Developing a vacuum cooking equipment prototype to produce strawberry jam and optimization of vacuum cooking conditions

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Abstract 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) and minimum Hue value and HMF content. The optimum vacuum cooking conditions determined were 74.4 °C temperature and 19.8 time. The soluble solid content strawberry jam made by vacuum process were similar to those prepared by traditional method. HMF contents of jams produced with vacuum cooking method were well within limit of standards.

Keywords Jam processing · Strawberry jam · Vacuum cooking · Evaporation · Optimization

Introduction

Fruits are the major part of our daily diet in consequence of they are a valuable source of nutritional compounds. However, fruits are perishable and only consumable with their highest nutritional value at their season (Osvold and Stirn 2008). The perishable structure and seasonality of the fruits lead producers to apply some preservation technologies (Giannakourou and Taoukis 2003). One of the most common preservation technologies to extend the shelf-lives of fruits is “jam processing” (Kansci et al. 2003).

According to European Union Council Directive 2001/113/EC, jams are a mixture, brought to a suitable gelled consistency, of sugars, with the pulp and/or puree of one or more kinds of fruit and water. The reason of the popularity of jam products are their price, being accessible throughout the year and their delicious taste (Gałkowska et al. 2010).

Strawberries (*Fragaria x ananassa* Duch.) are most commonly used fruits for preparation of jam, jellies and spreads not only because of their aroma, attractive color and flavor but also their nutritious effect on human health (Curi et al. 2016). Strawberries are an excellent source of potassium, calcium, magnesium and contains high amount of vitamin C, flavonoids and anthocyanins (Souza et al. 2014). Likewise, most of the fruits, strawberries are seasonal and their texture tends to get softer because of the natural ripening process (Cordenunsi et al. 2005). Processing strawberries into jam is a perfect way to extend its shelf-life and get value added product (Amaro et al. 2013).

Jam is produced by using modern equipments at industrial level beside that, traditional methods at the household levels are still being used (Gałkowska et al.

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2010). In jam production traditional methods consist of many treatments such as fruit blanching, sugar concentration at high temperature and long cooking time that causes loss of bioactive compounds and sensorial quality of fruit products (Vibhakara and Bawa 2006). The excessive thermal treatment and long processing time may also lead to Maillard reaction and caramelisation of carbohydrates in the acidic medium which could cause formation of hydroxymethylfurfural (HMF), furfural and melanoidins (Rada-Mendoza et al. 2002a).

Recently, vacuum cooking has gained attention as an alternative cooking method in terms of application at low temperatures in short processing time, non-oxygen environment, the better protection of nutritional value and texture of the food (Garcia-Segoiva et al. 2007). Vacuum cooking provides protection of the natural color and the flavor of the food by means of the low temperature and oxygen environment (Andres-Bello et al. 2009). Formation of enzymatic and non-enzymatic aerobic spoilage reactions that take place in the traditional cooking process and effect on the quality of the final product, could be reduced due to low oxygen environment (Martinez-Hernández et al. 2013). Besides that, due to applied low temperatures, the product preserves its specific fresh flavor, pigment content and bioactive compounds (Amaro et al. 2013).

Vacuum cooking process is operated in the closed vessels at food industry for production of concentrated products such as jam, jelly and tomato paste. However, to our knowledge there is no a household vacuum cooking equipment on the market to enable producing jam at home with healthier way and short processing time.

In the literature, it was known that there was a device equipped with vacuum cooking and frying function called Gastrovac (Andres-Bello et al. 2009). This device was designed for more gastronomic cuisine and did not have the feature of household cooking appliance in terms of its high cost. Also this device was designed for cooking and frying processes and did not include a mechanism to allow the evaporation process. Therefore, to our knowledge there is no such a household equipment that can perform under vacuum for jam production and no study has been made in the literature to produce jam with this equipment.

The objective of this study was to develop prototype vacuum process based equipment that can be operated under vacuum and to test its performance for production of strawberry jam.

Materials and methods

Materials

The strawberries (*Fragaria × ananassa* Duchwere) harvested in the beginning of the May. Strawberries were harvested by cutting them with a nail so that the fruit stays 1 cm in length, without holding the fruit according to Turkish Strawberries Standard (TS 185, 2008). After harvesting, strawberries were immediately transported to production place. Before jam production, strawberries were cleaned to remove stems and deteriorated parts. Sugar and citric acid was obtained from a local market in İzmir.

Design of the vacuum cooking equipment prototype

Vacuum based prototype equipment was developed and diagram of the same is shown in Fig. 1. The developed equipment made up a 6 L vessel equipped with a reductor mixer that worked in the 0–50 Hz range continuously or batch, an electrical heater with 1.5 kW power, an oily type vacuum pump of 0.55 Hp power and a condenser of 1 kW power. PLC system was used to control mixer rate, vacuum level and cooking time, while PID system was used to control the electrical heater.

Strawberry jam production

The cleaned strawberries were weighed (600 g) and mixed with sugar (400 g). This mixture was kept in refrigerator for an overnight before cooking to ensure sugar penetration to strawberries. Citric acid which provided gel formation and acidic taste in jam production was added in the beginning of the cooking. For the vacuum treatment, the strawberry jam was cooked according to Central Composite Rotatable Design (CCRD) as given in Table 1.

Analysis

The soluble solid content

The soluble solid content was measured using Abbe refractometer at 25 °C according to method described by Cemeroğlu (2010).

Color

CIE L*, a* and b* values were measured for color determination of strawberry jam with a Minolta Chromameter

Fig. 1 Developed vacuum cooking equipment prototype

(Konica Minolta, Osaka, Japan). The instrument (D65 optical sensor, 2° observer) was calibrated using white (Y 85.7; x 0.3203, y 0.3382) reference tile. The color intensity (Chroma, C^*), the color tone (Hue, h°), total color difference (ΔE), browning index (BI) and yellowness index (YI) were calculated with Eqs. 1, 2, 3, 4 and 5, respectively (Hunter 1975).

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

$$h^\circ = \arctan(b^* + a^*) \quad (2)$$

$$\Delta E = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \quad (3)$$

where, ΔL^* ($L^*_{\text{sample}} - L^*_{\text{standard}}$) is difference in lightness and darkness (+ = lighter, − = darker), Δa^* ($a^*_{\text{sample}} - a^*_{\text{standard}}$) is difference in red and green (+ = redder, − = greener) Δb^* ($b^*_{\text{sample}} - b^*_{\text{standard}}$) is difference in yellow and blue (+ = yellower, − = bluer) a^*_{standard} , b^*_{standard} and L^*_{standard} are the CIE-Lab values of the untreated fresh sample.

$$BI = \frac{100 * \left(\frac{a^* + 1.75L^*}{5.645L^* + a^* - 3.012b^*} - 0.31 \right)}{0.17} \quad (4)$$

$$YI = \frac{142.86 * b^*}{L^*} \quad (5)$$

pH

A digital pH meter (inoLab pH/Cond 720, WTW, Germany) was used for measuring the pH of the strawberry jam at 25 °C.

Titrateable acidity

For the titrateable acidity analysis, strawberry jam was blended in blender (Ema Mixer). (10 g) Sample was diluted to 100 ml with distilled water. Then the mixture was filtered through filter paper, 20 ml filtrate was taken from slurry, using 1–2 drops of fenolftalein as indicator and titrated with 0.1 N NaOH (Cemeroğlu 2010). The titrateable acidity was calculated as citric acid % (w/v).

Hydroxymethylfurfural (HMF) content

HPLC method was used for the detection of HMF in the samples. Strawberry jam (5 g) was homogenized in a blender and diluted with 50 ml distilled water. This

Table 1 Physical, chemical and sensorial properties of the strawberry jams cooked under different experimental conditions

Exp. no	Temperature (°C)	Time (min)	L*	a*	b*	C*	Hue	ΔE
1	64.4	12.2	28.25 ± 0.08	1.38 ± 0.25	0.98 ± 0.18	1.69 ± 0.31	35.25 ± 0.09	1.34 ± 0.09
2	85.6	12.2	28.52 ± 0.03	1.22 ± 0.21	0.87 ± 0.03	1.50 ± 0.18	35.83 ± 3.72	1.21 ± 0.15
3	64.4	22.8	28.39 ± 0.23	1.66 ± 0.31	1.10 ± 0.19	1.99 ± 0.37	33.52 ± 0.31	1.10 ± 0.31
4	85.6	22.8	28.38 ± 0.00	2.28 ± 0.11	1.33 ± 0.05	2.63 ± 0.07	30.24 ± 2.09	1.13 ± 0.02
5	60.0	17.5	28.99 ± 0.57	2.06 ± 0.24	1.04 ± 0.10	2.30 ± 0.26	26.88 ± 0.41	0.46 ± 0.05
6	90.0	17.5	29.11 ± 0.37	2.70 ± 0.74	1.26 ± 0.33	2.97 ± 0.81	25.02 ± 0.33	0.82 ± 0.04
7	75.0	10.0	28.32 ± 0.04	0.77 ± 0.00	0.76 ± 0.01	1.08 ± 0.01	44.62 ± 0.53	1.68 ± 0.07
8	75.0	25.0	28.24 ± 0.00	1.19 ± 0.04	0.87 ± 0.01	1.47 ± 0.03	36.03 ± 1.19	1.45 ± 0.16
9	75.0	17.5	28.22 ± 0.13	1.32 ± 0.03	0.87 ± 0.02	1.58 ± 0.04	33.24 ± 0.08	1.40 ± 0.12
10	75.0	17.5	28.76 ± 0.07	1.50 ± 0.23	1.05 ± 0.17	1.83 ± 0.28	34.82 ± 0.33	0.83 ± 0.04
11	75.0	17.5	28.46 ± 0.13	1.57 ± 0.19	0.94 ± 0.02	1.83 ± 0.15	31.03 ± 3.50	1.07 ± 0.02
12	75.0	17.5	28.60 ± 0.35	1.82 ± 0.16	1.02 ± 0.07	2.09 ± 0.11	29.28 ± 3.76	0.86 ± 0.32
13	75.0	17.5	28.92 ± 0.37	1.52 ± 0.40	0.86 ± 0.09	1.75 ± 0.39	29.76 ± 3.73	0.73 ± 0.23
Exp. no	BI	YI	Soluble solid content	Reducing sugar content (%)	Total sugar content (%)	HMF content (mg/kg)	Consistencyin spoon (sensorial)	
1	6.96 ± 1.29	4.96 ± 0.91	54.00 ± 2.83	7.53 ± 1.30	47.17 ± 3.96	11.98 ± 0.14	3.60 ± 0.14	
2	6.10 ± 0.60	4.36 ± 0.21	51.00 ± 0.00	10.52 ± 0.66	42.69 ± 1.16	25.89 ± 0.80	3.50 ± 0.42	
3	8.06 ± 1.41	5.54 ± 0.93	56.00 ± 0.00	9.97 ± 1.44	52.35 ± 2.22	16.27 ± 0.26	3.79 ± 0.86	
4	10.45 ± 0.08	6.69 ± 0.25	58.50 ± 2.12	16.55 ± 1.88	47.66 ± 0.84	30.75 ± 0.70	4.06 ± 0.48	
5	8.66 ± 1.10	5.13 ± 0.60	58.00 ± 2.83	10.21 ± 1.60	51.47 ± 3.92	13.46 ± 2.21	3.88 ± 0.01	
6	10.96 ± 3.11	6.18 ± 1.69	54.50 ± 3.54	14.57 ± 1.01	45.93 ± 4.42	74.96 ± 3.33	4.24 ± 0.02	
7	4.62 ± 0.14	3.83 ± 0.35	47.50 ± 2.12	8.44 ± 1.47	40.81 ± 0.03	14.85 ± 0.07	3.36 ± 0.26	
8	6.09 ± 0.18	4.40 ± 0.10	59.00 ± 1.41	11.07 ± 0.17	50.05 ± 0.22	21.35 ± 1.83	4.32 ± 0.14	
9	6.42 ± 0.16	4.40 ± 0.13	60.00 ± 0.00	9.14 ± 0.06	51.34 ± 3.21	14.41 ± 1.49	4.31 ± 0.27	
10	7.38 ± 1.15	5.22 ± 0.84	59.00 ± 1.41	9.93 ± 0.01	49.57 ± 3.19	15.43 ± 0.33	3.97 ± 0.24	
11	7.24 ± 0.44	4.72 ± 0.07	57.50 ± 0.71	8.92 ± 0.09	48.35 ± 2.41	14.39 ± 0.23	4.10 ± 0.14	
12	8.11 ± 0.06	5.10 ± 0.39	56.00 ± 1.41	9.90 ± 0.07	47.53 ± 3.40	14.42 ± 2.07	4.30 ± 0.11	
13	6.72 ± 1.39	4.25 ± 0.52	59.00 ± 0.00	9.13 ± 0.01	47.65 ± 3.16	14.72 ± 0.99	4.30 ± 0.11	

homogenized sample was filtered through a blue filter paper. Finally the filtrate was injected into the HPLC equipped with C₁₈ (15 cm × 4.6 mm) column. The HPLC conditions were the following: isocratic mobile phase, 80% HPLC grade water and 20% HPLC grade methanol; flow rate, 1 ml/min; injection volume, 20 µl. HMF was identified by splitting the peak in sample with a standard HMF (Sigma-Aldrich), and by comparison the spectrum of HMF standard with that of samples. The amount of HMF was determined using an external calibration curve, measuring the signal at $\lambda = 285$ nm (Vorlová et al. 2006).

Degree of inversion

Volumetric Lane-Eynon method was used to evaluate the degree of inversion of the strawberry jam samples (Cemeroğlu 2010).

Sensory analysis

Sensory analysis was carried out for appearance (remaining in all without disintegration), color, consistency in spoon (fluidity), taste and overall acceptance by 10 panelists (Lawless and Heymann 1998). However, only the consistency in spoon scores was given in this paper. The intensity of the properties was determined using a 5-point scale (1 being the lowest and 5 the highest).

Experimental design and statistical analysis

Response surface methodology (RSM) is generally used to optimize the responses. RSM has been carried out for optimization of different processes in foods. RSM was applied to estimate the effect of cooking temperature and time on Soluble solid content, Hue value, amount of HMF (mg/kg) and consistency in spoon which was one of

sensory evaluation criteria for evaluation of strawberry jam. CCRD was used to design the experimental data.

Cooking temperature (60–90 °C) and cooking time (10–25 min) were chosen as independent variables with respect to literature research and pre-elementary tests. CCRD consisted of 13 experiments runs with five replicates at the central point (Table 1). Besides, each experiment was done in duplicate. Thus, the relationship between the responses and the independent variables is not known, it is assumed to be closer to the actual response function with a quadratic polynomial model (Eq. 6). Experimental data which is required to fit the polynomial model was determined using the CCRD trial plan. Four models were generated with using the following form according to four responses (Y) such as soluble solid content (SSC), Hue, HMF and consistency in spoon (CS) to two process variables (X);

$$Y_k = \beta_{k0} + \sum_{i=1}^2 \beta_{ki} X_i + \sum_{i=1}^2 \beta_{kii} X_i^2 + \sum_{i=1}^1 \sum_{j=i+1}^2 \beta_{kij} X_{ji} \quad (6)$$

$$k = (1, 2)$$

where; β_{k0} , β_{ki} and β_{kij} are constant regression coefficients and X is the coded independent variable.

Means of multiple linear regression analysis were evaluated for each response in the mathematical models. The analysis of variance (ANOVA) were performed to determine individual linear, quadratic and interaction regression coefficient with using Design Expert software, version 7.0 (State Ease, Inc., Minneapolis, MN, USA). Whether a model is an appropriate approach to the actual response of the system, has been decided with respect to “lack of fit” test and 95% confidence level. The model adequacies were determined by regression coefficients in the model (R^2), adjusted regression coefficient (Adj- R^2), predicted R^2 and prediction error sum of squares (PRESS).

For each result ANOVA at a confidence level of 95% was carried out. Also, one sample *t* test were evaluated using SPSS version 13.0 Windows program (SPSS Inc., Chicago, IL) to test the significant differences between the results estimated by model and obtained by optimum point experiments.

Optimization

Numerical methods were used for optimization (desirability function). At least five attempts were carried out at the optimum point as determined by the model (the optimum process conditions) and the optimum point was confirmed experimentally. In this study, desirability functions were evaluated for the criteria of maximum Soluble solid content and sensory attributes (consistency in spoon) and minimum Hue value and HMF content (mg/kg). These criterion was chosen according the literature data. In this study,

consistency in spoon criteria was used to evaluate the fluid behavior of jam in terms of consumer's acceptance. Although sensorial evaluation is a subjective approach, there is a common flavor perception in Turkish culture which the structure of strawberry jam must be viscous. Furthermore, response surface graphs and contour lines that helps to determine the optimum point is plotted using models obtained by regression analysis.

Results and discussion

The physical, chemical properties and consistency in spoon scores of the strawberry jams cooked at different experimental conditions are given in Table 1.

ANOVA and regression analysis were evaluated to fit the model and determined the statistical significance of the model terms, as shown in Table 2 and 3. The quadratic polynomial model represented significantly the experimental values of responses at $p < 0.05$ level, besides the lack of fit of models were not significant. The counter plots of the predicted model of soluble solid content, HMF, reducing sugar, % and total sugar, % content and a^* , b^* , Hue value and C^* were given in Figs. 2 and 3, respectively.

Oxygen, pH, heat, light, sugar content, existence of ascorbic acid and metal ion effects the red color pigments in strawberries which gives the specific charming color of the fresh fruits and undesirable color losses can occur due to the degradation of the color pigments (Stintzing and Carle 2004). Color stability of the product is also affected by the total amount of pigments in jam (Wicklund et al. 2005). During the jam production process, color change is unavoidable due to the degradation of anthocyanins pigments, the formation of yellowing and browning compounds, Maillard reactions, ascorbic acid degradation and polymerisation of anthocyanins with other phenolics (de Moura et al. 2012). CIE L^* , a^* , b^* and C^* values of the strawberry jam cooked at different temperatures and times were measured and given in Table 1. As stated by Rada-Mendoza et al. (2002b) heat treatment and improper storage conditions result Maillard reaction and sugar caramelization which provide characteristic flavor and color in jam. However, if these changes are not controlled, they could case undesirable darkening in the last product.

When a^* values of vacuum cooked strawberry jam were evaluated, an increase in the a^* values were observed due to darker color occurring with increase in cooking temperature and time. The highest a^* values (2.70 ± 0.74) was determined at 90 °C and 17.5 min cooked strawberry jam. Chroma values, an indicator of color intensity, were also increased with an increasing a^* values.

Effect of vacuum cooking process variables (X_1 and X_2) on C^* and a^* values of strawberry jam was can be

Table 2 ANOVA results for color properties of vacuum cooked strawberry jam

Variation Source	Df	L*			a*			b*			C*			Hue			ΔE			BI			YI		
		Sum of square	p value	Sum of square	p value	Sum of square	p value	Sum of square	p value	Sum of square	p value	Sum of square	p value	Sum of square	p value	Sum of square	p value	Sum of square	p value	Sum of square	p value	Sum of square	p value	Sum of square	p value
Model	5	0.65	0.195	2.83	0.001*	0.25	0.031*	2.83	0.001*	270.3	0.001*	1.02	0.046*	33.41	0.002*	5.87	0.040*								
X ₁	1	0.024	0.565	0.23	0.033*	0.02	0.182	0.24	0.039*	3.53	0.360	0.021	0.537	2.86	0.053	0.52	0.208								
X ₂	1	0.002	0.878	0.47	0.007*	0.07	0.039*	0.49	0.008*	46.85	0.009*	0.052	0.340	7.09	0.008*	1.73	0.039*								
X ₁ X ₂	1	0.02	0.597	0.15	0.068	0.03	0.145	0.18	0.068	3.76	0.346	0.006	0.730	2.64	0.060	0.77	0.136								
X ₁ ²	1	0.18	0.142	1.13	0.001*	0.11	0.015*	1.17	0.001*	50.66	0.008*	0.15	0.128	13.55	0.001*	2.37	0.021*								
X ₂ ²	1	0.35	0.053	0.6	0.004*	0.01	0.287	0.51	0.008*	139.9	0.001*	0.70	0.007*	4.82	0.019*	0.24	0.376								
Residual	7	0.45		0.23		0.07		0.26		25.75		0.35		3.68		1.88									
Lack of Fit	3	0.16	0.589	0.099	0.471	0.04	0.268	0.13	0.396	3.62	0.879	0.063	0.826	1.98	0.331	1.17	0.234								
Pure Error	4	0.29	0.195	0.13	0.001	0.03	0.031	0.14		22.13		0.28		1.70		0.72									
Total	12	1.11	0.565	3.06	0.033	0.32	0.182	3.09		296.1		1.37		37.09		7.75									

* Significant differences in 0.05 level

explained by the selected quadratic model ($p < 0.05$) (Table 2). Also, C* and a* values of strawberry jams are significantly affected by independent variables ($p < 0.05$). However, L* values of the strawberry jam did not varied with temperature and time, so it was not in accordance with the quadratic model ($p > 0.05$) (Table 2).

The quality properties which describes a good strawberry jam are desirable red color, specific sweet–sour flavor and also sufficient viscous structure (Wicklund et al. 2005). The terms of color tone called Hue was a color wheel and it subtended 0–360°, with red–purple traditionally placed at the far right (or at an angle of 0°); yellow, bluish-green, and blue follow counter-clockwise at 90°, 180°, and 270°, respectively. It was determined that vacuum cooking time was the most effective independent parameter on Hue values of vacuum cooked strawberry jam (Table 2). Hue values of vacuum cooked strawberry jam were found to be similar to Mazur et al. (2014)'s findings.

It can be clearly seen in Fig. 3. Hue values of vacuum cooked strawberry jam gave saddle point in response surface counter plots. At the minimum point of time, Hue values reached the highest level since the strawberry jam has got the vivid red color specific to fresh strawberries. At the maximum point of time, formation of dark red color was observed due to the increase in dry matter content of strawberry jam.

Besides, hue and chroma value, browning index (BI), yellowness index (YI) and color change (ΔE) of strawberries jams were evaluated for determining the color properties of strawberries jams. As seen in Table 1, browning index of the vacuum cooked strawberry jam increased with both increasing cooking time and cooking temperature. Red color of the strawberry degraded easily by application of heat processing (Rodrigo et al. 2007). Heat processing causes non-enzymatic browning and as a result of this, undesirable products forms such as HMF which also leads to color changes in sugary products (Ibarz et al. 1999). In our study, higher browning index values were calculated in the 4th and 6th experiments, which possessed also higher HMF contents.

Similar to BI values, YI values increased with cooking time and temperature. Highest YI value was obtained at 85.6 °C–22.8 min cooking conditions. As shown in Table 2, the cooking time was determined to be the most effective parameter on the both BI and YI values of jams ($p < 0.05$). However, no significant changes were observed in ΔE values with cooking time and temperature ($p > 0.05$) (Table 2). The lowest ΔE (0.46) value was determined at lowest temperature (60 °C) for 17.5 min cooking time (Table 1).

Citric acid used as acidity regulator provides typical fruit taste of the jam and also plays a role in the formation of desired gel structure. Titratable acidity of jams found to be varied between 0.473 and 0.588%. The titratable acidity

Table 3 ANOVA results for physical, chemical and sensorial properties of vacuum cooked strawberry jam

Variation Source	Df	Soluble solid content		Reducing sugar content (%)		Total sugar content (%)		HMF (mg/kg)		Consistency in spoon	
		Sum of square	<i>p</i> value	Sum of square	<i>p</i> value	Sum of square	<i>p</i> value	Sum of square	<i>p</i> value	Sum of square	<i>p</i> value
Model	5	140.7	0.003*	68.58	0.001*	122.4	0.001*	2795	0.016*	1.07	0.017*
X ₁	1	3.71	0.269	30.96	0.000*	36.18	0.002*	1663	0.004*	0.057	0.242
X ₂	1	82.97	0.001*	18.53	0.002*	67.40	0.000*	42.0	0.516	0.560	0.005*
X ₁ X ₂	1	7.56	0.130	3.21	0.076	0.012	0.935	0.083	0.977	0.035	0.351
X ₁ ²	1	6.87	0.146	15.88	0.002*	0.0004	0.988	1050	0.011*	0.100	0.129
X ₂ ²	1	43.26	0.005*	0.260	0.573	18.41	0.013*	4.13	0.836	0.370	0.014*
Residual	7	18.02		5.22		11.76		627.2		0.240	
Lack of Fit	3	8.22	0.440	4.30	0.054	1.60	0.884	626.4	<0.0001*	0.150	0.242
Pure Error	4	9.8		0.91		10.15		0.79		0.094	
Total	12	158.7		73.8		134.1		3422		1.320

Fig. 2 Calculated effects of process variables; cooking temperature and cooking time on Soluble solid content, HMF, reducing sugar and total sugar content of vacuum cooked strawberry jam

values determined to be similar to the data presented in the literature. pH values of strawberry jam were found to be ranged between 3.63 and 3.81. The results showed that the soluble solid contents of the strawberry jam increased with

increasing cooking time. Although cooking time was the main parameter affecting the soluble solid content of strawberry jam, a slight increase in the soluble solid content was also identified with increasing vacuum cooking

Fig. 3 Calculated effects of process variables; cooking temperature and cooking time on a^* , b^* , Hue value and C^* value of vacuum cooked strawberry jam

temperature. The importance of the soluble solid content in jam products was explained by Üstün and Tosun (1998) that the microbiological stability of jam was not only associated with hygienic production conditions but also it was closely related with the total soluble solid content of jam. In Turkish jam standard, total soluble solid content determined by refractometer should not be <60% in jam. The maximum The soluble solid content was obtained at the temperature of 75 °C and for 17.5 min., whereas the minimum The soluble solid content was at the temperature of 75 °C and for 10 min (Table 1).

Sugar which is one of the main ingredients in jam processing provides the formation of rheological behavior of jam. It does not only help to extend the shelf-life, but also enhances taste and forms the texture of the jam. However, using high amount of sugar resulted in re-crystallization which was one of the main problems in jam (Ahmed Khan et al. 2016). As given in Table 1, reducing sugar content of vacuum cooked strawberry jam has been found to increase with increasing cooking time and ranged between 7.53 and 16.55%, while the total sugar content varied between 40.81 and 52.35%.

The rate of crystallization can be determined from amount of reducing sugar and total sugar content of jams. Gülpek and Başoğlu (1989) reported that reducing sugar should be formed from 30 to 35% of the total sugar in jams to avoid crystallization problem. When the vacuum cooked jams were evaluated in terms of preventing crystallization, inversion was found to be insufficient due to the cooking process applied at low temperature and the short-term except for the jams cooked at 85.6 °C–22.8 min and 90 °C–17.5 min under vacuum (Table 1). According to the results of ANOVA (Table 3), the effect of cooking temperature and time on the reducing sugar content of the strawberry jam was found to be significant ($p < 0.05$). Total sugar content of the strawberry jam was also found to be significantly affected by both temperature and time ($p < 0.05$).

HMF content was also another important parameter for jam production. HMF was generally used as an indicator for the applied heat treatment or long-term storage especially in sugar rich foods, since formation of HMF was mostly occurred under acidic conditions (Sadilova et al. 2009). HMF is not just an indicator for heat treatment, also

its potential carcinogenic properties to human health has been widely studied (Hidalgo and Pompei 2000).

In this study, HMF content of the strawberry jams produced at different process conditions changed between 11.98 and 74.96 mg/kg (Table 1). HMF content of the strawberry jams increased with increasing vacuum cooking temperature. However, there were no food standard for HMF content of jams, in Turkish literature it has been noted that HMF content of 1st class and 2nd class jams recommended not to exceed the level of 50 mg/kg and 100 mg/kg, respectively. Only one sample cooked at 90 °C for 17.5 min did not meet the limitations of the 1st class jams (74.96 mg/kg), although HMF content of all other jams was under the 1st class jams limit (<50 mg/kg). Vorlová et al. (2006) stated that heat process required for extending the shelf-life leads to formation of HMF especially in ketchups, jams and tomato purées. Maillard reactions and caramelization occurred with increasing of the temperature, particularly in the presence of high carbohydrate content at low pH values (Rada-Mendoza et al. 2002a). In order to determine the dependence of the HMF concentration on total soluble content, a correlation was found as $r = 0.959$. As seen in Fig. 2, increase in cooking temperature and time resulted higher total soluble content and that caused to increase in formation of HMF in the product. Besides, cooking temperature were found to be most effective parameter on the HMF content in the product (Fig. 2). In contrast, Flores and del Castillo (2016) reported that longer heating process causes much more formation of HMF than the higher temperatures.

Sensory evaluation was conducted to test the consumer's acceptance on the sensory properties of vacuum cooked strawberry jam in terms of appearance (remain undeformed of the whole grain), color, consistency in spoon (fluidity), taste and overall preference. In sugar products like jam, consistency is one of the most important criteria that has an effect on consumer's acceptance or rejection of food. Because even if the visible properties such as color and odor which are the first evaluable properties by human senses is acceptable, a jam with low viscosity is not acceptable by consumers. For this reason, consistency in spoon criteria was selected to evaluate the fluid behavior of jam in terms of consumer's acceptance. It was observed that vacuum cooking time was the most effective independent variable on the consistency in spoon values (Table 3). Due to the increase in the soluble solid content of strawberry jam with vacuum cooking time, higher consistency in spoon scores were obtained in panel. On the other hand, lower consistency in spoon results were given as a result of increasing viscous structure of jam with increasing cooking temperature after 75 °C by panelists. Consistency in spoon scores got the maximum value of 4.32 at 75 °C and 25 min (Table 1).

Regarding to ANOVA analysis (Table 3) and considering that sensory evaluation is a subjective assessment, except for the consistency in spoon scores, effect of vacuum cooking conditions (temperature and time) on appearance, color, taste and overall acceptance were found to be statistically insignificant ($p > 0.05$). In addition, it was determined that only consistency in spoon scores were in compliance with the quadratic model ($p < 0.05$). So, other sensory properties such as appearance, color, taste and overall acceptance results had been not evaluated and mentioned in this paper due to the lack of their statistically importance.

Optimization

The optimum vacuum cooking process conditions in terms of cooking temperature and time were determined with targeting the maximum Soluble solid content and consistency in spoon score and minimum HMF content (mg/kg) and Hue value. The optimization procedure was performed with Design Expert-version 7.0 software (Stat-Ease Inc., MN, USA).

Second-order polynomial model was used for each response for determining the optimum point. The desirability function approach was applied to obtain the optimum point solution given in Table 4. For optimum point of cooking temperature and cooking time was found to be 74.4 °C and 19.8 min. The Soluble solid content, Hue value, HMF content (mg/kg) and consistency in spoon score at the optimum conditions were predicted as 59.23%, 31.48°, 14.63 mg/kg and 4.26, respectively.

The results of the five validation experiments at optimum vacuum cooking conditions were also given in Table 4, comparatively as average results and the estimated values. Only the Soluble solid content of the obtained samples were found to be not significantly ($p > 0.05$) different from the predicted values determined by Design Expert, however Hue value, HMF content (mg/kg) and consistency in spoon scores were found to be significantly ($p < 0.05$) different. Consistency in spoon scores in the optimum point were found to be higher than the predicted value, this indicates a considerable increase in positive way.

Conclusion

In our study, a vacuum cooking equipment prototype was developed and the performance of the developed device was tested on strawberry jam production. Effect of vacuum cooking independent variables (temperature and time) on strawberry jam production was investigated according to CCRD experimental design. Also, vacuum cooking process conditions in terms of cooking temperature and time were optimized to produce strawberry jam with targeting maximum Soluble solid content and

Table 4 Results of statistical analysis for verification the optimization results

Responses	Predicted value	Experimental value ^a	SE ^b	Difference	% Error ^c	p value
SSC (%)	59.23	59.00 ± 2.24	1.000	−0.230	0.39	0.829
Hue (°)	31.48	28.18 ± 0.53	0.237	−3.294	11.69	0.000
HMF (mg/kg)	14.73	17.51 ± 0.37	0.166	2.784	15.90	0.000
CS	4.26	4.61 ± 0.88	0.039	0.352	7.64	0.001

^a Experimental values were given as mean ± standard deviation^b Mean standard error^c % Error = $(|y_{exp} - y_{pre}| / y_{exp}) * 100$

consistency in spoon scores and minimum Hue value and HMF (mg/kg) content. Vacuum cooking process ensured the protection of appearance and color properties close to the fresh fruit and soluble dry matter of obtained jam that indicates the consistency and shelf-life was found to be similar to jam cooked with conventional method. The encountered problems, when targeted to achieve the desired dry matter content in jam production at home, such as high HMF content, darkening of color and long processing time were eliminated with this developed prototype. As a conclusion, developed vacuum cooking equipment prototype could help consumers to prepare the jam under vacuum.

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