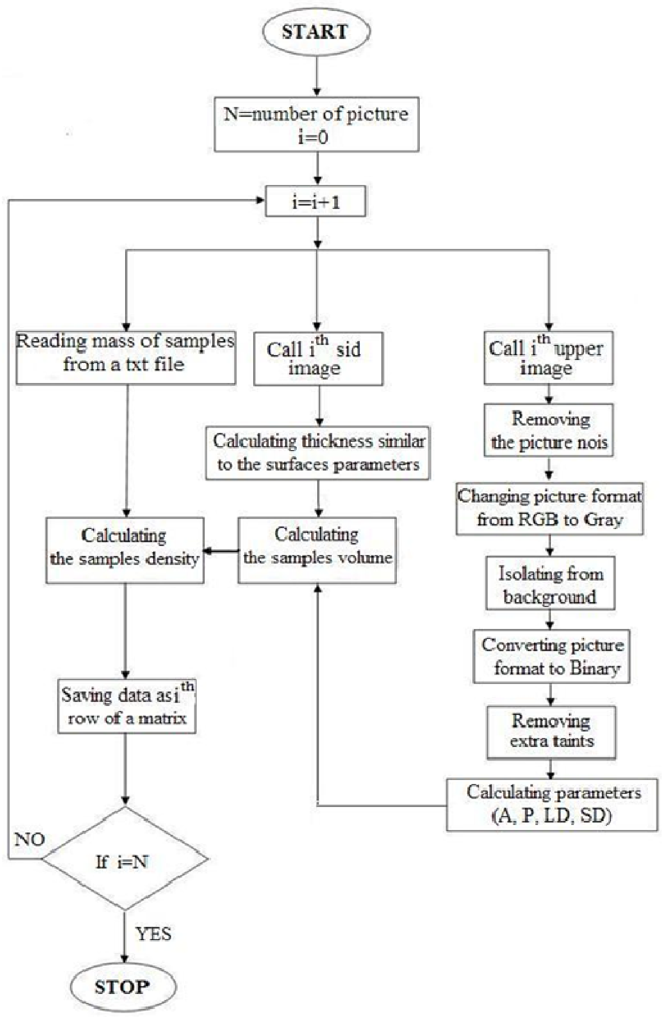

Fig 11. Flowchart of the side and up image processing.

calculated parameters was used to analyze the samples shrinkage.

Determination of parameters

Roundness and elongation are the most important determinant parameters in the shape of the objects. Roundness is ratio of the area (A) of the object and that of a circle with the same perimeter (P) and elongation is a ratio of the longest diameter (LD) to the shortest diameter (SD) of the slice (Yadollahinia and Jahangiri, 2009). Because of non-isotropic changes of the samples shape during drying process, roundness and elongation were changed. These parameters were determined by image-processing data using the following equations,

$$R = \frac{4\pi A}{P^2} \quad (1)$$

$$E = \frac{LD}{SD} \quad (2)$$

The slice stability is defined as the ability of an slice to maintain equilibrium or resume its original shape against deformation during the drying time. This parameter can be calculated by the following equation (4).

$$Slice\ \ stability = \left(\frac{dS_b}{dt}\right)^{-1} = V_0 \times \left(\frac{dV}{dt}\right)^{-1} \quad (3)$$

The ratios of area, perimeter, thickness, volume, density versus initial values, were used to define the shrinkage kinetics of banana.

Conclusions

An image processing technique was used to describe the shape variation of banana slices during thin layer drying method. Decreasing of moisture content was found to decrease roundness, area, perimeter, thickness, volume, and density of banana slices. But, the slice stability and elongation increased. A linear model was found between the samples shrinkage and moisture content ratio due to suitable coefficient of determination parameter. The effect of drying temperature on the shape parameters variations was not clear. But, the slice thickness was found as an effective parameters on shape parameters variations. Hence, the variation rate of area, perimeter, thickness, volume, and density of banana slices increased with increasing the slice thickness from 3 to 7 mm.

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