MATHEMATICAL MODELLING OF HOT AIR DRIED APPLE AND EFFECTS OF VARIETY, SHAPE AND TEMPERATURE ON DRYING BEHAVIOR AND QUALITY CHARACTERISTICS

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***Abstract*— In this study, drying kinetics and quality characteristics of apple cv. *Starking*, *Gala* and *Granny Smith* circles and squares were studied at two different drying temperatures, 60 °C and 70 °C. Drying times were varied between 85-165 min.Depending on variety, shape and temperature. The falling rate period was observed and drying rate changed depending on the drying parameters. Four mathematical models were fitted to experimental data and Logarithmic model was found to be the best for all the samples. Total phenolic contents and antioxidant capacities of dried apple samples varied in the range of 4.11-8.36 mg GAE/g dry matter and 4536.43-7370.47 mmol AEAC 100/g dry matter, respectively and showed a tendency to increase or decrease after drying depending on the variety and shape interaction. Shape had also significant effect on antioxidant capacities of samples as well as the variety ($p<0.05$). The results of variance analysis demonstrated that there were significant differences among color values of apple samples dried at 60 ºC and 70 ºC.**

***Keywords*— apple, drying kinetics, antioxidant capacity, total phenolics**

I. INTRODUCTION

Apple (*Malus domestica*) is rich in phytochemicals and epidemiological studies have demonstrated that consumption of apple reduced the risk of some cancers, cardiovascular disease, asthma and diabetes (Boyer and Liu, 2004). Apple contains a significant amount of different classes of phenolic compounds (Paunović *et al.,* 2010). Antioxidant activity of apple polyphenols is the highest among the mostly consumed fruits and vegetables (Vega-Gálvez *et al.,* 2012). Therefore, apple should be preserved for consumption in all seasons (Aghilinategh *et al.,* 2015). Dehydration is a classical method used to reduce the moisture content of food to a certain value allowing safe storage and preservation, longer shelf life, less volume and more derivability (Zura-Bravo *et al.*, 2013). Dried apples are main ingredients of many products including healthy snacks, baby food, cakes, integral breakfast foods and other functional foods (Vega-Gálvez *et al.,* 2012).

Hot air drying is the widely used method. However, the most important disadvantage of this method is the length of drying time and so, low energy efficiency (Jabeen *et al.,* 2015). At the same time, it can adversely influence the quality parameters of the final product such as color, texture and rehydration ability (Vega-Gálvez *et al.,* 2009). Drying is influenced by many factors such as size and shape of material, dryer type and drying kinetics parameters (such as temperature, moisture ratio, drying rate and air velocity) (Yu *et al.,* 2017). One of the important points in drying technology is the modelling of the drying process. An appropriate drying kinetics are needed to estimate the drying rate and optimize drying parameters (Naderinezhad *et al.,* 2016).

Based on literature data there is no information on the effects of shape, variety and temperature on polyphenol content and antioxidant capacity of dried apple as well as drying behavior. Therefore, this study was undertaken to evaluate the effect of product shapes (square and circle) and drying temperatures (60 °C and 70 °C) on drying kinetics and quality properties of *Starking*, *Gala* and *Granny Smith* apple varieties.

II. METHODS

A. Sample preparation

Fresh, high-quality apples (var. *Starking*, *Gala* and *Granny Smith*) were purchased from a local store via local farmers. All varieties were grown in Süle-Inegöl (Bursa, Turkey, 40º 2' 21.6816" N 29° 23' 57.1848" E) and harvested in October in 2019. The samples were kept at 4 ºC until the experiments were conducted. Just before drying, apples were washed and wiped with blotting towel paper to remove excess surface water. They were cored, sliced into 2.8 mm thickness with a domestic slicer and then one part was prepared as circle with a diameter of 62 mm using a circular cutting tool. The second part was cut into square with dimensions of 12.2 mm x 12.2 mm. After cutting, fruits were processed immediately. Initial moisture content of fresh apple samples was about 83.81% wet basis.

B. Drying process

Drying process was conducted at 60 °C and 70 °C in 20% relative humidity using a convective cabinet type laboratory drier (Yucebas Machine Analytical Equipment Industry Y35, Izmir, Turkey). The initial moisture content of the apple was determined by an infrared moisture analyzer (Sartorius MA150) at 105 °C. Drying experiments were performed in three replicates. During the drying period, samples (about 20 g) were taken out of the dryer at regular intervals (every 15 min during the whole drying period or every 15 min at the early stage of drying and every 10 min and/or 5 min at the later stages of drying depending on the drying parameters applied) and weighed in a short time with digital weighing device (Mettler Toledo, MS3002S) with an accuracy of ± 0.01 g. Weighing of samples was done manually outside the dryer until their moisture content reached below 10 %. The dried apples were cooled down to the room temperature, then were packaged in zip-lock plastic bags to prevent moisture exchanges and stored in a refrigerator at 4°C until analyses.

C. Determination of moisture content

During drying of the apple samples at different temperatures, the moisture content at any time of t was calculated as follows;

$$Mt = \frac{m - DM}{DM}, \quad (1)$$

where Mt is the moisture content at any time of t (g water/g DM), m is the mass (g) and DM is the amount of dry matter (g).

D. Determination of drying rate

To calculate the drying rate (g water/g DM min), a suitable empirical equation was fitted to the experimental moisture removal data and then differentiated with respect to time using following equation.

$$Drying\ Rate = \frac{M_{t+dt} - M_t}{dt}, \quad (2)$$

where M_{t+dt} is the moisture content at $t + dt$ (g water/g DM) and dt is the time between two sample weighing (min).

E. Determination of moisture ratio

The moisture ratio (MR) was calculated from the weight changes of the samples and these values were used in the modelling related to drying kinetics as follows;

$$MR = \frac{M_t - M_e}{M_0 - M_e}, \quad (3)$$

where MR is the moisture ratio (dimensionless), M_t is the moisture content at any time of t (g water/g DM), M_o is the initial moisture content (g water/g DM) y M_e is the equilibrium moisture content (g water/g DM).

F. Mathematical Modelling

Four thin layer drying models, commonly cited in the literature, were selected to describe the drying characteristics of apple samples. These are Newton (Eq. 4), Page (Eq. 5), Logarithmic (Eq. 6), and Henderson and Pabis (Eq. 7) models.

$$MR = \exp(-k.t), \quad (4)$$

$$MR = \exp\ (-k.t^n), \quad (5)$$

$$MR = aexp(-kt) + c, \quad (6)$$

$$MR = aexp(-kt). \quad (7)$$

The models were evaluated based on coefficient of determination (R^2), root mean square error (RMSE) and Chi-square (χ^2). The constants k and n of model equations below were calculated through nonlinear regression analysis using MINITAB (16) software. Model validation was also performed to determine the suitable model. Model parameters were calculated using equations (Walther and Moore, 2005) as follows:

$$\text{RMSE} = \left[\frac{1}{N}\sum_{i=1}^{N}\left(-\text{MR}_{\text{exp,i}}\right)^2\right]^{1/2}, \quad (8)$$

$$\chi^2 = \frac{\sum_{i=1}^{N}(\text{MR}_{\text{pred,i}} - \text{MR}_{\text{exp,i}})^2}{N - z}. \quad (9)$$

where N is the number of observations, z is the number of drying constants, $\text{MR}_{\text{exp,i}}$ is the experimental moisture ratio of i^{th} data and $\text{MR}_{\text{pred,i}}$ is the predicted moisture ratio of i^{th} data.

G. Color measurement

Color properties of dried apples were measured by a Konica Minolta Chroma Meter (CR-5, Bench-top, Japan). Color values were recorded as *L (*brightness), *a* (redness-greenness), *b* (yellowness-blueness), *C* (chroma) and *h* (hue angle).

H. Extraction of polyphenols

Dried and fresh samples were extracted according to Turkmen *et al.*, (2005). The clear extracts were analyzed both for determinations of phenolic content and antioxidant capacity.

I. Total polyphenol content (TPC)

The content of total phenolics was determined using the Folin-Ciocalteu method (Obanda and Owuor, 1997). The results determined from regression equation of the calibration curve ($y = 0.0157x$, R^2=0.99) were expressed as mg gallic acid equivalents (GAE) per gramme of dry matter (DM).

J. Antioxidant capacity (AC)

Antioxidant capacity was determined by the 2,2, diphenyl-2-picryl-hydrazyl (DPPH) method of Turkmen *et al.*, (2005). Antioxidant capacity was calculated as percentage inhibition of the DPPH radical by the following equation:

$$AC\ (\%) = \frac{Abs_{control} - Abs_{sample}}{Abs_{control}} x100. \quad (10)$$

K. Statistical analysis

All data were expressed as means ± standard deviation of triplicate measurements and analyzed by SPSS software (SPSS statistics 23, IBM.2015) Experimental data were analyzed using analysis of variance (ANOVA). Means were compared by using Duncan's Multiple Comparison Test. Values of $p < 0.05$ were considered as significantly different.

III. RESULTS

A. Drying Kinetics

The effect of variety, air temperature and shape on drying times of apple samples is presented in (Fig. 1). Initial moisture contents of *Starking, Gala* and *Granny Smith* varieties were 5.46, 4.98 and 5.10 g water/g DM, respectively. Square and circle shaped apples were thin layer dried at 60°C and 70°C in a hot air drier to a final average moisture content of 0.072 g water/g DM. While the longest drying time (165 min.) was observed in circle shaped *Gala* variety dried at 60°C, the shortest drying time (85 min.) was determined in square shaped *Starking* variety dried at 70°C. Increase in drying temperature for all apple samples resulted in reduction of drying time which is in consistent with the results of Bakal *et al.* (2012). With the increasing of temperature from 60°C to 70°C, reduction of drying time of square shaped *Starking*, *Gala* and *Granny Smith* were 26.09%, 37.93% and 20.83%, respectively and for circle shaped apples these reductions were 20%, 27.27% and 21.88%, respectively. Also, square shaped apples dried faster than circle shaped ones for each drying temperature and variety, which was in consistent with the results of Naderinezhad *et al.* (2016). However, Bakal *et al.* (2012) reported that drying time was not dependent on shape for potato. The longer drying times for circle shaped apples could be explained by the increase of the amount of water to be removed from the material, because of the increased surface area in those. The changes in MR of apple samples dried at different temperatures as a function of time are presented in Fig. 1. For all apple samples, the MR decreased with increasing of drying temperature. Also, at the beginning of drying, the MR was very high and decreased as time progressed (Fig. 1). This could be attributed to increasing resistance to moisture diffusion inside the product.

In order to investigate the effect of variety, temperature and shape on drying rate of three apple varieties, drying rate was calculated according to Logarithmic model and plotted against moisture content (dry basis) (Fig. 2). It was apparent that drying rate decreased continuously because of decrease in moisture content, which caused decreased moisture migration and evaporation rate from the surface of the product (Kaur *et al.*, 2018). For apple samples, a constant rate period was not observed in the drying experiments. Therefore, the all drying process took place in the falling rate period, which was in also

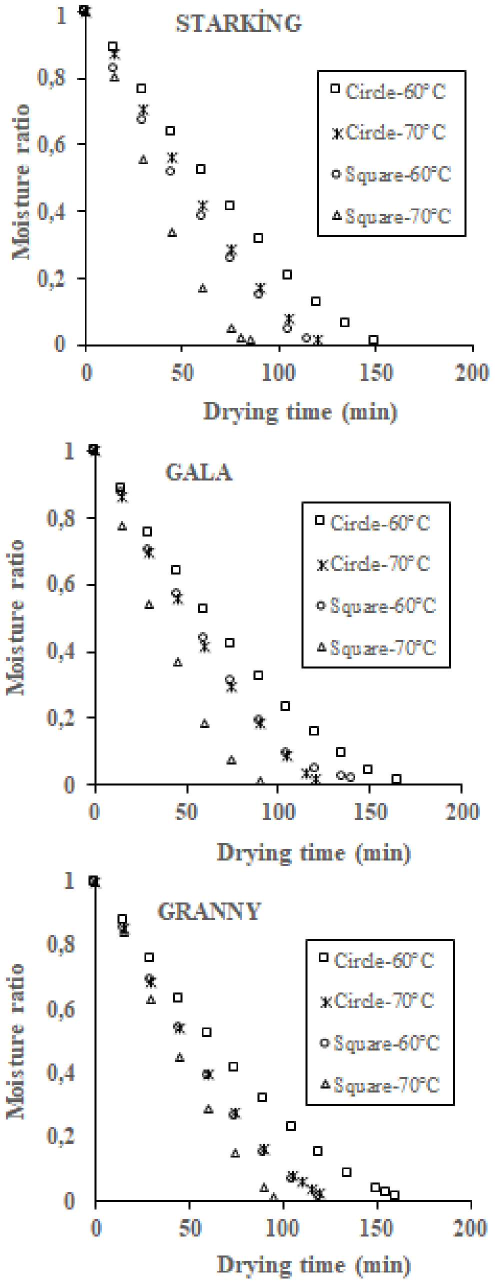

Figure 1. Moisture ratio of apple varieties dried at different temperatures for *Starking, Gala* and *Granny Smith.*

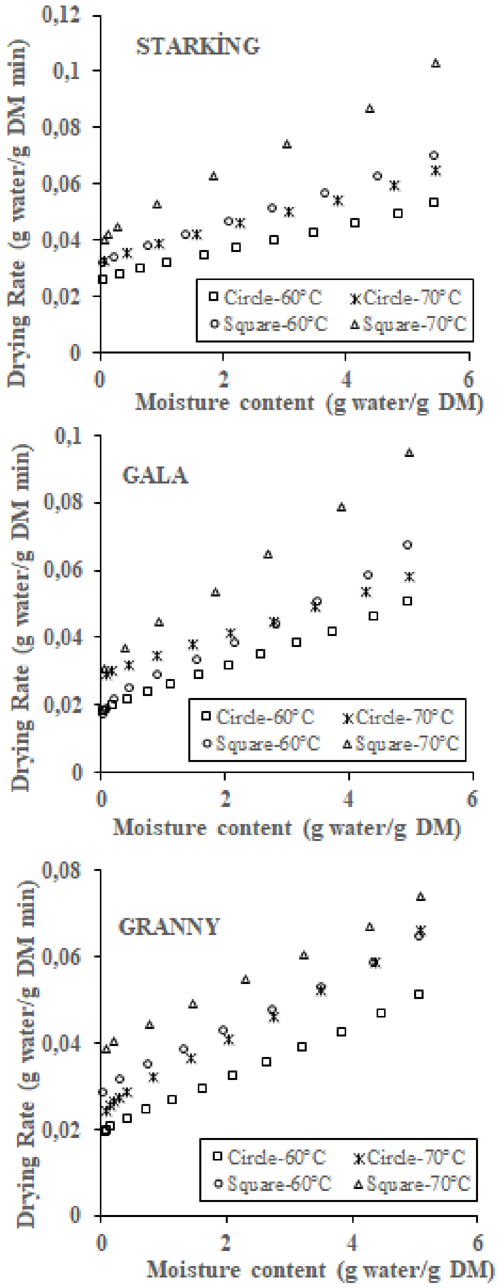

Figure 2. Drying rate of apple varieties dried at different temperatures for *Starking, Gala* and *Granny Smith*

consistent with the studies reported for apple (Vega-Gálvez *et al.,* 2012) and potato (Jabeen *et al.*, 2015; Naderinezhad *et al.,* 2016). This reason could be that diffusion was dominant physical mechanism governing moisture movement in the samples (Falade and Abbo, 2007).

For all apple samples drying rate increased as the temperature increased from 60ºC to 70ºC (Fig. 2). Similar results were reported by Kaur *et al.* (2018) for fenugreek and Kaleta and Gornicki (2010) for apple. This can be due to the increment in heat transfer between the air and the apple slices, and the acceleration of moisture movement from within the apple to the surface during drying (Bakal *et al.,* 2012). Also it is known that, air relative humidity of which decreases as a result of increasing temperature has a high drying potential (Doymaz and Aktas, 2018). Eventually, increase in temperature decreased in time to loss of moisture from the product and that's why accelerated the drying process (Jabeen *et al.,* 2015).

Square shaped apples had higher drying rates than circle ones (Fig. 2), which showed that drying rate was dependent on the shape. Similarly, Kaleta and Gornicki (2010) reported that drying rate of apple cubes were higher than slices due to the higher surface area exposed for a given volume of the product. This was in agreement with the result of Shi *et al.* (2008) who found that drying rates increased with decrease in berry size. It might be due to the fact that minimizing the size of the product reduced the distance of the water to diffuse and so caused the product to dry faster (Ertekin and Yaldız, 2004). From the results, it was seen that the variety also affected the drying rate. During the initial phase of drying, the highest drying rate (0.1037 g water/g DM min) was observed for square shaped *Starking* variety which was dried at 70ºC, followed by *Gala* (0.0949 g water/g DM min) and *Granny Smith* (0.0742 g water/g DM min). varieties, respectively. Differences in drying rates of apple varieties could be because of variation in their initial moisture content and composition (Falade and Abbo, 2007).

B. Mathematical Modelling

Four different mathematical models, namely Newton, Page, Logarithmic and Henderson and Pabis were tested to describe the behavior of apple samples along drying using non-linear regression analysis technique. The model parameters and the statistics used to evaluate the suitability of models for *Starking*, *Gala* and *Granny Smith* varieties were presented in Table 1. Logarithmic model mostly provided the highest R^2 values and the lowest χ^2 and RMSE values so, it was found to be the best for describing the drying characteristics of apple samples according to these values. Similar results were reported by the study of Kaleta and Gornicki (2010).

C. Total Polyphenol Content (TPC) and Antioxidant Capacity (AC)

TPC of dried apple samples is presented in Table 2. The results in this study indicated that TPC of dried samples varied in the range of 4.11-8.36 mg GAE/g DM. These values were in agreement with those reported by Baegbali *et al.* (2019) (5.27 mg GAE/g DM). The initial TPC of fresh *Starking, Gala* and *Granny Smith* apples were 5.4 mg GAE/g DM, 4.59 mg GAE/g DM and 8.85 mg GAE/g DM, respectively. Parallel to our results, Francini *et al.* (2017) reported that apple varieties showed different TPC (6.86-14.11 mg GAE/g DM) and also Lutz *et al.* (2015) found different contents of total polyphenol (6.8 and 9.2 GAE/g) for two apple varieties.

The results revealed that after drying, *Gala* had an increase of TPC respect to fresh sample. Similar results were reported by the study of Lutz *et al.* (2015). It is attributed to the release of phenolic compounds from food matrix during drying process (Yang *et al.,* 2010) or the formation of Maillard reaction products which could cause new phenolic compounds to form from precursors (Önal *et al.*, 2019). In other words, although natural antioxidants are lost during heating, the overall antioxidant properties of foods could be maintained or enhanced by the development of new antioxidants (Zura-Bravo *et al.,* 2013). Joshi *et al.* (2011) also reported that TPC of apple was not affected by air and oven drying. However, dried other two varieties, *Starking* and *Grannny Smith* had a reduction of TPC compared to fresh samples as observed by Francini *et al.* (2017) for apple, which could be due to chemical degradation of phenolic compounds during drying (Vega-Gálvez *et al.,* 2008; Kuyu *et al.*, 2018; Önal *et al.,* 2019). The other reason of decrease in polyphenol content during drying could also be attributed to the binding of polyphenols with the other compounds like proteins or modifications in the chemical structure of polyphenols, which could not be extracted or determined by available methods (Zura-Bravo *et al.,* 2013). Additionally, the polyphenols are affected by hydrolysis and oxidation reactions. Polyphenol oxidases (PPO) catalyze the oxidation of phenolic compounds in fruits (Sturm *et al.,* 2012). Damage to the cell membrane releases the enzyme and therefore activates it (Aghilinategh *et al.*, 2015). For this reason, under our experimental conditions (at drying temperatures of 60ºC and 70ºC) PPO activity could have been remained high for longer periods depending on the variety due to the fact that higher temperatures such as 75-80ºC are needed to inactivate the enzyme (Madrau *et al.,* 2009).

After drying, the highest TPC was recorded from *Granny* Smith (7.02-8.36 mg GAE/g DM) but in general TPCs of *Gala* (4.54 -5.38 mg GAE/g DM) and *Starking* (4.11-5.46 mg GAE/g DM) were similar (Table 2). Variation in TPC of dried apples might be due to the fact that heat inactivation of PPO from different apple cultivars differs (Yemenicioğlu *et al.*, 1997) as well as their initial TPC is different. There is limited literature on the effect of variety on dried apple TPC. According to Lutz *et al.* (2015), there was no difference between TPC of *Granny* Smith and Red Delicious apple varieties. However, Kuyu *et al.* (2018) reported that sweet potato varieties showed differences in polyphenol content, which is in consistent with our results. Regarding drying temperature and shape, TPC of dried apples was almost similar (Table 2).

Table 1. Statistical results obtained from the modelling of dried *Starking, Gala* and *Granny smith* varieties

Variety	Models		60 ºC		70 ºC	
			Square	Circle	Square	Circle
Starking	Newton	R^2	0.9730	0.9635	0.9656	0.9654
		RMSE	0.07234	0.07856	0.08473	0.07933
		χ^2	0.00589	0.00679	0.00820	0.00708
	Page	R^2	0.9920	0.9908	0.9980	0.9941
		RMSE	0.03501	0.03141	0.01845	0.02570
		χ^2	0.00158	0.00121	0.00045	0.00085
	Logaritmic	R^2	0.9994	0.9979	0.9949	0.9978
		RMSE	0.01367	0.01837	0.02571	0.01625
		χ^2	0.00028	0.00046	0.00105	0.00040
	Handerson and Pabis	R^2	0.9763	0.9549	0.9593	0.9576
		RMSE	0.05922	0.07052	0.07840	0.07119
		χ^2	0.00421	0.00608	0.00819	0.00652
Gala	Newton	R^2	0.9767	0.9788	0.9777	0.9682
		RMSE	0.07530	0.06723	0.06589	0.07837
		χ^2	0.00619	0.00493	0.00507	0.00682
	Page	R^2	0.9974	0.9953	0.9962	0.9954
		RMSE	0.02154	0.02627	0.02356	0.03511
		χ^2	0.00056	0.00082	0.00078	0.00154
	Logaritmic	R^2	0.9927	0.9987	0.9976	0.9980
		RMSE	0.02988	0.01391	0.01739	0.02367
		χ^2	0.00119	0.00026	0.00053	0.00080
	Handerson and Pabis	R^2	0.9700	0.9726	0.9734	0.9690
		RMSE	0.06393	0.05988	0.06157	0.07161
		χ^2	0.00491	0.00430	0.00531	0.00641
Granny Smith	Newton	R^2	0.9671	0.9758	0.9567	0.9701
		RMSE	0.07890	0.06931	0.08850	0.07573
		χ^2	0.00700	0.00520	0.00895	0.00626
	Page	R^2	0.9950	0.9944	0.9931	0.9945
		RMSE	0.02432	0.02625	0.02933	0.02508
		χ^2	0.00076	0.00081	0.00115	0.00075
	Logaritmic	R^2	0.9970	0.9989	0.9972	0.9962
		RMSE	0.01933	0.01094	0.02224	0.01451
		χ^2	0.00056	0.00016	0.00079	0.00028
	Handerson and Pabis	R^2	0.9601	0.9688	0.9490	0.9629
		RMSE	0.07111	0.06197	0.08089	0.06833
		χ^2	0.00650	0.004534	0.00872	0.00560

On the other hand, Ahmed *et al.* (2010) stated that higher temperatures release more of the bound polyphenols due to breakdown of cell wall phenolic compounds.

Antioxidant capacities of dried apple samples varying from 4536.43 to 7370.47 mmol AEAC 100/g DM were shown in Table 2. The initial values of fresh apples *Gala*, *Starking* and *Granny Smith* were 1806.85, 1947.94 and 2289.92 mmol AEAC 100/g DM, respectively. In contrary to the trend for TPC after drying, all three apple varieties had higher antioxidant capacities than fresh counterparts. This is in accordance with the work of Yang *et al.* (2010) who reported that drying enhanced antioxidant activity of sweet potatoes despite a decrease in antioxidant components such as ascorbic acid at drying temperature above 60 °C, suggesting the formation of new phenolic compounds. In addition, increase in reducing sugar and the formation of Maillard reaction products with high AC may be other factors related to the increase in AC (Vega-Gálvez *et al.*, 2012).

It can be possible to see from Table 2 that of all drying parameters, variety alone and interactions between drying parameters had significant effect on antioxidant capacities of dried apple samples. The highest AC was recorded from Granny Smith (5992.34-7370.47 mmol AEAC 100/g DM), followed generally by *Starking* (4750.26-6819.22 mmol AEAC 100/g DM) and *Gala* (4536.43-5849.42 mmol AEAC 100/g DM), respectively (Table 2). Kuyu *et al.* (2018) stated that antioxidant activity varied with variety, which is in agreement with our results.

D. Color values

Color is one of the important quality characteristics in food acceptance. Colors of dried apples were analyzed and the results are summarized in Table 2. It was observed that there were significant differences among color values of apple samples dried at 60 ºC and 70 ºC. L values were in the range of 56.50-76.38 and for each temperature the highest L values were observed in circle shaped *Granny Smith* variety, followed by *Gala* and *Starking* varieties respectively. Baeghbali *et al.* (2018) found that L value of apple slice dried by cabinet dryer was 53.35 lower than those found in our study. It is

Table 2. TPC (mg GAE/g DM), AC (mmol AEAC/100 g DM) and color values of apple varieties

	Variety	60 ºC		70 ºC	
		Square	Circle	Square	Circle
TPC	*Starking*	4.11 ± 0.30[a]	5.04 ± 0.41[a]	4.79 ± 0.30[a]	5.46 ± 0.53[a]
	Gala	4.86 ± 0.08[b]	5.38 ± 0.30[a]	4.54 ± 0.43[a]	5.13 ± 0.47[a]
	Granny Smith	7.02 ± 0.09[c]	8.36 ± 0.15[b]	8.35 ± 0.83[b]	8.04 ± 0.61[b]
AC	*Starking*	4924.14 ±78.48[b]	6819.22 ± 142.92[b]	5194.96 ± 204.40[a]	4750.26 ± 344.08[a]
	Gala	4536.43 ± 106.65[a]	5849.42 ± 225.74[a]	5483.34 ± 164.90[a]	5115.31 ± 590.80[a]
	Granny Smith	5992.34 ± 27.01[c]	7370.47 ± 180.61[b]	7256.78 ± 384.06[b]	6094.48 ± 152.61[a]
L	*Starking*	56.50±0.84[a]	65.18±0.22[a]	58.15±0.75[a]	63.31±0.70[a]
	Gala	62.80±0.85[b]	68.12±0.14[b]	60.52±0.77[b]	70.38±2.76[b]
	Granny Smith	65.12±0.55[b]	75.87±0.43[c]	74.32±0.42[c]	76.38±1.18[b]
a	*Starking*	12.30±0.73[b]	9.64±0.22[b]	11.13±0.23[b]	10.38±0.24[c]
	Gala	10.18±1.34[ab]	8.89±0.47[b]	11.79±0.94[b]	8.75±0.66[b]
	Granny Smith	7.31±0.49 [a]	1.53±0.24[a]	1.28±0.18[a]	2.80±0.10[a]
b	*Starking*	41.63±0.93[b]	38.71±0.39[b]	39.20±0.07[b]	38.99±0.14[b]
	Gala	40.66±1.07[b]	37.61±0.65[b]	40.82±0.93[b]	36.20±2.79[b]
	Granny Smith	36.91±0.39[a]	27.92±1.09[a]	27.72±0.33[a]	27.74±0.98[a]
C	*Starking*	43.28±0.94[b]	39.12±0.10[b]	40.84±0.12[b]	39.78±0.24[b]
	Gala	42.83±0.97[b]	38.32±0.54[b]	41.56±0.50[b]	39.42±0.24[b]
	Granny Smith	38.10±0.12[a]	28.66±0.66[a]	27.75±0.34[a]	27.44±1.01[a]
h	*Starking*	73.16±0.57[a]	76.19±0.35[a]	73.65±0.39[a]	75.11±0.31[a]
	Gala	76.39±1.93[ab]	77.84±0.34[a]	72.86±0.35[a]	76.55±0.13[a]
	Granny Smith	79.12±0.81[b]	87.44±0.69[b]	87.25±0.74[b]	86.26±1.43[b]

known that browning reactions such as ascorbic acid oxidation, polyphenol enzymatic oxidation, Maillard reaction and caramelization in apple cause the color alterations and decrease L value of the product (Baeghbali *et al.,* 2018). Differences in L values may be due to different browning degree in drying process. Regardless of the variety the highest L values were recorded from square shaped apples dried at 70ºC, which could be due to their shortest drying times.

As shown in Table 2, a (redness) (1.28-12.3), b (yellowness) (27.72-41.63), C (27.44-43.28) and h (72.86-87.44) values differed depending on the investigated parameters (variety, shape and temperature). High a values indicate browning reactions and rise throughout the drying process (Sturm *et al.,* 2012). The highest a, b and C values were obtained from *Starking* followed by *Gala* and *Granny Smith*, respectively. Similarly, Paunović *et al.* (2010) observed that *Granny* Smith showed the least oxidation of polyphenolic compounds (browning). Increase in temperature generally caused decrease in these values. With respect to product shape, square shaped apples had higher C values than circle shaped samples whereas h values of circle shaped apples were higher than square shaped samples (Table 2).

IV. CONCLUSIONS

In this study, the impact of variety, shape and temperature on dying kinetics and other properties of cv. *Starking*, *Gala* and *Granny Smith* apples was investigated. The results showed that the drying kinetics of apple was significantly affected by variety, shape and temperature. Drying rate was found to be the highest in square shaped *Starking* variety Thin layer drying of apple occurred in the falling drying rate period. Logarithmic model was found the best to describe the drying behavior of apples for thin layer drying conditions under this study. After drying, the highest TPC and AC were recorded from *Granny Smith* variety. Color values of apple samples differed depending on parameters analyzed. These results showed that when choosing the most suitable variety for convective drying of apple, it is necessary to consider the quality characteristics as well as the drying kinetics. As a conclusion, to minimize the disadvantages of hot air drying of the fruits and vegetables, their drying behaviors should be taken into consideration.

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