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Effects of Different Drying Methods on Modelling, Energy Consumption and Final Quality of Tomato (*Lycopersicum esculentum Mill*)[#]

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A B S T R A C T

Agricultural developments mostly depend on rapidly increasing world population. Tomato is a highly nutritious vegetable. Post-harvest technologies are often applied to prolong the consumption periods of tomato. Drying is one of the oldest methods of conservation. In this study, five different drying methods (oven drying, vacuum oven drying, sensitive drying, shaded-open atmosphere drying and sun drying) was used. Drying processes were carried out with dryers at 55°C, 60°C, 65°C and 70°C temperatures. All drying trials were performed in three replications. Drying performance (drying duration, final moisture content), drying kinetics, colour analysis, energy consumption, chemical analyses were performed for all drying methods. Fresh samples reached to desired moisture contents in 20-300 hours. To define time-dependent changes in moisture contents, Page, Logarithmic and Midilli-Küçük equations were used. Page equation yielded the worst estimations. There were not significant differences in "a" redness values of fresh samples, 65-70°C of oven dryer and all temperatures of sensitive dryer. Sensitive dryer yielded the closet pH values to fresh samples. Based on current findings, it was concluded that oven drying, and sensitive drying were suitable for drying Selinus tomato variety.

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Introduction

Rapid increases in food demands of ever-increasing world population always put agricultural sector and technological developments of the sector into the first place of country agendas. Tomato is the leading vegetable worldwide with regard to both production and consumption rates.

Tomato was first discovered at South American coasts. The first tomato cultivars were yellow in color and red ones cultivated later on Tomato (*Lycopersicum esculentum Mill.*) is rich in various nutrients. Annual tomato production of Turkey is around 8 million tons. Majority of this production is consumed as fresh and about 25-30% is used as processed food stuff (Duzyaman and Duman, 2003).

Tomato consumption has also various health benefits, especially in reducing risk of prostate cancers (Hollman et al., 1996). Tomato reduces blood serum lipid levels and LDL (Low density lipoprotein) oxidation (Agarwal et al., 2001). Health preventive impacts of tomato come from its lycopene, ß-carotene, ascorbic acid and phenolics compounds (Abushita et al., 2000).

Beside fresh consumption, tomato is used in various other forms during the periods out of production seasons or in periods with difficulties in supply. Such uses include tomato paste, sauce, ketchup, tomato juice, puree, peeled tomato, sliced tomato, chopped tomato, canned tomato and etc. (Xu et al., 2016). In addition to above mentioned methods, recently dried tomato has gaining popularity. About 90-95% of tomato is composed of water, thus it quite prone to spoilage and it is also quite hard to dry.

The present study was conducted to dry tomato with different methods and at different temperatures and to compare drying performances. Within the scope of the study, oven drying, vacuum oven drying, sensitive drying, shaded-open atmosphere drying and sun drying were used. Experiments were conducted in three replications. Drying characteristics, data modeling, quality and chemical characteristics of dried tomato were investigated (Güngör, et al., 2001).

Material and Method

This study was done to investigate effects of five different drying methods on drying characteristics of tomato. Drying methods were selected as oven drying, vacuum oven drying, sensitive drying, shaded-open atmosphere drying, and sun drying. Tomato drying kinetics, mathematical modelling, drying efficiency at different temperatures, colour loss values, energy consumption, and chemical changes were compared based on drying methods.

Sample Preparation

In this study, tomato cultivar named as Selinus was used. Selinus cultivar which proper for drying process yields high and is resistance against diseases (Aybak, 2004). Before drying processes, pre-treatments such as washing, selection, cleaning, slicing (tomatoes were sliced vertically into two halves), salting were done. For salting pre-treatment, six salt tablets (15 grams in total) were dissolved in 90 ml of water, and then this solution was added to four litters of water. Tomatoes sliced were immersed in this water for a minute to prevent tarnishing (Özler, et al. 2004).

Drying Experiments

For drying experiments, ST-055 type normal dryer, Nüve brand EV 018 model vacuum dryer, and sensitive dryer were used. Drying was performed under 100 mmHg of pressure in vacuum oven. Sensitive dryer consists of a drying chamber, three drying canals and a control panel. A three-phase fan/heater with a heating capacity of 6 kW was used in heater. Levels of drying temperature selected for sensitive, regular oven, and vacuum oven methods were 55°C, 60°C, 65°C and 70°C (Günhan, 2005). During drying process, products were weighed at certain intervals to create drying curves. Drying processes were ended when moisture content of final product reached percent of 10-13 (Vural and Duman, 2000). Natural drying process was done in two ways; under shade and sun. Products were weighed four times in a day and drying curves were determined. All drying experiments were performed in triplicate.

Colour Parameters

Colour parameters of fresh and dried products were analysed with a Minolta (CR–400) chromameter. The colorimeter yields numerical values for three different colour scales (L, a, b) in each reading (McGuire, 1992).

Since L, a and b values are not perceived directly from the buyer and sellers in markets, these values were used to calculate hue angle and chroma values appealing color perception of humans. Hue angle and chroma values were calculated with the following equations (McGuire, 1992).

$$h^{\circ}=\tan^{-1}\left(\frac{b}{a}\right) \quad (1)$$

$$C=(a^2+b^2)^{1/2} \quad (2)$$

There are two concepts to express the change observed in colour. One of them is total colour change parameter and it is calculated with the following equation:

$$\Delta E=\sqrt{(L_t-L_k)^2+(a_t-a_k)^2+(b_t-b_k)^2} \quad (3)$$

where, t-subscripts represent the values for fresh samples and k-subscripts express the values for dried samples (Maskan, 2001; Kocabiyik, 2015).

Specific Energy Consumption

Entes (MPR 63) brand power analyser was used to determine the total electrical energy consumption (to heat the air, to run the fan) in each drying experiment. Specific energy consumption was calculated with two different methods. In the first method, increase in ambient temperature at end of drying process was not taken into consideration, while increase in ambient temperature at end of drying process was included in calculations in the second method. The second method allows the comparison specific energy consumption (SEC) of drying experiments performed under different environmental conditions (Wang and Sheng, 2006; Kocabıyık and Demirtürk, 2008). SEC_1 and SEC_2 were calculated by using the following calculations:

$$SEC_1=\frac{TEC}{\Delta W} \quad (4)$$

$$SEC_2=\frac{TEC}{\Delta W\cdot(T_{hat}-T_{at})} \quad (5)$$

where, SEC_1 and SEC_2 are specific energy consumptions, TEC is total energy consumption (kWh), ΔW is amount of water removal (kg), SEC_2: Specific energy consumption (kWh·/kg water·°C), T_{hat}: Average heated air temperature (°C), T_{at}: Average ambient temperature (°C).

Mathematical Modelling

During drying process, samples were taken at least two-hour intervals and weighed in a precise balance (±0.01). Detachable moisture ratio to be used in creation of drying curves was calculated as follows (Yağcıoglu, 1999).

$$DMR = \frac{M-M_e}{M_0-M_e} \quad (6)$$

where, DMR is detachable moisture ratio, M is instant moisture content at any time of drying, M_e is equilibrium moisture content of drying material under specified conditions, M_o is initial moisture content of the material to be dried. The common models for mathematical modelling of tomato drying were listed below (Özcan, et al, 2018). The modelling equations are follows:

Page Equation (Page, 1949, Da Silva, et al. 2005).

$$f=\exp(h.(t^j)) \quad (7)$$

Logarithmic (Menges & Ertekin, 2006).

$$f = h.\exp(-j.t)+k \quad (8)$$

Midilli - Küçük (Midilli, et al. 2002).

$$f = h.\exp(-j.(t^k)) + (l.t) \quad (9)$$

where, f is function, t is measurement time, h, j, k and l are model equation coefficients.

Numerical values for the parameters of drying models were determined. Besides parameter values, variance analyses results and coefficient of determination (R^2) were also determined.

Chemical Analysis

The pH and titration acidity (TA) values were measured on fresh samples before drying process and dried samples after drying process and drying methods were compared with regard to these parameters. The pH values were determined with WTW brand (pH 330/set) pH-meter through directly dipping glass electrode into tomato pulp homogenized in a mixture (Cemeroğlu, 1992). Tomato pulp was titrated with 0.1 normal NaOH and phenolphthalein until reaching a pH value of pH-8.1 and the amount of consumption was determined. Then, % acidity was calculated with the following equation and expressed in g/100g (Konopacka and Plocharskı, 2004).

$$\% \text{ Acidity} = \frac{V \times N \times M_e}{M} \times 100 \quad (10)$$

V = The amount spent by volume
N = Normality
M_e = Mili equivalent grams of malic acid (0.067)
M = Sample weight (g)

Results and Discussion

Drying Performance Values

The target in this study was to dry fresh tomato samples from initial moisture content of 91.85±0.1% until final moisture level of 10-13%. Wet-based final moisture contents of samples for each drying experiment are provided in Table 1 as the average of three replications. Drying durations were also provided in table as hours.

As it was provided in Table 1, the shortest drying duration was achieved in sensitive dryer at 70°C as 20 hours and final moisture content was measured as 12.40%. The longest drying duration was observed in shade-drying at 27.68°C.

Mathematical Modelling

Within the scope of this research, Page, Logarithmic, and Midilli-Küçük equations were used for modelling drying processes. The parameter values, variance analysis results (P values) and coefficient of determination (R^2) values used. The biggest R^2 value (0.9984) was observed in sensitive dryer at 65°C and the lowest value (0.9764) was seen in sun-drying for the Page equation. These findings revealed that Page equation yielded the best results for sensitive dryer at 65°C and the least values for sun-drying. The biggest R^2 value (0.9997) was observed in vacuum oven at 65°C and the lowest value (0.9897) was seen in sensitive dryer at 70°C for the Logarithmic equation. As the Midilli-Küçük equation was investigated, the biggest R^2 value (0.9998) was observed in vacuum oven at 60°C and 65°C and the lowest R^2 value (0.9904) was seen in sensitive dryer at 70°C.

Colour Values

In colour analyses, 10 data were obtained from each sample and average of them were used in assessments. Chroma (C), hue angle (h°), and total color change (ΔE) values were calculated by using L, a, and b values (Table 2).

As seen from Table 2, "L" brightness values were different in all treatments and at all temperatures compared to fresh samples. Significant differences were observed at 60 and 65°C of normal oven, 60 and 70°C of vacuum oven and 70°C of sensitive dryer ($P<0.05$).

Considering "a" values, significant differences were not observed between fresh samples and 65° - 70°C of normal oven and all temperatures of sensitive dryer at 5% level. These findings revealed that these drying methods would preserve red colour of tomato which is a significant quality attribute for tomatoes and increase market value of the products. The differences in other methods were mainly because of extended drying durations and consequent increases in colour losses. The "a" value was measured as 8.55 in sun-drying and 10.67 in shade-drying. Considering the dryers and drying temperatures, the lowest "a" value was observed in sun-drying. In previous studies, "a" values varied between 24.31-32.83 in fresh samples and between 8,67-24,30 in dried products (Mutlu and Ergüneş, 2008; Şahin et al., 2012; Uzun et al., 2004).

Table 1 Final moisture contents (% wet base) and drying durations of tomato sample.

Dryer Type	Temperature	Moisture content (% wb)	Drying Time (h)
Oven	55°C	12.70	68
	60°C	12.31	50
	65°C	12.00	41
	70°C	11.92	28
Vacuum oven	55°C	12.36	74
	60°C	11.83	59
	65°C	12.65	50
	70°C	11.86	44
Delicate dryer	55°C	11.82	37
	60°C	12.10	29
	65°C	11.39	24
	70°C	12.40	20
Sun drying	32.95°C	12.85	220
Shaded-open atmosphere drying	27.68°C	12.61	300

Table 2 Measured and calculated colour parameters*

Dryer Type	Temperature	L	a	b	C*	h°	ΔE
Fresh		30.00[bcd]	18.63[a]	13.97[ab]	23.28	36.86	--
Oven	55°C	25.36[g]	12.79[cd]	11.51[abc]	17.21	41.99	0.000264
	60°C	26.45[fg]	15.95[ab]	11.88[abc]	19. 89	36.67	0.001722
	65°C	27.02[fg]	18.15[a]	12.15[ab]	21.84	33.81	0.006525
	70°C	28.59[de]	17.87[a]	13.74[ab]	22.54	37.55	0.147545
Vacuum oven	55°C	25.52[g]	13.53[bc]	10.79[abcd]	17.30	38.57	0.000317
	60°C	22.54[h]	9.24[ef]	9.14[bcd]	13.00	44.71	0.000036
	65°C	21.58[hı]	11.22[cdef]	8.60[bcd]	14.13	37.49	0.000042
	70°C	22.71[h]	11.85[cde]	15.53[a]	19.53	52.64	0.000097
Delicate dryer	55°C	33.80[a]	17.99[a]	12.39[ab]	21.84	34.56	0.003306
	60°C	29.62[cd]	17.30[a]	13.55[ab]	21.97	38.07	0.228147
	65°C	31.14[bc]	17.96[a]	12.87[ab]	22.09	35.64	0.113897
	70°C	28.49[de]	16.99[a]	13.26[ab]	21.55	37.97	0.033538
Sun drying	32.95°C	19.79[j]	8.55[f]	6.12[d]	10.51	35.59	0.000014
Shaded-open atmosphere drying	27.68°C	20.59[hı]	10.67[def]	6.79[cd]	12.65	32.50	0.000024

Table 3 Specific energy consumption values*

Dryer Type	Temperature	Energy Consumption (kWh)	SEC_1 (kWh/kg water)	SEC_2 (kWh/kg water·°C)
Oven	55°C	22.5[f]	12.86[e]	0.51[d]
	60°C	23[f]	13.14[e]	0.44[ef]
	65°C	25[e]	14.29[d]	0.41[ef]
	70°C	27.5[d]	15.71[c]	0.35[g]
Vacuum oven	55°C	28.5[d]	16.29[c]	0.65[b]
	60°C	28[d]	16.00[c]	0.53[d]
	65°C	31.5[c]	18.00[b]	0.51[d]
	70°C	33[c]	18.86[b]	0.42[ef]
Delicate dryer	55°C	29[d]	16.57[c]	0.66[b]
	60°C	31.5[c]	18.00[b]	0.60[c]
	65°C	33[c]	18.86[b]	0.54[d]
	70°C	35.5[b]	20.29[a]	0.45[e]

Current findings revealed that fast and controlled drying may preserve colour values of the final products. ΔE total colour change was also separately investigated for drying methods and temperatures. The lowest ΔE value (0.000014) was observed in sun-drying and the greatest value (0.228147) was seen at 60°C of sensitive dryer.

Specific Energy Consumption

While performing drying experiments, energy consumption was determined for each method and at each temperature. Average energy consumption of drying methods and temperatures are provided in Table 3.

As seen from Table 3, SEC_1 values varied between 2.34-20.29 (kWh/kg water) and SEC_2 values varied between 0.35-0.94 (kWh/kg water °C). The SEC_1 values were calculated by dividing total energy consumption with the amount of water removed. The differences in energy consumptions at 55 and 60°C of normal and vacuum oven were not significant. The differences in energy consumptions at 60 and 65°C of sensitive dryer, 60, 65 and 70°C of vacuum oven were not also significant.

Considering SEC_2 values, the lowest value (0.35) was observed at 70°C of normal oven and the greatest value (0.66) was observed at 55°C of sensitive dryer. Duncan's test revealed that the differences in SEC_2 values at 60-65°C of normal oven and 70°C of vacuum oven were not significant (Table 3).

Chemical Analysis

Chemical analysis results for fresh and dried samples were subjected to statistical analyses and Duncan's test at 5% level. Chemical analysis results are provided in Table 4.

As seen in Table 4, pH value of fresh samples was measured as 4.78. In general, pH values of samples approached from acidity to neutral with all drying methods and temperatures. Except for 70°C of vacuum oven and 65°C of sensitive dryer, pH values of all treatments were significantly different from each other. Increasing pH values were observed with decreasing drying temperatures. Sensitive dryer at 70°C yielded the closest pH values to fresh samples (Şahin et al., 2012).

Average titratable acidity (TA) value of fresh samples was determined as 0.36. Compared to fresh samples, all drying methods and temperatures yielded significantly different titratable acidity values.

Table 4 Chemical analysis results*

Dryer Type	Temperature	pH	Average Titratable Acidity
Fresh		4.78^{k}	0.36^{m}
Oven	55°C	6.35^{a}	2.07^{l}
	60°C	6.16^{c}	$2.76^{hı}$
	65°C	5.99^{de}	3.22^{fg}
	70°C	$5.39^{ı}$	4.11^{b}
Vacuum oven	55°C	6.28^{ab}	2.32^{kl}
	60°C	6.02^{d}	2.45^{jk}
	65°C	6.19^{bc}	$2.50^{ıjk}$
	70°C	5.62^{h}	2.95^{gh}
Delicate dryer	55°C	6.18^{bc}	$2.68^{hıj}$
	60°C	5.81^{fg}	2.88^{h}
	65°C	5.63^{h}	3.93^{bc}
	70°C	4.99^{j}	4.48^{a}
Sun drying	32.95°C	5.76^{g}	3.73^{cd}
Shaded-open atmosphere drying	27.68°C	5.89^{ef}	3.40^{ef}

Conclusions

Natural drying methods are not preferred because of excessive losses in quality attributes and active ingredients. However, drying with industrial devices is a costly process. Rapid drying is desired in tomato for both economic and labour concerns. High temperatures should be applied to shorten drying durations. However, such high temperatures should not result in losses in colour and chemical characteristics of tomato. Therefore, optimum temperatures should be applied for drying processes. The drying time shows that in the beginning drying rate an increase and then a decrease toward the end drying (Çelen and Kahveci, 2013).

Drying data were mathematically and Page equation was found to have poor calculation capacity. If the proper drying method will preserve the redness rates, the market values would increase. The differences among the methods were because of prolonged drying durations and consequent increases in colour losses.

The lowest energy consumption was observed in 55°C of normal oven as 22.5 kWh. When the removed water was included into the calculation, the lowest energy consumption was observed at 70°C of normal oven as 0.35 kWh/ kg water·°C and the biggest value was observed at 55°C of sensitive dryer as 0.66 kWh/ kg water·°C. In general, decreasing pH values were observed with increasing temperatures.

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