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## ENGINEERING SCIENCES

# Comparison of Quality Characteristics of Tomato Paste Produced under Atmospheric Conditions and Vacuum Evaporations

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**Abstract:** Herein we report a comparison study of the quality characteristics of tomato paste produced under atmospheric conditions and vacuum evaporation. Tomato pulp (5 Brix) was evaporated under vacuum and at atmospheric pressure using a developed evaporation equipment for household application. Various quality i.e.  $a^*$  and  $a^*/b^*$  color values, soluble solids content, dark speck amount, titratable acidity, lycopene content and sensory properties of tomato paste were compared. The final total soluble solid contents were not affected by evaporation method whereas the lycopene content in vacuum evaporated samples was found as higher than that in the atmospheric ones at the same soluble solid content. Overall preference scores of vacuum evaporated tomato paste have approximately equal scores with the paste produced at atmospheric conditions.

**Key words:** Color, evaporation, Lycopene content, tomato paste, vacuum cooking.

## INTRODUCTION

Tomatoes (*Solanum lycopersicum*) are consumed as paste, puree, pulp, juice and ketchup (Cadavid 2014) as well as sliced in salad. In Turkish Food Codex, tomato paste is described as a product obtained from the evaporation of tomato pulp with more than 24 % soluble solids (Hayes et al. 1998) consistency and flavor. Overall, there is an absence of standardization of methods and instruments to define quality. While color can now be measured objectively, there are currently no standard color requirements for tomato concentrates. Rheological measurements on both tomato juice and concentrates are reviewed; the power law finds wide applicability, although other rheological characteristics, particularly time dependency, have received far less attention and there has been little effort to relate

rheological understanding to the commonly used empirical tests such as consistency measurements. The volatiles responsible for flavor and odor have been identified to the point where the natural odor of tomato paste can be imitated. Attempts to develop objective methods as a substitute for sensory assessment are reviewed. Excessive consumption of tomato paste in homemade dishes in Turkey (Capanoglu et al. 2008) increases its market demand, and so is the industrial production.

Production of tomato paste at industrial scale consists of the following steps: cleaning, pulping, evaporating/concentrating in steam-jacketed vacuum boilers, heat treatments and packaging (Yıldız 2004). Evaporation by heat helps in disinfection from microorganisms and enzyme degradation. This process also improves sensorial properties i.e. texture, color and

nutritional contents (lycopene) (Barreiro et al. 1997) 'a', 'b' tristimulus values were measured to characterise the colour, and colour difference ( $\Delta E$ ).

The undesired physico-chemical changes can be easily controlled by various techniques e.g. vacuum evaporation. For instance, the color and the flavor has been preserved by low pressure and temperature under vacuum evaporation (Hayes et al. 1998, Andrés-Bello et al. 2009, Iborra-Bernad et al. 2013) consistency and flavor. Overall, there is an absence of standardization of methods and instruments to define quality. While color can now be measured objectively, there are currently no standard color requirements for tomato concentrates. Rheological measurements on both tomato juice and concentrates are reviewed; the power law finds wide applicability, although other rheological characteristics, particularly time dependency, have received far less attention and there has been little effort to relate rheological understanding to the commonly used empirical tests such as consistency measurements. The volatiles responsible for flavor and odor have been identified to the point where the natural odor of tomato paste can be imitated. Attempts to develop objective methods as a substitute for sensory assessment are reviewed Vacuum cooking (cook-vide). Tomato juice can be concentrated under vacuum evaporation in a shorter period without adding salt or thickening agent.

Tomato paste is also traditionally produced at home in Turkey. In this process, washed fresh tomatoes are blended, filtered and evaporated in a boiler at atmospheric conditions until it reaches to a desired consistency and color. Most of the times, tomato paste produced at home is less concentrated as compared to the industrial one. To deal this situation, tomato paste is kept under sunlight to evaporate the excess water but

it is also a less productive method. So relatively high amount of salt is added to extend the shelf life of the tomato paste. Moreover, exposing tomato paste to sunlight causes an increase in microbial load and breakdown of proteins and other beneficial organics (Atak et al. 2017). In Turkey, public prefer to consume homemade products than industrial. Thus, there is a need to make a household vacuum evaporator.

A vacuum cooking and frying pot called Gastrovac was developed by (Andrés-Bello et al. 2009). The main function of this equipment was cooking/frying the vegetables and meat under vacuum. However, Gastrovac does not perform the evaporation process and produce concentrated products such as jam and tomato paste. Besides, this equipment was more suitable for gastronomic cuisine due to its high price. Therefore, to the best of our knowledge, there is no such household equipment that can produce jam/tomato paste under vacuum. In addition, there are two reports to produce jam/tomato paste with this equipment (Tomruk et al. 2016, Okut et al. 2018) testing its performance on strawberry jam production and its comparison with atmospheric cooking. Purpose of this study was to develop prototype cooking equipment that can work at reduced pressure and to evaluate its performance for production of strawberry jam. The effect of vacuum cooking conditions on color soluble solid content, reducing sugars total sugars HMF and sensory properties were investigated. Also, the optimum vacuum cooking conditions for strawberry jam were optimized for Composite Rotatable Design. The optimum cooking temperature and time were determined targeting maximum soluble solid content and sensory attributes (consistency). Although literature on the physical and chemical composition of commercial and homemade types of tomato pastes is available, studies on developing cooking prototype and comparing

of tomato paste produced under atmospheric conditions and vacuum evaporation are inexistent.

The main parameters of evaporation process are time, temperature and their combinations (Cemeroğlu 2011). During evaporation process, various physico-chemical reactions may occur that can affect the product quality i.e. nutritional value, taste and color. Ismail & Revathi (2006) cooled, drained and tested for enzyme activity (peroxidase and lipoxygenase) found a decrease in that color values (L and a) of chili when the evaporation time and temperature were increased. Long evaporation time resulted in an increase in the titratable acidity and lycopene content of final product due to an increase in total soluble solids (Sabanci & Icier 2017, Hadley et al. 2002, Zhang et al. 2014) 55, 75, and 85 min for 14 V/cm, 12 V/cm, and 10 V/cm, and vacuum evaporation (VE).

The purpose of this study was to compare the quality characteristics of tomato paste produced under atmospheric conditions and vacuum evaporation by using developed prototype. The results obtained were examined using various quality parameters ( $a^*$  and  $a^*/b^*$  color values, soluble solids content, dark speck amount, titratable acidity, lycopene content and sensory properties).

## MATERIALS AND METHODS

### Material

Tomatoes (*Lycopersicon esculentum* Mill.) of commercial maturity were purchased from a local market in Izmir, Turkey. After washing and removing stalks and deteriorated parts, the fruits were passed through a pulp extractor fitted with a sieve having a pore diameter of 2 mm to remove peelings and seeds. The pulp (5° Brix) was packaged in 2 kg and stored at -24°C for further usage.

### Tomato paste production

Tomato paste was produced at atmospheric pressure *via* evaporation process using a prototype given in Okut et al. (2018) reducing sugars total sugars HMF and sensory properties were investigated. Also, the optimum vacuum cooking conditions for strawberry jam were optimized for Composite Rotatable Design. The optimum cooking temperature and time were determined targeting maximum soluble solid content and sensory attributes (consistency). The equipment can work under wide range of vacuum and temperature. It consists of four main parts: 1) vacuum evaporation vessel (6 L); 2) an electrical heater (1.5 kW); 3) an oily vacuum pump (0.55 Hp); 4) and a condenser (1 kW) worked with R-404a refrigerant. The constructional and working details of the equipment have been already reported (Tomruk et al. 2016, Okut et al. 2018) testing its performance on strawberry jam production and its comparison with atmospheric cooking. Purpose of this study was to develop prototype cooking equipment that can work at reduced pressure and to evaluate its performance for production of strawberry jam. The effect of vacuum cooking conditions on color soluble solid content, reducing sugars total sugars HMF and sensory properties were investigated. Also, the optimum vacuum cooking conditions for strawberry jam were optimized for Composite Rotatable Design. The optimum cooking temperature and time were determined targeting maximum soluble solid content and sensory attributes (consistency).

Tomatoes were processed into paste at different temperatures and times (70, 80, 90 and 100 min) at various amount of vacuum and at atmospheric pressure according to Central Composite Rotatable Design (CCRD) as given in Table I. For the atmospheric evaporation, the tomato paste was produced at 100°C in the same equipment without vacuum. All the evaporation

**Table I. Physical, chemical and sensorial properties of the tomato paste evaporated at different experimental conditions.**

Run	Temperature (°C)	Time (min)	Soluble solids content (Brix)	Titratable acidity (% citric acid)	Dark speck (count/10 g sample)	Lycopene content (mg/kg)	a*	a*/b*	Consistency (Sensorial)	Overall preference
1	64.4	75.9	13.0±0.5	1.173±0.010	2.0±0.0	50.77±0.09	16.43±0.12	1.92±0.05	3.30±0.09	3.46±0.10
2	85.6	75.9	10.0±0.0	0.727±0.012	0.0±0.0	35.54±0.15	14.93±0.06	1.60±0.09	2.64±0.12	2.79±0.08
3**	64.4	104.1	-	-	-	-	-	-	-	-
4	85.6	104.1	30.5±1.0	2.318±0.025	15.5±0.8	90.71±0.98	12.42±1.05	1.04±0.11	4.49±0.02	3.74±0.11
5	60.0	90.0	25.0±0.2	1.863±0.043	391.5±1.8	86.80±0.59	6.68±0.95	1.37±0.02	3.88±0.25	1.55±0.07
6	90.0	90.0	21.0±0.5	1.318±0.022	3.5±1.1	49.23±1.01	15.08±0.25	1.67±0.06	3.81±0.03	3.75±0.02
7	75.0	70.0	10.0±0.0	0.756±0.032	0.0±0.0	21.42±0.25	14.48±0.53	1.74±0.05	2.13±0.15	2.83±0.19
8	75.0	110.0	31.0±0.5	2.283±0.045	84.0±0.5	133.43±0.36	8.93±0.04	1.49±0.08	4.19±0.14	1.79±0.26
9	75.0	90.0	20.5±1.0	1.470±0.085	3.0±0.2	66.66±0.12	15.95±0.08	1.84±0.10	3.75±0.01	3.93±0.05
10	75.0	90.0	21.0±0.0	1.552±0.013	3.5±0.6	76.17±0.96	16.27±0.07	1.81±0.03	4.28±0.08	4.34±0.09
11	75.0	90.0	19.0±0.5	1.307±0.078	5.0±0.5	60.55±0.52	16.03±0.16	1.77±0.02	3.73±0.07	4.12±0.05
12	75.0	90.0	20.5±1.0	1.181±0.101	1.5±0.2	67.60±0.06	16.79±0.50	1.85±0.04	4.57±0.19	4.51±0.12
13	75.0	90.0	20.5±0.5	1.386±0.112	4.0±0.0	64.03±0.45	16.05±0.10	1.80±0.07	4.06±0.21	4.31±0.15

\*\* It can not be analyzed due to tomato paste completely burned.

experiments were carried out in duplicate for each operating condition.

## **Analysis**

### ***Soluble solids content***

The soluble solid (Brix) content of tomato paste was determined by Abbe refractometer at 25 °C (Cemeroğlu 2010).

### ***Color***

The color of tomato paste was determined by measuring CIE Yxy, L\* a\* b\* values with a Minolta colorimeter (CM-2600d / 2500d, Konica Minolta, Osaka, Japan). Only a\* and a\*/b\* results are being reported.

### ***Titrateable acidity***

The titrateable acidity of the tomato paste was determined by titration with 0.1 N NaOH using phenolphthalein as indicator (Cemeroğlu 2010). The titrateable acidity was calculated as citric acid % (w/v).

### ***Dark speck***

10 mL distilled water was added to 10 g of tomato paste and homogenized. The mixture was placed between two glass plates (20 x 20 cm) and black speck was counted (Cemeroğlu 2010).

### ***Lycopene content***

The lycopene content of the tomato paste was determined by extracting the lycopene and measuring its absorbance (max) at 503 nm spectrophotometrically (Varian Cary 50 Bio, UV / VIS Spectrophotometer) (Fish et al. 2002) tomato, and red grapefruit and may exert positive effects on human health. Spectrophotometric and HPLC techniques are commonly employed for analysis of lycopene content in food sources. A rapid

and inexpensive spectrophotometric assay for lycopene is presented. This method requires 80% less organic solvents for release and extraction of lycopene from watermelon than do the existing procedures. Comparative analyses for 105 watermelons from 11 cultivars yielded results equivalent to those provided by larger-volume spectrophotometric assay procedures. Limited numbers of assays suggest that this reduced volume method may be applicable for tomatoes and tomato products.

### ***Sensory analysis***

Sensory analysis of the tomato paste was performed by 10 semi trained panelists from its appearance, color, consistency (fluidity), flavor (taste and smell) and overall acceptance according to the procedure of Altuğ & Elmaci (2005). The intensity of the properties was determined using a 5-point scale (1 being the lowest and 5 the highest). Only the consistency and the overall preference results are given here.

### ***Experimental design and statistical analysis***

In this study, Response Surface Method (RSM) was applied to estimate the effect of evaporation time and temperature on soluble solid content (Brix), color values (a\* and a\*/b\*), titrateable acidity, dark speck, lycopene content and sensory properties of tomato paste during the vacuum evaporation. Central Composite Rotatable Design (CCRD) was used to arrange the experimental data (Table I). Evaporation temperature (60-90°C) and evaporation time (70-110 min) were chosen as independent variables according to literature and preliminary tests.

For vacuum evaporation, the analysis of variance (ANOVA) were performed to determine individual linear, quadratic and interaction regression coefficient using Design Expert software version 7.0 (State Ease, Inc.,

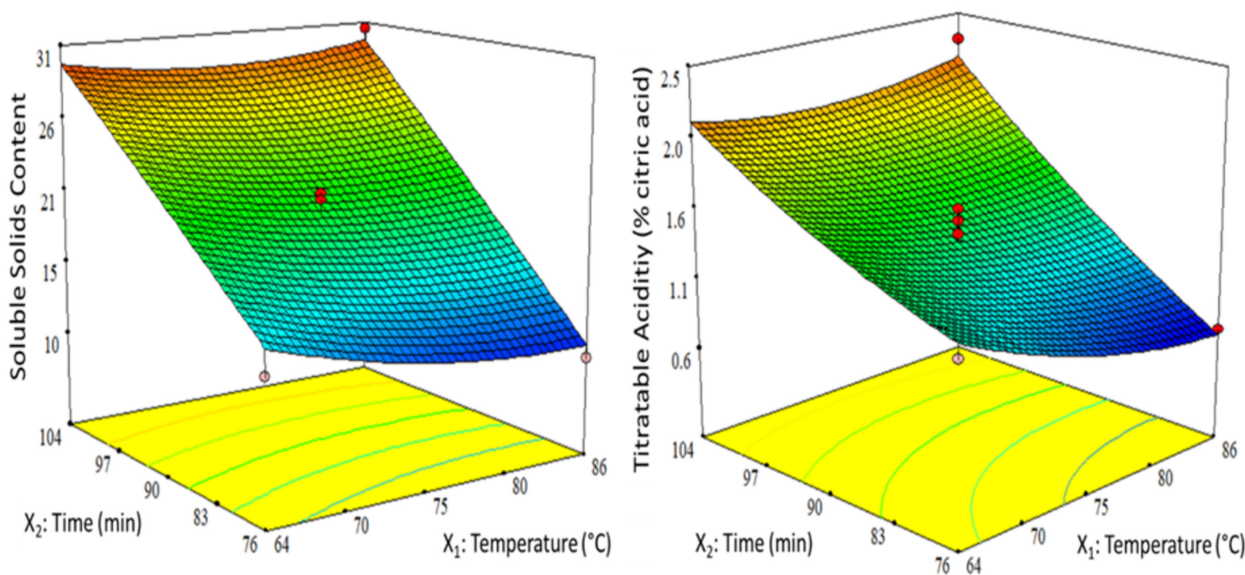


Minneapolis, MN, USA). The effect of independent variables (evaporation temperature and time) on samples quality of atmospheric evaporated was investigated using SPSS (Statistical Package for the Social Sciences, SPSS Chicago, Illinois, USA) software version 15.0, where significant differences ( $p < 0.05$ ) were detected.

## RESULTS AND DISCUSSION

The main objective of this study was to investigate the effects of temperature and time on the tomato paste quality produced by vacuum evaporation. The experimental design of vacuum evaporation was arranged with respect to CCRD and physical, chemical and sensorial properties of the tomato paste evaporated at different conditions (Table I). Counter plots of the predicted model of soluble solid content (SSC) and titratable acidity were given in Fig. 1. ANOVA and regression analysis were evaluated to fit the model. Statistical significance of the model terms (temperature and time), were also determined (Table II).

SSC is one of the key characteristic that is used to classify tomato paste as well as defining the endpoint of evaporation process (Zhang et al. 2014) soluble solids content, titratable acidity and Bostwick consistency of tomato pastes in continuous processing. The spectrometer was tested for two processing operations, dilution and evaporation. A total of 34 tomato paste samples were prepared by blending 9 different tomato pastes together in various proportions with final Bostwick consistency ranging from 2 to 11 cm. During the processing operation, spectra of 5 samples were obtained when different soluble solids contents were achieved. At the same time, standard reference methods were used to measure the parameters of interest on the same samples taken from the processing flow loop. The spectrum was recorded from 136 to 2690 MHz in 2 MHz steps. Partial Least Square (PLS. SSC of fresh tomatoes may increase from 4.9 to 27.5 during processing into tomato paste, and final tomato paste may have a SSC value between 25 and 30 (Koh et al. 2012). According to the Turkish food standards, total SSC of



**Figure 1.** Calculated effects of process variables; cooking temperature and cooking time on soluble solid content and titratable acidity of vacuum evaporated tomato paste.

tomato paste should be more than 28° Brix. The SSC of tomato paste increased with extension of evaporation time. Even though increasing

temperature caused a slight increase in SSC, evaporation time was found as main effective parameter for vacuum evaporation ( $p < 0.05$ ) (Table

**Table II. ANOVA results for physical, chemical and sensorial properties of vacuum evaporated tomato paste.**

Variation Source	Df	Soluble solids content		Titratable acidity (% citric acid)		Dark speck (number/10 g sample)		Lycopene content (mg/kg)		a*		a*/b*		Consistency (Sensorial)		Overall preference	
		SS	P-value	SS	P-value	SS	P-value	SS	P-value	SS	P-value	SS	P-value	SS	P-value	SS	P-value
Model	5	496.4	< 0.000*	2.69	0.001*	103.99	0.006*	8910.41	0.000*	103.9	0.005*	0.24	0.017*	5.32	0.005*	10.39	0.000*
X <sub>1</sub>	1	5.67	0.152	0.099	0.082	33.69	0.001*	1130.49	0.002*	33.69	0.005*	0.033	0.068	4.8*10 <sup>-3</sup>	0.826	3.23	0.000*
X <sub>2</sub>	1	418.55	< 0.000*	2.08	< 0.000*	49.38	0.019*	8156.68	< 0.000*	49.38	0.002*	0.12	0.006*	2.75	0.001*	1.26	0.002*
X <sub>1</sub> X <sub>2</sub>	1	2.26	0.340	0.061	0.154	15.27	0.030*	103.12	0.158	15.27	0.026*	0.054	0.030*	0.21	0.178	2.52	0.000*
X <sub>1</sub> <sup>2</sup>	1	7.95	0.010*	0.084	0.103	41.01	0.003*	17.66	0.529	41.01	0.003*	0.12	0.005*	0.056	0.464	3.87	0.000*
X <sub>2</sub> <sup>2</sup>	1	0.13	0.811	0.040	0.235	28.72	0.495	261.98	0.042*	28.72	0.007*	0.052	0.033*	1.23	0.011*	5.76	< 0.000*
Residual	7	12.63		0.14		10.64		238.08		10.64		0.041		0.55		0.30	
Lack of Fit	3	10.33	0.063	0.054	0.367	10.18	< 0.000*	103.09	0.321	10.18	0.002*	0.037	0.008*	0.038	0.865	0.100	0.442
Pure Error	4	2.30		0.083		0.46		134.99		0.46		3.552*10 <sup>-3</sup>		0.51	0.0049	0.20	
Total	12	508.67		2.2		114.63		9148.49		114.3		0.28		5.87	0.8265	10.69	

\*Significant differences in 0.05 level. X<sub>1</sub>: Temperature (°C), X<sub>2</sub>: Time (min).



II). During this study, the effect of temperature was supposed to be ineffective since the evaporation of tomato paste took considerably longer time. The highest SSC in tomato paste samples reached after evaporation at 75 °C for 110 min, which was the longest evaporation time. However, part of tomato paste burnt at 64.4 °C for 104.5 min. Since the heat energy transferred from electrical heater to the tomato paste was more than the heat energy used for evaporation during this time, the temperature of the dry matter of tomato paste has increased. The reason for this is that evaporation occurs quickly at low temperatures due to low vacuum pressure. Wu et al. (2007) 5 and 10kPa, and drying temperature ranging from 30 to 50°C. The effects of drying pressure and temperature on the drying rate and drying shrinkage of the eggplant samples were evaluated. The suitable model for describing the vacuum drying process was chosen by fitting four commonly used drying models and a suggested polynomial model to the experimental data; the effective moisture diffusivity and activation energy were calculated using an infinite series solution of Fick's diffusion equation. The results showed that increasing drying temperature accelerated the vacuum drying process, while drying chamber pressure did not show significant effect on the drying process within the temperature range investigated. Drying shrinkage of the samples was observed to be independent of drying temperature, but increased notably with an increase in drying chamber pressure. A linear relationship between drying shrinkage ratio and dry basis moisture content was observed. The goodness of fit tests indicated that the proposed polynomial model gave the best fit to experimental results among the five tested drying models. The temperature dependence of the effective moisture diffusivity for the vacuum drying of the eggplant samples was satisfactorily

described by an Arrhenius-type relationship has also reported the faster evaporation under vacuum. Thus, burning was observed in the sample produced under these conditions.

As expected, for atmospheric conditions, the SSC of tomato paste was affected evaporation time and it increased with evaporation time (Table III). When SSC of vacuum evaporated tomato paste were compared with atmospheric ones, it was determined that SSC of vacuum evaporated tomato paste were approximately equal values with atmospheric evaporated sample for same evaporation time (Tables I and III).

Katircı et al. (2018) studied on compare homemade and commercial types of tomato pastes. SSC of commercial type tomato pastes ( $28.20 \pm 0.90$ ) was higher than that of homemade samples ( $25.35 \pm 9.74$ ). Because of uncontrolled conditions during production, variation in the SSC of homemade tomato pastes was much higher than that for commercial counterparts mostly. Also, Kaya et al. (2013) determined SSC of commercial tomato pastes ( $n = 10$ ) from 4 local and 6 national companies were found between 27.93 and 39.83. Our results were lower than those reported in the literature.

The acidity of tomato is an indicator of fruit maturity. Besides, it is also an important basis of the flavor of the tomato products (Paulson & Stevens 1974). In tomato products, citric acid is the main acid that contributes to the total titratable acidity (Anthon et al. 2011). Titratable acidity of the tomato paste evaporated under vacuum was found in the range of 0.727 and 2.318 %. Titratable acidity of the samples increased with increasing the evaporation temperature and time ( $p < 0.05$ ). As similar to the vacuum evaporated paste, titratable acidity increased drastically as the evaporation time increased in traditional process ( $p < 0.05$ ). Sabancı & İcier (2017) have also reported that titratable acidity of sour

**Table III. Physical, chemical and sensorial properties of atmospheric evaporated tomato paste.**

Properties of tomato paste	Atmospheric evaporation time (min)			
	70	80	90	100
Soluble solids content (Brix)	10.0 <sup>a</sup> ±1.0	12.5 <sup>b</sup> ±0.5	22.5 <sup>c</sup> ±1.0	32.5 <sup>d</sup> ±1.25
Titrateable acidity (% citric acid)	0.687 <sup>a</sup> ±0.009	0.919 <sup>b</sup> ±0.015	2.037 <sup>c</sup> ±0.028	2.599 <sup>d</sup> ±0.012
Dark speck (count/10 g sample)	1.0 <sup>a</sup> ±0.0	0.5 <sup>a</sup> ±0.0	4.0 <sup>b</sup> ±1.0	40.5 <sup>c</sup> ±3.0
Lycopene content (mg/kg)	26.40 <sup>a</sup> ±0.85	35.44 <sup>b</sup> ±1.08	63.92 <sup>c</sup> ±1.12	89.31 <sup>d</sup> ±3.25
a*	14.78 <sup>a</sup> ±0.05	15.96 <sup>b</sup> ±0.08	14.42 <sup>c</sup> ±0.05	12.21 <sup>d</sup> ±0.24
a*/b*	1.68 <sup>a</sup> ±0.01	1.75 <sup>b</sup> ±0.13	1.65 <sup>c</sup> ±0.02	1.57 <sup>d</sup> ±0.08
Consistency (Sensorial)	2.71 <sup>a</sup> ±0.08	3.19 <sup>b</sup> ±0.05	4.25 <sup>c</sup> ±0.00	4.43 <sup>d</sup> ±0.10
Overall preference	3.16 <sup>a</sup> ±0.12	3.52 <sup>b</sup> ±0.09	4.35 <sup>c</sup> ±0.04	2.18 <sup>d</sup> ±0.02

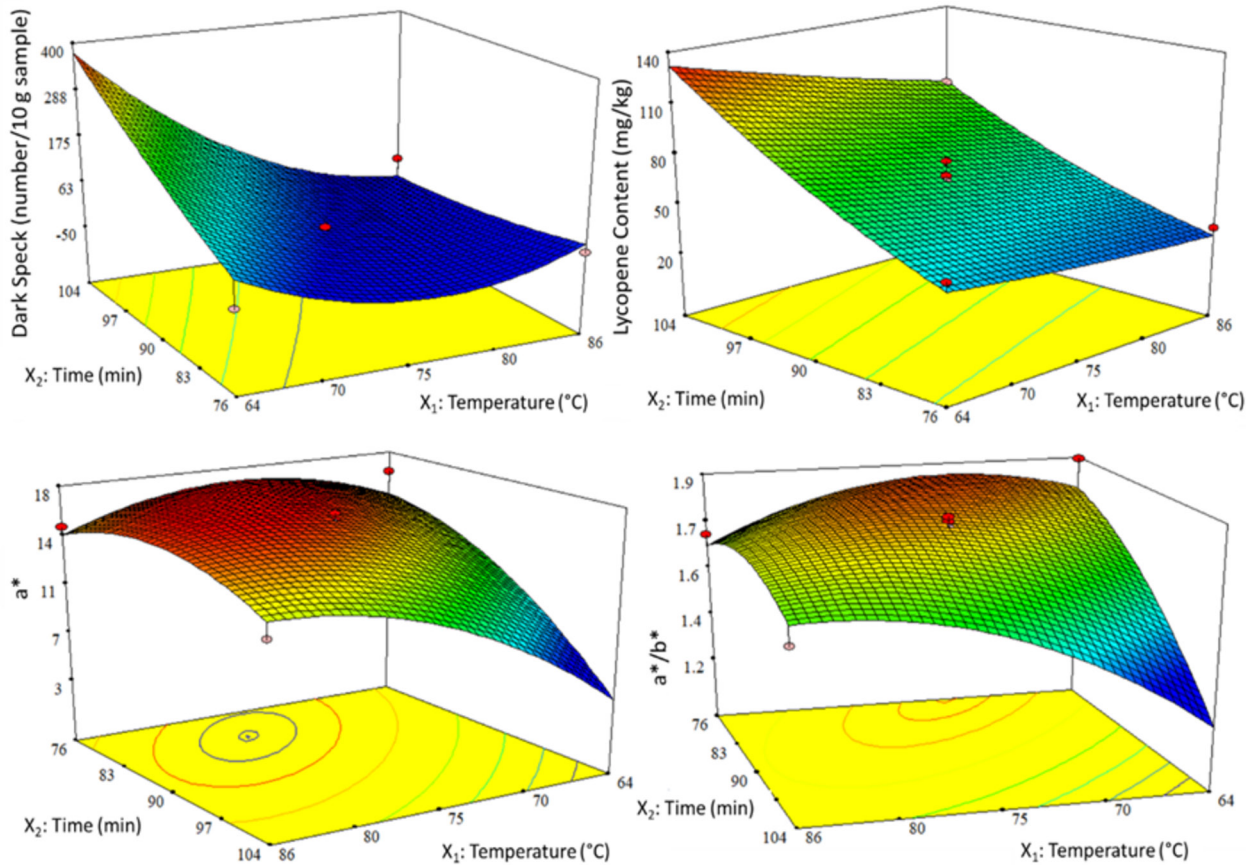
The different letter in the same row are significantly different ( $p < 0.05$ ).

cherry juice increased with increase of total SSC during evaporation process. Wiese & Dalmaso (1994) reported that organic acids (lactic, malic, citric and pyrocarboxylic acids) increased after processing tomato juice. Moreover, Gancedo & Luh (1986) found lower acidity in tomato juice that was processed at higher temperature.

Dark specks are considered as important quality parameter in tomato paste that generally occur due to excessive heat treatments during evaporation or existence of the molds in the paste (Velioğlu et al. 2011). According to Turkish Food Codex, there can be maximum 7 dark specks in 10 g of tomato paste (Anon 2014). For vacuum evaporation, the highest counts of dark specks (391.5 counts/10 g tomato paste) were determined at 60 °C for 90 min which was higher than that allowed by Turkish Food Codex. The sample was almost burnt due to the long time applied under the vacuum. It is obvious that both the evaporation time and temperature affected the counts of dark specks ( $p < 0.05$ ) (Table II). As shown in Fig. 2, the number of dark specks increased for long evaporation process at low temperature. The dark specks of the tomato paste evaporated at atmospheric conditions

were found in the range of 0.5 and 40.5 counts in 10 grams of the paste and increased with time ( $p < 0.05$ ) (Table III). The counts of dark specks in vacuum evaporated samples was found similar as that in the atmospheric ones at the same soluble solid content.

Lycopene, the main carotenoid found in tomatoes, comprises approximately 83 % of the total pigments and gives the typical red color (Gould 1983). Literature shows that lycopene consumption decreases the chances of prostate cancer and cholesterol level in LDL, which protects from cardiovascular diseases (Simpson et al. 2008, Djuric & Powell 2001, Anguelova & Warthesen 2000, Rao & Agarwal 1999) especially for countries like New Zealand and Chile. The main objective of this research was to propose a new economic evaluation procedure to optimize the design and operation of multiple effect evaporators and compare it with the traditional chemical engineering approach of total cost minimization. The proposed strategy incorporates a quality factor expressed as a function of lycopene concentration on the final product to find the optimal number of effects and operating conditions through the maximization



**Figure 2.** Calculated effects of process variables; cooking temperature and cooking time on dark speck, lycopene content, a\* and a\*/b\* of vacuum evaporated tomato paste.

of the net present value. The mathematical model was implemented using Microsoft Excel and considered mass and energy balances, specific relations for tomato concentration and a first order degradation kinetic for lycopene. The results indicate that when augmenting the capacity of the evaporation system of 5 effects from 50 to 75Ton/h, the lycopene retention increases from 95.25% to 96.27%. When evaluating the system through the logic of the total cost minimization, an optimum of 4 effects is found, but when evaluating the system using the maximization of the Net Present Value including lycopene as a quality parameter, the optimum is 3 effects. It appears of extreme relevance to consider quality as an intrinsic and integral part

of the process design, as it will then be possible to identify several potential improvements in different food processes. Increased consumption of tomatoes and tomato products has been associated with decreased cancer risks. One fat-soluble compound identified in tomatoes which may be responsible for this association is lycopene. There may, however, be other antioxidants present in tomato-based foods, and total antioxidant capacity may be another way to rate the health benefits of these foods. In this work, we examined the Trolox-equivalent antioxidant capacity (TEAC). Lycopene is stocked in a matrix of protein and fiber in fresh tomatoes. Disintegration of tomato cell walls by heat releases the lycopene. Therefore, the

concentration of lycopene in tomato products is higher than that of fresh tomatoes (Hakala & Heinonen 1994). Moreover, the bioavailability and nutritional quality of lycopene are increased during the process (Hadley et al. 2002).

The effect of temperature and time was found as statistically significant ( $p < 0.05$ ) on the amount of lycopene (Table II) that increased with evaporation time at constant temperature as stated in the literature (Dewanto et al. 2002) indicating most of the activity comes from the natural combination of phytochemicals. This suggests that processed fruits and vegetables may retain their antioxidant activity despite the loss of vitamin C. Here it is shown that thermal processing elevated total antioxidant activity and bioaccessible lycopene content in tomatoes and produced no significant changes in the total phenolics and total flavonoids content, although loss of vitamin C was observed. The raw tomato had  $0.76 \pm 0.03$  micromol of vitamin C/g of tomato. After 2, 15, and 30 min of heating at 88 degrees C, the vitamin C content significantly dropped to  $0.68 \pm 0.02$ ,  $0.64 \pm 0.01$ , and  $0.54 \pm 0.02$  micromol of vitamin C/g of tomato, respectively ( $p < 0.01$ ). However, at constant evaporation time at various temperatures, lycopene content was higher at lower temperature ( $64.4^\circ\text{C}$ ) (Fig. 2). It can be stated that at lower temperatures around  $60^\circ\text{C}$ , the obtained product was very concentrated and the lycopene concentration was higher as compared to the product evaporated for the same time at  $85.6^\circ\text{C}$ . On the other hand, lycopene concentrations were found to be in the range of 26.40 and 89.31 mg/kg for the samples evaporated at atmospheric conditions (Table III). Lycopene content of the vacuum evaporated paste at  $75^\circ\text{C}$ -110 min was higher than the atmospheric one at  $100^\circ\text{C}$ -100 min at the same final Brix (31-32 Bx). This can be attributed to the longer evaporation process under vacuum

(Tables I and III). Lycopene degradation during thermal processes has usually been observed and the extent of loss found to be dependent on the type of treatment, temperature, duration and the presence of oxygen and light. Boskovic (1979) observed a reduction of lycopene content by up to 20% following processing and extended storage of dehydrated tomato products. According to Zanoni et al. (1999), during drying of tomato halves at  $80^\circ\text{C}$  no significant lycopene loss occurs, whereas a significant, though small, loss (12%) occurs at  $110^\circ\text{C}$ . Isomerization of lycopene in tomato products as a result of thermal treatments has been also reported by many researchers (Stahl & Sies 1992, Schierle et al. 1997, Shi et al. 1999). Lycopene loss increased with increases in air inlet temperature in spray drying and the decrease in lycopene content reported was due to an actual degradation of lycopene, rather than to a progressive conversion from the all-trans-lycopene to a less strongly colored, less intensely absorbing cis form (Goula & Adamopoulos 2005).

CAC and US Standards (Anon 2004) defines the color of tomato concentrate and paste as one of the main quality criteria. According to Turkish Food Codex, color value for the tomato paste should be minimum 1.8 based on  $a^*/b^*$  ratio (Anon 2014). Desired color of the tomato paste should be between red and yellow; preferred is incline towards red (Velioğlu et al. 2011). Only vacuum evaporated tomato paste at  $75^\circ\text{C}$ -90 min reached to  $a^*/b^*$  value of 1.8 in this study. For atmospheric evaporation, no sample provided this color property. The relationship of quality and color of tomato paste products has been explained by Akıllıoğlu et al. (2015). If the  $a^*/b^*$  ratio is greater than 1.90, then the tomato paste can be accepted as of first quality in terms of color. Ratio of  $a^*/b^*$  smaller than 1.80 gives poor quality to tomato paste. In current study, average  $a^*/b^*$  ratios for homemade and

commercial tomato pastes were calculated as 1.81 and 1.80, respectively. Kaya et al. (2013) reported that the  $a^*/b^*$  ratio for tomato pastes varied between 1.98 and 2.23 while Yıldız (2004) found the  $a^*/b^*$  ratio between 1.69 and 2.04. As shown in Fig. 2,  $a^*/b^*$  value of vacuum evaporated paste increased with increasing temperature, however decreased with increasing time ( $p < 0.05$ ).  $a^*$  values, indicating red color for CIE system, increased during evaporation and reflected darker color. The highest  $a^*$  value was determined at 75 °C and 90 min under vacuum ( $p < 0.05$ ) (Fig. 2). However, color values of atmospheric samples were not affected by evaporation time ( $p > 0.05$ ). Wiese & Dalmaso (1994) reported significant increase in the hue angle of tomato juice after processing and storage and lost red color. Color retention in tomato products is better at lower temperature (Villari et al. 1994).

Sensory evaluation of tomato paste was conducted in terms of appearance, color, smell, consistency, taste and overall preference. Only the consistency and the overall preference results are given in Table I for vacuum evaporated samples and in Table III for atmospheric ones. The highest score in terms of overall preference was obtained for 90 minutes at atmospheric evaporation ( $p < 0.05$ ) (Table III). When the evaporation time was 100 min, excessive moisture loss occurred and caused an unfavorable burnt color, odor and taste. Because of these effects, the panelists gave lower the overall preference scores and higher the consistency scores.

For vacuum evaporation, tomato paste evaporated at 75 °C for 90 min got the highest score in terms of overall preference while 85.6 – 104.1 min evaporated tomato paste got the highest score in terms of consistency due to higher SSC. Tomato paste was processed at a wide range of the temperature and time according to CCRD. Because of these reasons,

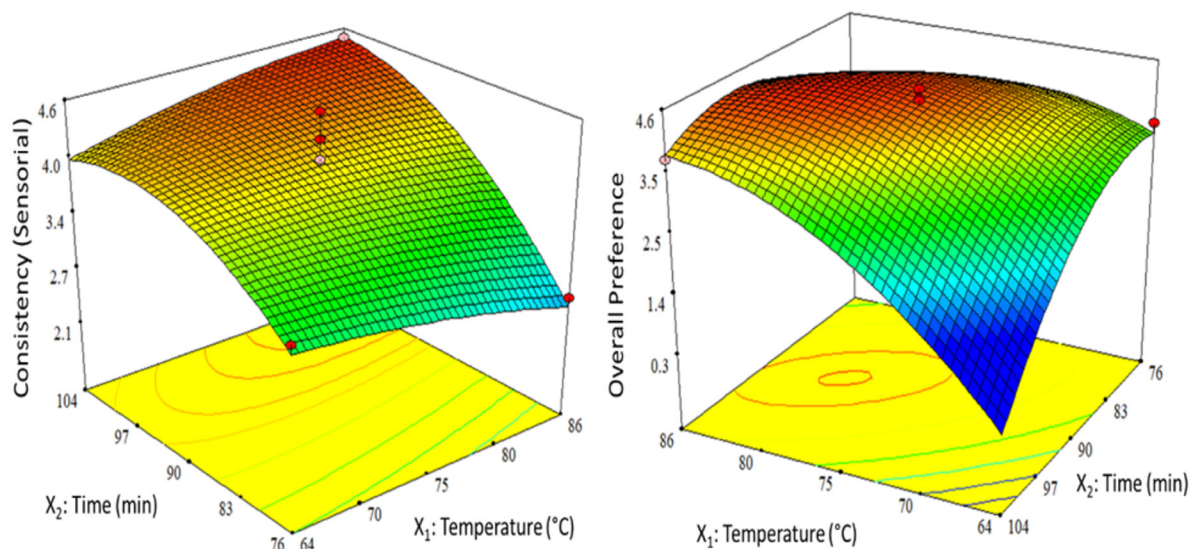
some of overall acceptance results were considerably low for trials especially at boundary conditions, but the overall acceptance results at the center point of CCRD (75 °C, 90 min) were between 3.93 and 4.51. The overall preference scores of samples increased with an increase in evaporation time and temperature (Fig. 3). In addition, Pearson correlation coefficient ( $r$ ) between consistency and SSC was found as 0.821. As shown in Fig. 3, the consistency of the paste was significantly affected by evaporation time ( $p < 0.05$ ). Okut et al. (2018) reducing sugars total sugars HMF and sensory properties were investigated. Also, the optimum vacuum cooking conditions for strawberry jam were optimized for Composite Rotatable Design. The optimum cooking temperature and time were determined targeting maximum soluble solid content and sensory attributes (consistency) found that vacuum cooking time was the most effective independent variable on the consistency.

When the overall preference values of vacuum evaporated tomato paste compared with the paste produced at atmospheric conditions, the panellists for the overall preference evaluation of tomato paste gave approximately equal scores. As a result, it could be pointed out that the characteristic sensorial quality of tomato paste produced at atmospheric conditions was positively protected by vacuum evaporation process.

## CONCLUSION

Performance and time/temperature conditions were tested on tomato paste production in a vacuum cooking prototype that was developed for household applications. Besides, evaporation process was also carried out at atmospheric pressure at different temperatures. With increasing time of vacuum evaporation, soluble





**Figure 3.** Calculated effects of process variables; cooking temperature and cooking time on consistency (sensorial) and overall preference of vacuum evaporated tomato paste.

solid contents in tomato paste increased, whereas  $a^*/b^*$  value decreased. The counts of dark specks of tomato paste were increased with increasing time and temperature. However, higher lycopene content was observed under vacuum at lower temperature and constant evaporation time. As a conclusion, the developed cooking prototype can help consumers to prepare tomato paste under vacuum with protection of beneficial components and natural color. Future research needs to be performed to elucidate optimum vacuum evaporation conditions for the tomato paste by using the developed vacuum cooking prototype.

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MK planned the experimental design. ED and DO developed the laboratory and statistical analysis. HK developed the vacuum evaporation prototype. FK supervised and monitored of the study. All authors discussed the results and contributed to the writing of final manuscript.

