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Full Length Article

The Thin Layer Drying Characteristics of Apple Slices

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ABSTRACT
The aim of this work was to determine the effect of temperature, pre-treatments and slice thickness on drying characteristics and quality parameter of convection dried apples slices. Apple slices var. Golden Delicious with initial slice thicknesses of 3 and 5 mm were treated with citric acid or Sodium Meta bi sulfite and dried as single layer in the ranges on 50–80 °C of the drying air temperature and air velocity of 1 m-s in a fully automatic experimental convective hot air dryer. It was found that apple slices would dry perfectly within 60-200 min under these drying conditions. Drying time curves and drying rate curves was defined in studying term. Results and statically analysis of the data show that the changes in temperature and thickness have very significant effects (α=1%) on drying time. The results indicated that the 5 mm slice thickness in 50°C temperature is not suitable for applying of drying. The 60 and 70°C temperature have been recognized suitable for two pre-treatments while the 80°C temperature could gain the necessary points in citric acid treatments. The color index of the treatments with 5 mm is higher than 3 mm and the color index of the treatments that used sodium Meta bi sulfite is less than citric acid. The maximum shear force occurred at 80°C, 5 mm citric acid, so that was the most firmness dried sample, and can result in high temperature occurred case hardening. Rehydration Capacity of the treatment with 3 mm thickness is higher than 5mm.
Keywords: Apple, Convection drying, Color, Firmness, Rehydration

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INTRODUCTION

Iran is one of the leading fruit producing countries with an annual production of 14 million tons. The apple is one of the most important fruits in Iran and its annual apple production is over 1, 7 million tons. The fruits contain a high percentage of their fresh weight as water, thus making most fruits highly perishable commodities. One of the simplest methods to improve the shelf life of fruits is to reduce their moisture content to such extent that the microorganism cannot grow. Drying is a classical method of food preservation and it is a difficult food processing operation mainly due to undesirable changes in quality of dried product [11]. The basic objective in drying agricultural products is the removal of water in the solids up to certain level, at which microbial spoilage and deterioration chemical reactions are greatly minimized [11]. The apples are consumed either fresh consumption or in the form of various processed products such as juice, jam, marmalade and dried product, etc.
Several studies have been carried out to investigate the drying characteristics of the apple by several studies have been carried out to investigate the drying characteristics of the apple; Vega-Galvez et al *(*[13] Studied effect of temperature and air velocity on drying kinetics, color, texture of apple var. Granny Smith. He reported the rehydration ratio changed with varying both air velocity and temperature indicating tissue damage due to processing. The color difference showed the best results at 80°C . Bhardwaj et al [1] studied drying behavior of rings from three apple cultivars. He reported "Golden Delicious" among cultivars has given better quality. Sjoholm and Gekas *et al* [8] studied the shrinkage of apple slices during drying in convective oven. They reported as relationship between volume and thickness reduction as well as between volume reduction and water content. Haida *et al* [4] dried granule apples with fluidized bed drier and reported, this method of drying did not effect on aroma apple. Krokida et al (1999) evaluated drying related properties of apple for various different drying methods and their corresponding process

conditions. He reported in the convective drying, drying kinetics is greatly affected by the characteristic particle size and drying air temperature. Equilibrium material moisture content is affected by the temperature and humidity of the surrounding air [5]. Simal S. and Deya E. *et al* [9] reported that, drying curves of fresh apple cubes showed case-hardening when the air drying temperature was higher than 60°C. Funebo T. *et al* [3] compared hot-air drying and microwave-assisted hot-air drying. He resulted that low air velocity caused a browning of the products and a maximum air velocity of 1 m/s identified [3]. Prothon F. *et al* (2001) evaluated the effect of microwave-assisted air drying with or without osmotic pre-treatment on apple cubes. He resulted that osmotic pre-treatment before microwave-assisted air drying increased the final overall quality of the product. The rehydration capacity in water was significantly higher for non-treated samples than for the pre-treated ones [6]. Wang *et al* [14] studied hot air convective drying characteristics of thin layer apple pomace .He reported the logarithmic model can present better predictions for moisture transfer than other. Doymaz (2010) reported that both the drying temperature and pre-treatment affected the drying time. The shortest drying time were obtained from pre-treatment samples with citric acid and blanched samples have higher rehydration ratio than other sample [2]. Sacilick and Konuralp (2005) determined the effect of drying air temperature and slice thickness on the drying characteristic and quality parameters of the dried apple slice [11]. The present study was, therefore, undertaken to investigate the thin layer drying characteristics of apple slices in a convective dryer and influence of different air temperatures, thicknesses and pre-treatments on drying time and quality factors : color, rehydration capacity and firmness of dried apple var. Golden delicious.

MATERIALS AND METHODS

Experimental drier

Drying experiments were carried out by an experimental system, which consist four simultaneously working driers. Drier system was designed and fabricated to determine drying behavior of fruits and vegetables in Department of Food Science, Iranian Research Organization of science and Technology (Figure 1). The experimental dryers consist of a centrifugal blower, an electrical resistance air heating section, the measurement sensors and the data recording system coupled with a personal computer. The required air flow rate for drying is kept at the desired level by arranging the cycle number of the electrical motor without level. The air heated up to the desired dry bulb temperature by the heaters. Circuit elements, each with 2*1000 W, started to operate separately. A resistance connected in series to one of these circuit elements turns on or off it depending on the changes in the temperature via temperature control unit, thus the adjusted temperature kept at the same level during the experiments. During the experiments changes of sample weight, air velocity and temperature in the drying channel and temperature and relative air humidity of the surrounding room were recorded every 10 min using load cell (model Futek, LSB200‹and accuracy 5000 ± 1g), anemometer (model , 27106, young Taiwan and accuracy 0-30ms^{-1}), copper-constantan thermocouples (0-100 ± 0.5 °C) and humidity/temperature meter (model Hygrometer PCE-THA 10,U.K,and accuracy of 10-95 ± 1%), respectively. A door was provided in front of side of the chamber for placing and removing the sample tray. Prior to the drying experiments, the equipment was run for about 30 min to achieve steady-state for the desired conditions.

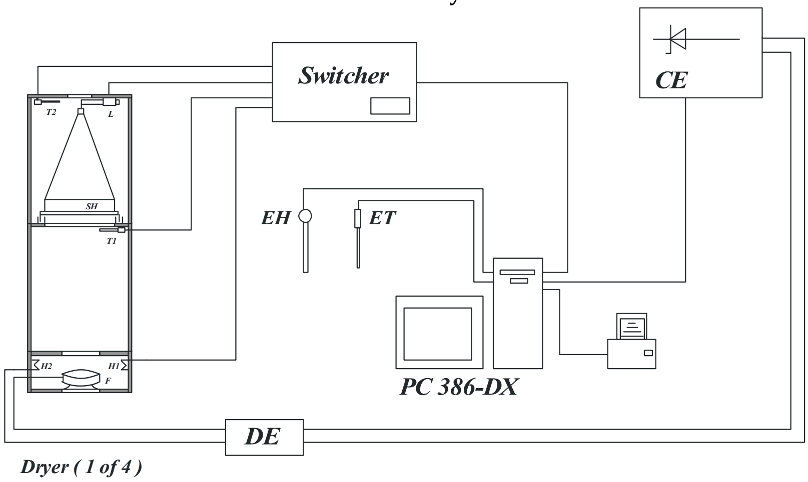

Figure 1. The schematic diagram of the drying system on the laboratory scale. F Blower ; H1 and H2 heaters, SH ,sample holder ; T1 and T2 , thermocouples ; L, load cell; SW, switcher ; DL, data logger, CS ,electronic control system; DE, electronic starter of drier; RH, ambient relative humidity sensor; AT, ambient temperature sensor; P, filling by liquid paraffin.

Experimental procedure

The apples (*var. Golden Delicious*) used in this study were obtained from Damavand area (Iran). Fresh apples for drying experiments were selected when they developed characteristics fruity flavor, color and attained the total soluble solids (T.S.S) 13 to 17 Brix and acidity 0.42 to 0.59 malic acid and moisture content 85 to 87%. Ripe and sound apples *var. Golden Delicious* were harvested by hand and stored in a refrigerator at 4 °C until drying experiments. After 2 h stabilization at ambient temperature, homogenous samples (range between 105 and 110 g) were washed with tap water and hand peeled, cored with a Corer and then cut vertical to their axis into cylindrical slices of 3 and 5 mm thickness using a Multi-purpose slicing Machine Model 3000. The apple samples were dipped in a 1% Citric acid solution for 15 min and in 2,5% Sodium Meta bi sulfite solution for 20 min and drained for 10 min. About 180 g samples of apple slices were used for drying measurement. They were spread on the drying chamber as pits on the top as a single layer. Then the material was air dried at temperatures in the range from 50 to 80°C and air flow of $1m^{-s}$. Surrounding air temperature was 22-24 °C and humidity 50-60%. Drying was terminated when no further mass change were observed (about 7.5 % w.b.). The dried slices were cooled for 15 min and then packed in poly propylene bags until the beginning quality experiments within one week after drying. The experiments were conducted in triplicate to obtain a reasonable average.

The final moisture content of apple slices was determined while the product reaches the fixed weight in the drying chamber, using the vacuum oven method at 70°C for 24 h (AOAC, 1990). The initial moisture content of the samples was found to be about 82% w.b. (wet basis).

The total soluble solids (TSS) contents were recorded with hand refractometer (AOAC 1990). Acidity was determined by method described in AOAC and expressed as malic acid (AOAC 1990). Texture was evaluated by measuring the force needed for the blade to shear through the dried slices. The maximum force value is related to firmness of the dried samples. The measurements were performed in a texture analyzer (Model QTS) a constant speed of 30 m/s using Warner-Blatlzer blade. The slices were cut in two halves, and the texture was measure by the maximum force that need for cutting slice [7]. For rehydration measurements, dried samples were allowed to rehydration in 20°C distilled water for 14 h. The rehydration capacity was calculated according a modification of one of the many equations for rehydration capacity. Rehydration Capacity = W_r / W_d. where: W_r is total weight after rehydration, and W_d is weight of dried samples [6]. Colors was determined with Loviband tintometer (Model E) and expressed in red (R), yellow (y) and blue (b) units. The color of the dried samples was match with a certain combination of the red, yellow and blue colored filter and color index was obtain by a formula similar to the yellowness index, where

Color Index = (R-B)/(Y+B) [12].

The experimental design was completely randomized factorial design (4*2*2) with four replication. All data were analyzed using Statistica (2015) software package. Analyses of variance were performed by ANOVA procedure. Significant differences between the means were determined by Duncan's multiple range test.

RESULTS AND DISCUSSIONS

Results and statically analysis of the data show that the changes in temperature and thickness have very significant effects (α=1%) on drying time, but no significant effect has the change of pre-treatment on drying time. However the interaction between temperature, thickness and pre-treatment is very significant (α=5%) on drying time (table 1, 2 and 3). The effect of pre-treatment depends on temperature and thickness variables. Comparison of means shows that with decreasing thickness from 5 to 3, drying time reduces. However this effect is different for each pre-treatment at different air temperature (table 2 and 3). The maximum effect occurred at 60°C, sodium Meta bi sulfite but at citric acid occurred at 80°C (table 2 and 3).

Table 1. ANOVA table for drying time

Source of variation	d.f	FS
Temperature	3	1175.42^{**}
Thickness	1	2547.51^{**}
Pre-treatment	1	0.47^{ns}
Temperature * Thickness	3	46.34^{**}
Temperature* Pre-treatment	3	26.97^{**}
Thickness* Pre-treatment	1	1033^{**}
Temperature* Thickness* Pre-treatment	3	39.21^{**}
Error	48	
Total	63	

**=significant at 1% level. ns= not significant at 5% level.

This increase in the drying time with increasing slice thickness was due to reduced distance the moisture travels and increased surface area exposed for given volume of the samples. Similar results have been noted by Sacilik and Konuralp (2005) and Wang &Chao (2007). The least effect occurred at 50°C when used sodium Meta bi sulfite (table 2 and 3).

Table 2: Comparison of the means for drying time of sodium Meta bi sulfite pre-treatment (min)*

	Temp. (°C)			
Thickness (mm)	50	60	70	80
3	146.86^{d}	104.83^{g}	67.58^{j}	50.24^{k}
5	192.15^{b}	174.61^{c}	130.93^{e}	97.21^{h}

* Means with the same letter have no significant difference (α=1%)

Table 3: Comparison of the means for drying time of Citric acid pre-treatment (min)*

	Temp. (°C)			
Thickness (mm)	50	60	70	80
3	139.61^{e}	103.81^{j}	66.59^{h}	53.65^{j}
5	199.69^{a}	177.97^{c}	122.04^{f}	91.33^{fg}

*Means with the same letter have no significant difference (α=1%)

The decrease in drying time with increase in drying air temperature have been observed by Doymaz (2010), Kamil and Konuralp (2005), Wang and Chao (2007), Vega-Galvez and et al (2012). The maximum reduction of drying time occurred by increasing the temperature of 50 to 60°C when used citric acid at 3 mm thickness (57.19%) and when used Sodium Meta bi sulfite, reduction of drying time occurred at change 60 to 70°C, When used Sodium Meta bi sulfite (49.97%) (Fig 2 and 3).

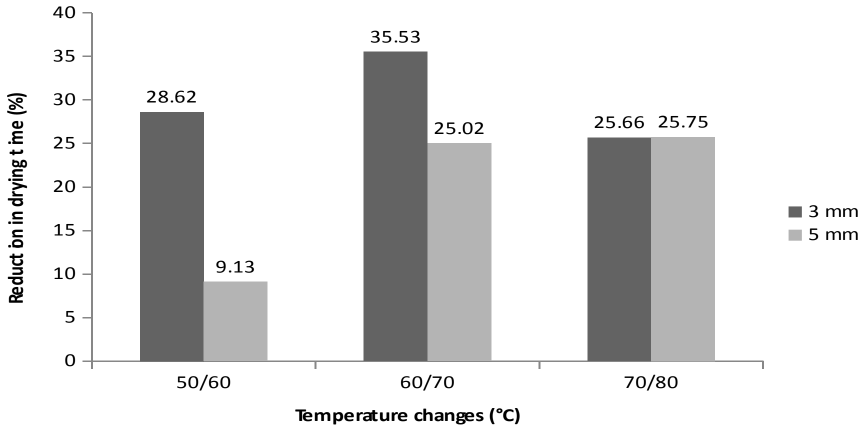

Figure *2.* Influence of temperature increase on reduction of drying time in two thickness and citric acid pre-treatment

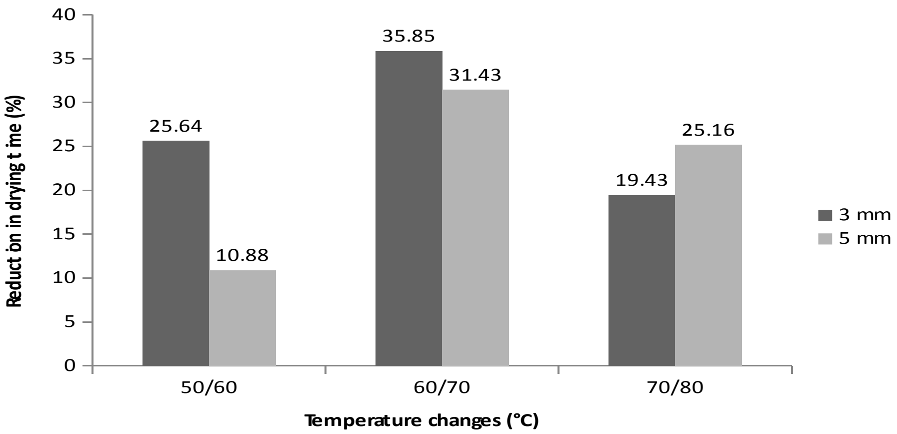

Figure3. Influence of temperature increase on reduction of drying time in two thicknesses and sodium Meta bi sulfite pre-treatment

Drying curves corresponding to apple slices of citric acid pre-treatment at different air temperatures (50, 60, 70 and 80°C) and 3 mm thickness are shown in Fig. 4. As it can be seen in this figure, drying rate clearly increased when temperature increased from 70 to 80°C. Nevertheless, the influence of air temperature was less important from 50 to 70°C. As it can be seen in Figure 4, drying curves to apple slices of citric acid pre-treatment at different air temperature and 5 mm thickness, drying rate increased when temperature increased from 60 to 70°C. In 3 mm thickness influence of air temperature was less important from 50 to 70°C and in 5mm thickness was from 70 to 80°C. A constant drying rate period was not detected in these drying experiments. As shown is figure 4, 5 slope of the drying during the first phase of drying are different. Similar result has been observed by Doymaz (2010) and Uretir & *et al* (1999). The 3 mm thickness curve has higher slope than 5 mm thickness curve. High temperature curves have higher slope the other in both thickness (Fig 9, 10).

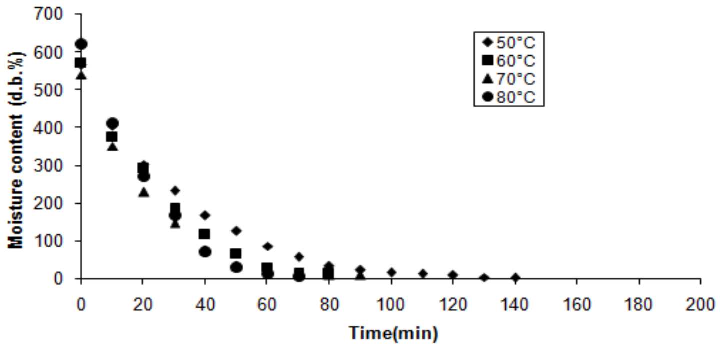

Figure 4. Change of moisture content with time at 3 mm thickness and citric acid Pre-treatment

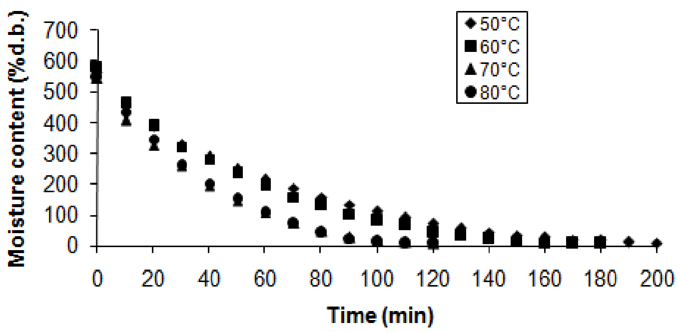

Figure 5. Change of moisture content with time at 5 mm thickness and citric acid pre-treatment.

As shown in table (4, 5 and 6) change in temperature, thickness and pre-treatment have very significant effect on rehydration, color and texture. No significant effect exists between temperature* thickness, thickness* pre-treatment and temperature* thickness* pre-treatment in relation to rehydration. Interaction effect between temperature* pre-treatment is significant (α=1%) in relation to rehydration (table 5, 6). The results from rehydration experiments show the most rehydration capacity was in 60°C temperature, Sodium meta bi sulfite pre-treatment and 3mm thickness (R.C.=5.803) and the least rehydration capacity was in 70°C, 5 mm and citric acid (R.C. =4.395) (fig.6).

Table 4: Results of ANOVA for quality parameters

Source of variation	d.f	Rehydration	Color	FS Texture
Temperature	3	5.06**	15.42**	31.24**
Thickness	1	83.53**	78.48**	142.71**
Pre-treatment	1	14.33**	31.02**	17.64**
Temperature * Thickness	3	2.7ns	2.81**	6.89**
Temperature * Pre-treatment	3	4.26*	9.46**	2.85**
Thickness * Pre-treatment	1	2.17ns	11.16**	6.42**
Temperature * Thickness* Pre-treatment	3	2.63ns	2.32**	3.86**
Error	48			
Total	63			

**=significant at 1% level *=significant at 5% level ns=not significant at 5%

Table 5: Comparison of the means for rehydration value at Sodium Meta bi sulfite pre-treatment

	Temp. (°C)			
Thickness (mm)	50	60	70	80
3	5.73[ab]	5.8[a]	5.62[a]	5.35[ab]
5	5.41[a]	4.99[bc]	4.68[cde]	4.88[cd]

Table 6: Comparison of the means for rehydration value at Citric acid pre-treatment

	Temp. (°C)			
Thickness (mm)	50	60	70	80
3	5.11[bc]	5.61[a]	5.09[bc]	5.67[a]
5	4.46[de]	4.93[bc]	4.39[e]	4.68[cde]

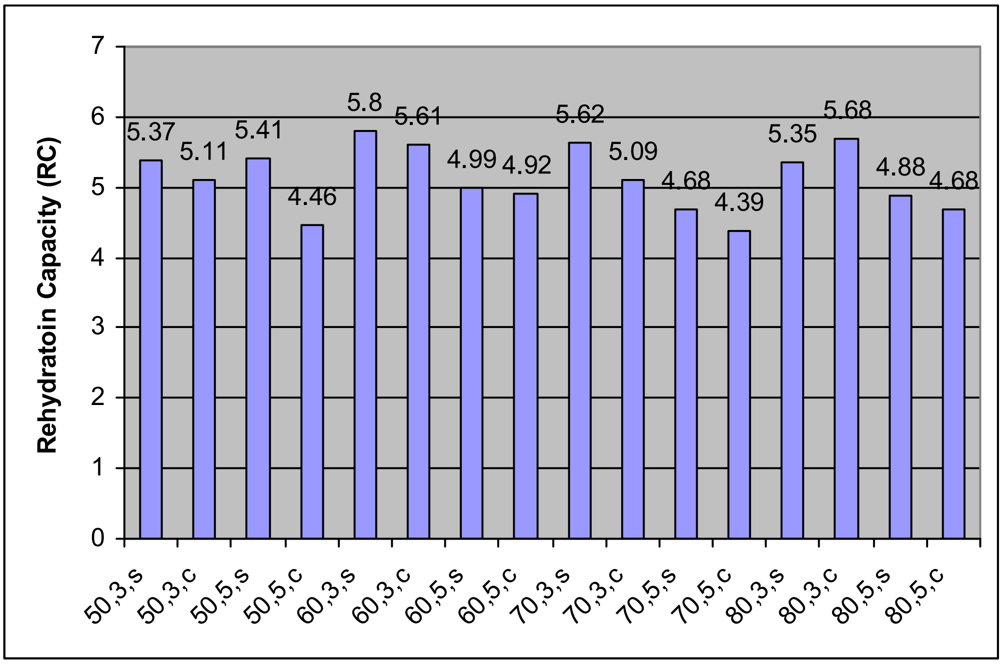

Figure 6. Rehydration Capacity, measured as water uptake, for the different process condition. The variation is given on the 95% confidence level.

The results show Rehydration Capacity of the treatment with 3 mm thickness is higher than 5mm. So for instance if a high rehydration capacity such as a fruit soup or a sauce is required, the apple slices with 3mm thickness are options. The rehydration kinetics is also important as a quality factor. We chose not to study rehydration kinetics here, because the main aim of this investigation was to increase the total rehydration capacity. The color of the product deteriorated due to browning product unacceptable. As shown in Fig. 7, the maximum color index in 80°C, 3 mm and sodium Meta bi sulfite. The results show the color index of the treatments with 5 mm is higher than 3 mm and the color index of the treatments that used sodium Meta bi sulfite is less than citric acid.

The shear force data indicated that dried samples are shown in Fig8. The shear force data indicated that 5 mm thickness were firmer than 3 mm thickness and similar cases. The maximum shear force occurred at 80°C, 5 mm citric acid, so that was the most firmness dried sample, and can result in high temperature occurred case hardening.

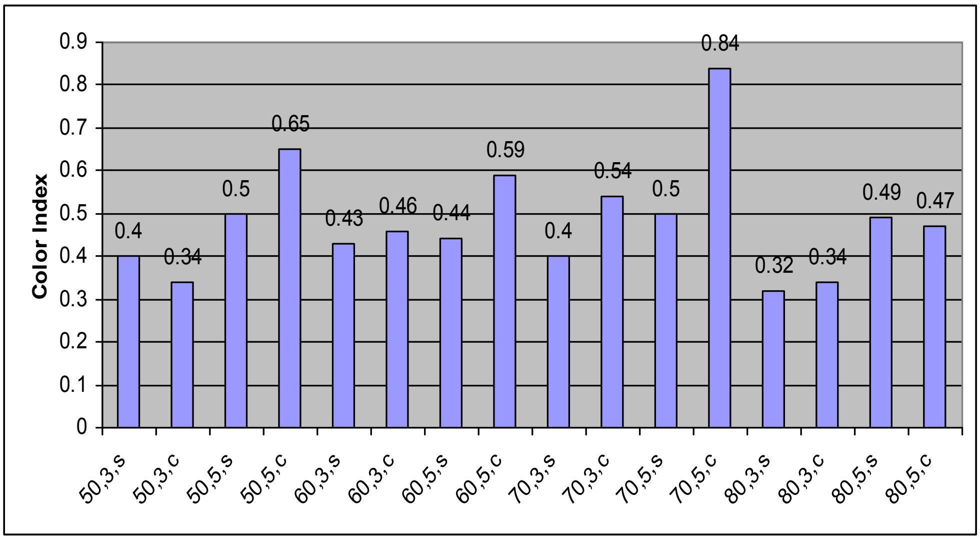

Figure 7. The color index for the different process condition

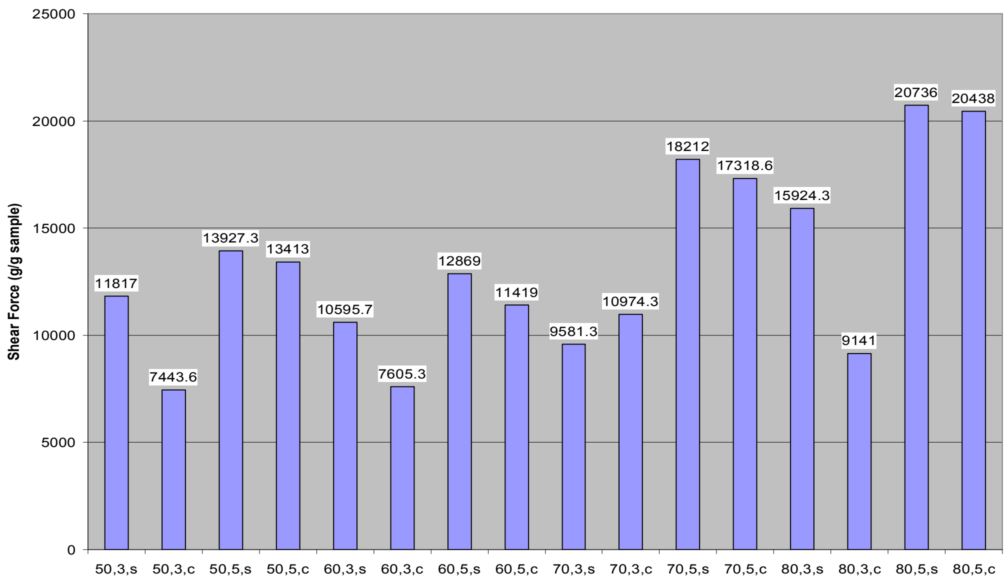

Figure 8. Effect of drying parameters (temperature, thickness and pre-treatment) on shear force (g/ g sample) of dried apples.

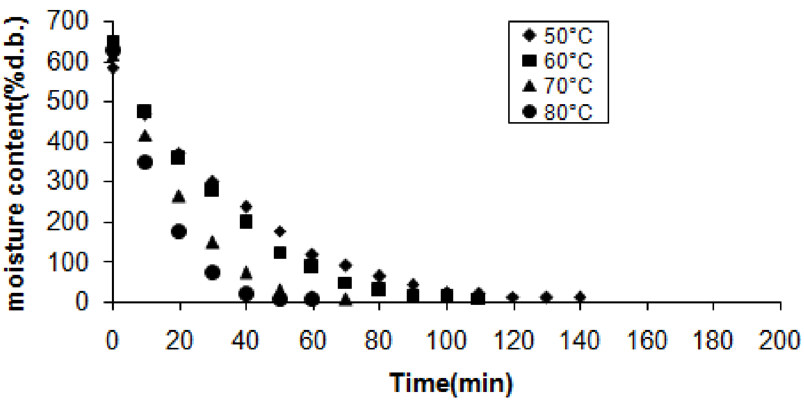

Figure 9. Change of moisture content with time at 3 mm thickness and Sodium Meta bi sulfite pre-treatment

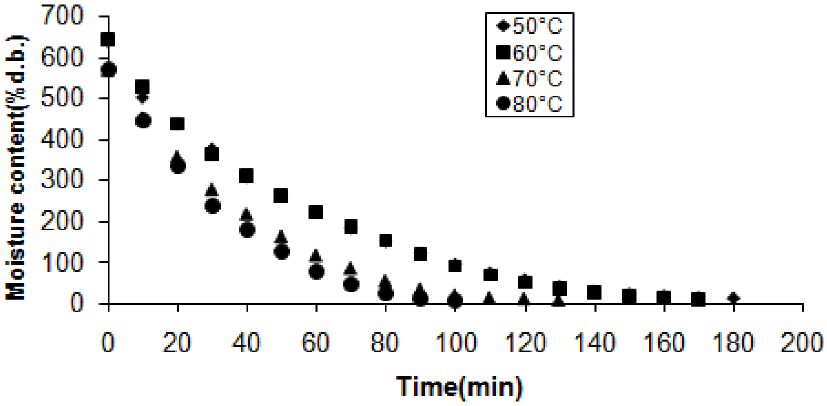

Figure 10. Change of moisture content with time at 5 mm thickness and Sodium Meta bi sulfite pre-treatment

CONCLUSION

1. Air temperature and thickness are the two basic parameters in apple drying process.
2. Increasing in the drying air temperature and decreasing in slice thickness caused a decrease in the drying time and an increase in drying rate.
3. Low Temperature and sodium Meta bi sulfite pre-treatment prior to drying resulted in a lighter slice color.
4. Based on analysis in high temperature occurred case hardening.
5. Based on analysis of results, drying of apple slice at air temperature and thickness of 50°C and 5 mm is not recommended.
6. Based on analysis of results, the 60 and 70°C air temperature is recognized suitable of two pre-treatment, while the 80°C air temperature give the necessary points in citric acid treatments.
7. Increasing temperature from 50 to 80°C significantly affect in quality parameters.

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