



Optimized Microwave-Assisted Blanching of Fresh Tomatoes (*Solanum lycopersicum* L.)

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ABSTRACT

Research was conducted to discover the ideal microwave blanching parameters for producing high-quality tomatoes. The experiment employed response surface methodology (RSM) with Box Behnken Design (BBD) and consisted of 17 treatments; each treatment combination was tested in duplicate. The independent variables were power (W) (X1), time (sec) (X2), and blanching water (mL) (X3). The experimental results were analyzed using ANOVA, and the optimization process was carried out and verified. The best treatment outcomes were obtained using a combination of 200 W power, 120 sec duration, and 450 mL of blanching water. After validation, the optimal yield response was 100.01%, with total soluble solids at 3.6 °Brix, vitamin C at 154 mg/100 g, and total tomato carotene at 3.3 mg/100 g. Overall, these data have a 95% confidence interval ranging from low to high.

Keywords: blanching, microwave-assisted, optimization, response surface methodology, tomatoes

INTRODUCTION

Tomatoes (*Solanum lycopersicum* L.) are among the most popular fruit vegetables, having a significant economic worth. Tomatoes contain vital nutrients and antioxidants for human health and illness prevention (Rahmadani *et al.* 2021). 100 g of tomato contains 1500 IU of vitamin A (carotene), 60 mg of vitamin B (thiamine), 40 mg of vitamin C, 27 mg of phosphorus, 1 g of protein, 4.2 g of carbohydrates, 0.3 g of fat, 5 mg of calcium, and 0.5 mg of iron (Mardaus *et al.* 2019). Tomatoes are quite perishable. This is owing to their high-water content, which amounts to 94% of their entire weight (Ashadi *et al.* 2021). According to John *et al.* (2020), tomatoes collected at the red ripening stage of 10–20% can only be stored at room temperature for four days. Based on this, pretreatment of tomatoes is a key step in preserving quality. Blanching is one approach that can be employed.

Blanching is a brief heat treatment designed to suppress enzyme activity, reduce microbial burden, maintain color, and aid in skin peeling (Saidi 2019). Blanching is also used to protect nutritional quality and make following processing procedures faster and more effective. Water blanching and steam blanching are traditional blanching processes widely utilized in the food processing sector. However, these technologies have drawbacks, such as taking more time and energy (Nguyen *et al.* 2019).

Advances in the food business promote the adoption of novel procedures that are more efficient and capable of inactivating enzymes with minimum impact on texture, flavor, and nutritional alterations (Başkaya & Demirdöven 2015). Microwave blanching is a modern blanching technique that can be used as an alternative. This approach employs high-frequency electromagnetic waves to rapidly and uniformly heat food items (Hanif *et al.* 2021). Microwave blanching is three times faster than conventional procedures. However, this method has some disadvantages, such as difficulty managing temperature and heating duration, as well as the possibility of hot areas that cause overcooking. Higher temperatures or longer treatment durations have a negative impact on the product, including flavor and texture loss, color alterations, and vitamin and nutrient deterioration (Başkaya & Demirdöven 2015). The purpose of this study was to discover the optimal microwave-assisted blanching settings for producing high-quality tomatoes utilizing response surface method (RSM).

METHODS

Research Period

The study was carried out from December 2023 to February 2024 at the Laboratory of Technology and Industrial Environmental Engineering, Faculty of Agricultural Technology, University of Jember.

Materials and Tools

The major ingredient was tomatoes sourced from Tanjung Market in Jember. Other supporting materials

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were water, distilled water, starch indicator solution (1%), iodine solution 0.01 N, technical *n*-hexane, and buffer solutions with pH 4, 7, and 9. Design Expert 13 application, digital balance, knife, mortar and pestle, measuring cylinder, beaker glasses, spatula, Erlenmeyer flask, LG MC8188HRC microwave oven, aluminum foil, plastic clip (LDPE), drop pipette, UV-Vis spectrophotometer, pH meter, color reader, refractometer, and refrigerator were all used.

Procedures

The blanching conditions were optimized utilizing the DX-13 (Design Expert 13) application and the Response Surface Methodology (RSM) approach, which employed Box Behnken Design (BBD). The independent variables used were adapted from the studies of Başkaya & Demirdöven (2015) and Nguyen *et al.* (2019), which were modified as follows: power (W) (X1) with a minimum value limit of 200 W and a maximum value limit of 600 W, blanching time (X2) with a minimum value limit of 20 sec and a maximum value limit of 120 sec, and blanching water volume (X3) with a minimum value limit of 150 mL and a maximum value limit of 450 mL (Table 1).

The microwave power range was chosen because it is often used in fruit and vegetable blanching research to inactivate enzymes while preserving sensory quality (Başkaya & Demirdöven 2015). The blanching time of 20–120 sec was chosen because too short a time is ineffective in deactivating enzymes, and too lengthy a time can harm sensory and nutritional quality (Nguyen *et al.* 2019). The water volume of

150–450 mL was utilized to ensure that the sample had even contact with water while being energy efficient and preventing excessive nutrient leaching (Quaye *et al.* 2022). There were 17 experimental treatments tested (Table 2). The acquired data was then entered into the DX-13 application for ANOVA. After analyzing all responses, an optimization process was performed. The optimization findings were then checked to verify they matched the application's projected results.

Yield Determination

The yield was calculated by weighing the tomato fruit before and after blanching using the following formula (Syamsul *et al.* 2020):

$$\text{Yield (\%)} = \frac{\text{Weight after blanching (g)}}{\text{Initial weight (g)}} \times 100\%$$

Total Soluble Solids Measurement

The total soluble solids (TSS) were determined using a refractometer. A 1–2 mL sample of tomato juice was put onto the refractometer prism, and the °Brix was determined. The reported °Brix value indicates the soluble solids in the solution (Wahyuni *et al.* 2021).

Vitamin C Content Analysis

The measurement of vitamin C levels was carried out using the titration method (Amelia 2016). The formula for calculating vitamin C was as follows:

$$\% \text{ Vitamin C} = \frac{\text{Vol } I_2 \times 0,88 \times Fp}{W \text{ Sample (g)}} \times 100\%$$

Table 1 Variables of tomato blanching treatment

Variable	Symbol	Level		
		-1	0	+1
Microwave power (W)	X1	200	400	600
Blanching time (sec)	X2	20	70	120
Blanching water (mL)	X3	150	300	450

Table 2 Optimization of microwave power, blanching time, and blanching water volume of tomatoes

Treatment	Coded variables			Microwave power (W)	Blanching time (sec)	Blanching water (mL)
	X1	X2	X3			
1	0	0	0	400	70	300
2	1	0	1	600	70	450
3	1	-1	0	600	20	300
4	0	-1	-1	400	20	150
5	0	0	0	400	70	300
6	0	-1	1	400	20	450
7	-1	1	0	200	120	300
8	0	1	-1	400	120	150
9	-1	-1	0	200	20	300
10	1	0	-1	600	70	150
11	0	0	0	400	70	300
12	0	0	0	400	70	300
13	-1	0	-1	200	70	150
14	0	0	0	400	70	300
15	-1	0	1	200	70	450
16	1	1	0	600	120	300
17	0	1	1	400	120	450

where:

- Vol I₂ = Volume of iodine (mL)
- 0.88 = 0.88 mg of vitamin C is equivalent to 1 mL of I₂ 0.01 N solution
- Fp = Dilution factor
- Ws = Sample weight (g)

Total Carotenoid Content Analysis

The measurement of total carotenoids was carried out using a spectrophotometer at a wavelength of 446 nm (Novita *et al.* 2015). Total carotenoids were calculated using the following equation:

$$\text{Total carotenoid (ppm)} = \frac{(25 \times (a - b) \times 383)}{100 \times W}$$

where

- A = Absorbance of the sample
- B = Absorbance of the blank
- W = Sample weight (g)

RESULTS AND DISCUSSION

Yield

The yield obtained ranged from 99.66% to 100.03%. According to the findings of the analysis of variance (ANOVA) (Table 3), the *F*-value was 18.15, suggesting that the model was significant. This demonstrates that each variable (microwave power, blanching duration, and blanching water) had a significant impact on yield. The ANOVA test's *p*-value was less than 0.0500, indicating statistical significance. The model's *p*-value (<0.0001) demonstrates its significance. The obtained lack of fit *F*-value (1.36) was non-significant. A non-significant lack of fit suggests that the model utilized matches the yield response data (Zakaria *et al.* 2021).

The suggested prediction model is linear (Table 4). The *R*² value of 0.8073 shows that the effect of microwave power, blanching duration, and blanching water on the yield response was 80.73%, with the

remaining 12.27% due to other factors not included in the model. The corrected *R*² value (0.7628) and projected *R*² value (0.6434) differed by 0.1194, indicating a positive outcome. According to Hanif *et al.* (2021), a discrepancy of less than 0.2 between adjusted and projected *R*² is considered acceptable. The mathematical model equation for the link between the three factors to optimize yield as a response is shown below.

$$\text{Yield (\%)} = 99,88 - 0,1*A - 0,04*B + 0,06*C$$

where

- A = Microwave power
- B = Blanching time
- C = Blanching water

The given equation has negative coefficient values for variables A and B and a positive coefficient for variable C. This suggests that increasing microwave power and blanching duration reduces yield, whereas increasing water volume enhances yield. This means that using more water during the blanching process can assist maintain tomato mass stability, whereas using too much heat may induce weight loss owing to evaporation or tissue softening.

The 3D plot graph of the yield response is typically linear in shape (Figure 1). The results demonstrate that the yield increases as the microwave power and blanching time decrease. Treatment 9 (200 W, 20 sec blanching time, and 300 mL blanching water) had the highest yield, 100.3%. Meanwhile, treatment 16 (600 W, 120 sec blanching duration, and 300 mL blanching water) had the lowest yield at 99.66%. The low microwave power and short blanching duration provide for enough time to blanch the tomatoes without harming them. This is consistent with the findings of Kusumiyati *et al.* (2018), that softening of fruit held at higher temperatures happens quickly due to internal disintegration during respiration. Polysaccharide degradation during respiration softens the fruit and

Table 3 ANOVA response on yield

Source	Sum of squares	df	Mean square	F-value	P-value	
Model	0.1314	3	0.0438	18.15	< 0.0001	Significant
A: Microwave power	0.08	1	0.08	33.15	< 0.0001	
B: Blanching time	0.0136	1	0.0136	5.64	0.0336	
C: Blanching water	0.0378	1	0.0378	15.67	0.0016	
Residual	0.0314	13	0.0024			
Lack of fit	0.0237	9	0.0026	1.36	0.4088	Not significant
Pure error	0.0077	4	0.0019			
Cor total	0,1628	16				

Table 4 Model summary statistics of yield response

Source	Std. dev.	R ²	Adjusted R ²	Predicted R ²	PRESS	
Linear	0.0491	0.8073	0.7628	0.6434	0.0581	Suggested
2FI	0.0514	0.8375	0.74	0.3598	0.1042	
Quadratic	0.0524	0.8818	0.7298	-0.2068	0.1965	
Cubic	0.0439	0.9526	0.8103		*	Aliased

breaks down cell wall molecules, which were initially insoluble protopectin, into soluble pectin.

The amount of blanching water utilized had an impact on yield, but it was not substantial. Yield value comparisons can be seen in several treatments with the same power and time combination but different amounts of water used, such as treatment 2 (99.9%) compared to treatment 10 (99.78%); treatment 4 (99.77%) compared to treatment 6 (99.99%); treatment 8 (99.76%) compared to treatment 17 (99.89%); and treatment 13 (99%) compared to treatment 15 (100.2%). The more water used, the greater the area is in direct touch with the material. According to Sabahannur *et al.* (2023), boiling brings food into direct touch with water, weakening its linkages. This increases yield because water may more easily enter the food material.

The yield percentages of 100.02% in treatment 15 (200 W, 70 sec, and 450 mL blanching water) and 100.03% in treatment 9 demonstrate that the tomatoes weighed more after blanching than before. This occurred during immersion in cold water following blanching, where water was absorbed via osmosis. Osmosis is the diffusion of water through a semi-permeable membrane. Water travels from a low-pressure location to a high-pressure area (Kaur *et al.*

2024). Blanching treatment reduces yield, indicating a drop in tomato quality. Lower yield implies mass loss due to water evaporation, tissue softening, and degradation of cell wall components, which reduces the physical quality and freshness of tomato.

TSS (Total Soluble Solids)

The TSS value of tomatoes ranged from 3.43 to 4.02 °Brix. This finding is consistent with recent research conducted by Khathir *et al.* (2019), that the TSS value of tomatoes ranged from 3.3 to 4.4 °Brix. Another study by Sholeha *et al.* (2015) found similar results, noting that the TSS value of fresh tomatoes ranged from 3.5 to 5.5 °Brix. The analysis of variance (ANOVA) results (Table 5) revealed that the *F*-value was 217.19 (significant). The model's *p*-value was less than 0.0001, indicating significance. Meanwhile, the *F*-value for the model's lack of fit was 1.45, indicating that it was not statistically significant. The ANOVA test utilized a significance threshold of 5% (0.0500), and the model's lack of fit result was not significant (Ashshiddiqi *et al.* 2019).

The suggested model method was linear (Table 6). The R^2 result of 0.9804 indicates that microwave power, blanching duration, and blanching water had a 98.04% influence on the TSS reaction, with the

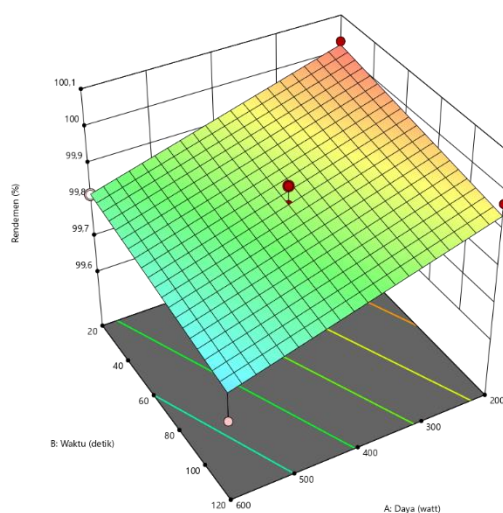


Figure 1 3D Plot of yield.

Table 5 ANOVA response of Total Soluble Solids (TSS)

Source	Sum of squares	df	Mean square	F-value	P-value	
Model	0.3251	3	0.1084	217.19	< 0.0001	Significant
A: Microwave power	0.2415	1	0.2415	484.01	< 0.0001	
B: Blanching time	0.08	1	0.08	160.33	< 0.0001	
C: Blanching water	0.0036	1	0.0036	7.24	0.0185	
Residual	0.0065	13	0.0005			
Lack of fit	0.005	9	0.0006	1.45	0.3821	Not significant
Pure error	0.0015	4	0.0004			
Cor total	0.3316	16				

remaining 1.96% driven by non-model factors. The R^2 number indicates how much independent variables influence the response value. According to Hanif *et al.* (2021), the model performs better when the R^2 value is close to 1. The adjusted R^2 (0.9759) and anticipated R^2 (0.9635) values showed a 0.0124 difference, indicating a positive outcome. According to Hanif *et al.* (2021), if the gap between adjusted and anticipated R^2 is lower than 0.2, the predicted R^2 value can improve the adjusted R^2 value. The mathematical model equation for optimizing the TSS response based on microwave power, blanching time, and blanching water is shown below.

$$TSS (\%) = 3,72 + 0,17*A + 0,1*B - 0,02*C$$

where

A = Microwave power

B = Blanching time

C = Blanching water

The preceding equation has positive coefficient values for variables A and B, but a negative coefficient for variable C. This means that the higher the power and blanching time, as well as the usage of less water, the higher the TSS value. The 3D plot graph for the TSS response has a linear form (Figure 2). This result indicates that the higher the power and blanching duration, the greater the TSS value produced. Treatment 16 (600 W, 120 sec, and 300 mL water) produced the highest TSS value of 4.04 °Brix. Meanwhile, treatment 9 with 3.43 °Brix, which used 200 W, 20 sec, and 300 mL of blanching water, had the

lowest TSS result. Longer cooking time and increased microwave power resulted in the breakdown of complex chemicals in tomatoes into more soluble forms. This is consistent with Fitriani *et al.* (2022), that the higher the applied temperature, the higher the respiration rate produced. The sugar content of tomatoes increases throughout the respiration process as starch (carbohydrates) is digested into simple sugars like glucose and fructose.

The volume of blanching water decreases as the TSS value increases. The more water is utilized, the longer it takes for heat energy to get from the water to the tomatoes. This is consistent with Fitriani *et al.* (2022), that water with a lower volume absorbs more heat. This notion is supported by Yunita & Rahmawati (2015), that the TSS value increases with higher temperature and longer processing time. This is related to a drop in product moisture content. Higher temperatures and longer processing times allow more water to evaporate, increasing the product's total solids. Changes in TSS value owing to blanching treatment indicate a decline in tomato quality. Unstable TSS values reflect fluctuations in the levels of simple sugars and water in the tissue, which affects the tomatoes' taste, freshness, and overall quality.

Vitamin C

The vitamin C content of tomatoes ranged from 127.6 to 167.2 mg/100 g. Yunita & Rahmawati (2015) findings of this investigation indicate that vitamin C content reduced during the blanching process. The vitamin C content in fresh tomatoes ranged between

Table 6 Model summary statistics of Total Soluble Solids (TSS) response

Source	Std. dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	0.0223	0.9804	0.9759	0.9635	0.0121	<i>Suggested</i>
2FI	0.0235	0.9833	0.9733	0.9328	0.0223	
Quadratic	0.0233	0.9886	0.9738	0.8831	0.0388	
Cubic	0.0195	0.9954	0.9817		*	<i>Aliased</i>

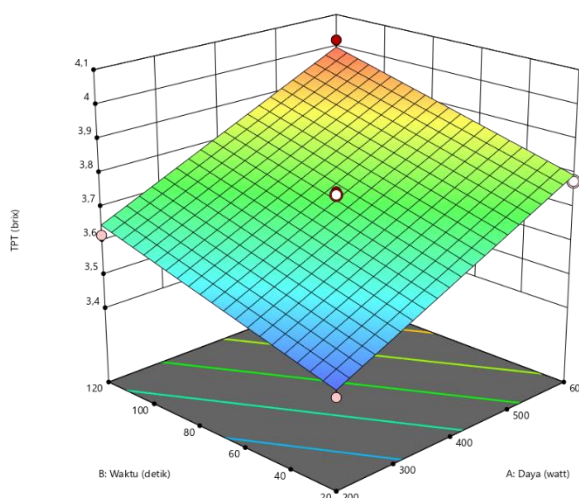


Figure 2 3D Plot of Total Soluble Solids (TSS).

217.31 and 257.31 mg/100 g. The ANOVA test (Table 7) revealed that the model was significant, with an *F*-value of 17.89. The model's *p*-value was 0.0005, indicating significance. Meanwhile, the *F*-value for lack of fitness in the model was 8.56, indicating that it was not significant. The ANOVA test utilized a 5% significance threshold (0.0500), and the model's lack of fit resulted in no significant results (Zewide *et al.* 2025).

The preferred predictive model designs were linear and quadratic (Table 8). The quadratic model was chosen based on the results in Table 7, which revealed three quadratic variables. According to Hanif *et al.* (2021), a difference of less than 0.2 between adjusted and projected *R*² is considered satisfactory. Based on this, the difference of 0.1632 suggests that the resulting model was satisfactory. The *R*² value (0.8514) suggests that the influence of microwave power, blanching duration, and blanching water on the response of TSS was 85.14%, with the remaining 14.86% explained by non-model parameters. The mathematical model equation defining the link between the three factors to optimize vitamin C content as a reaction is shown below.

$$\text{Vitamin C (mg/100 g)} = 144,32 - 6,3*A - 10,4*B + 7,5*C - 0,5 *AB + 1,1*AC + 1,7*BC + 4,79*A^2 + 4,39*B^2 - 0,61 C^2$$

where

A = Microwave power

B = Blanching time

C = Blanching water

The equation above indicates that variables A and B have negative coefficient values, while variable C has a positive coefficient. This indicates that the higher the power, the longer the blanching time, and the less water used, the lower the vitamin C level.

The 3D plot response for vitamin C demonstrates that lower microwave power and shorter blanching time result in higher vitamin C content (Figure 3). Treatment 9 (200 W, 20 sec, 300 mL water) had the highest vitamin C content, measuring 167.2 mg/100 g. The lowest value was 127.6 mg/100 g in treatment 8 (400 W, 120 sec, 150 mL water). This finding suggests that vitamin C is extremely sensitive to heat and heating

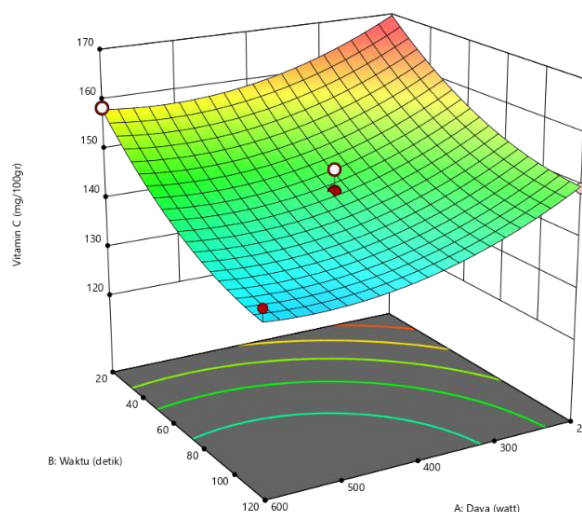


Figure 3 3D Plot of Vitamin C.

Table 7 ANOVA response of vitamin C

Source	Sum of squares	df	Mean square	<i>F</i> -value	<i>P</i> -value	
Model	1837.83	9	204.2	17.89	0.0005	<i>Significant</i>
A: Microwave power	317.52	1	317.52	27.82	0.0012	
B: Blanching time	865.28	1	865.28	75.82	< 0.0001	
C: Blanching water	450	1	450	39.43	0.0004	
AB	1	1	1	0.0876	0.7758	
AC	4.84	1	4.84	0.4241	0.5357	
BC	11.56	1	11.56	1.01	0.3477	
A ²	96.61	1	96.61	8.46	0.0227	
B ²	81.15	1	81.15	7.11	0.0322	
C ²	1.57	1	1.57	0.1373	0.722	
Residual	79.89	7	11.41			
Lack of fit	25.68	3	8.56	0.6316	0.6322	<i>Not significant</i>
Pure error	54.21	4	13.55			
Cor total	1917.72	16				

Table 8 Model summary statistics of vitamin C response

Source	Std. dev.	<i>R</i> ²	Adjusted <i>R</i> ²	Predicted <i>R</i> ²	<i>PRESS</i>	
Linear	4.68	0.8514	0.8171	0.7572	465.72	<i>Suggested</i>
2FI	5.17	0.8605	0.7768	0.5666	831.14	
Quadratic	3.38	0.9583	0.9048	0.7416	495.58	<i>Suggested</i>
Cubic	3.68	0.9717	0.8869		*	<i>Aliased</i>

duration. At high temperatures, ascorbic acid is unstable and readily degraded. Vitamin C's reactive and unstable nature allows it to rapidly oxidize into dehydroascorbic acid after heating, according to Dewi (2019).

Based on the findings, blanching time had the largest impact. This is demonstrated by the highest *F*-value (75.82) and the lowest *p*-value (<0.0001) (Table 7). Vitamin C levels decreased dramatically with longer blanching durations and lesser quantities of water. This combination generates high temperatures that stay longer, hastening ascorbic acid breakdown. According to the research conducted by Icha (2022), quick heating is more successful in maintaining heat-sensitive chemicals than medium-temperature heating with longer durations, because prolonged time increases the possibility for degradation. This can be seen in treatment 16 (600 W, 120 sec, 300 mL) against treatment 8 (600 W, 120 sec, 150 mL), where a large water volume necessitated more heat energy and a longer heating time. Microwave blanching reduces vitamin C concentration, indicating a drop in tomato quality. This is because vitamin C is a key predictor of tomato freshness, nutritional content, and antioxidant activity. Thus, lower vitamin C levels indicate lesser tomato quality.

Total Carotene

The total carotene concentration of tomatoes was found to range between 1.63 and 4.6 mg/100 g. When compared to standard blanching treatment, monoclonal antibody (MAb) in tomatoes was able to limit the reduction in total carotene content. Lilik *et al.* (2014) found that the total carotene concentration in

tomatoes after standard blanching was 1.376 mg/100 g. According to Perveen *et al.* (2015), the total carotenoid concentration of fresh tomatoes ranges between 3.0 and 7.0 mg/100 g. Based on this, the total carotene concentration in tomatoes after microwave blanching is higher than the conventional approach.

The ANOVA (Table 9) showed that the *F*-value of 34.38 indicates the model is significant. The *p*-value of the model is < 0.0001 (significant). Meanwhile, the *F*-value for lack of fit in the model was 6.23, showing that this value is not significant. The significance level used in the ANOVA test is 5% (0.0500), and the lack of fit result of the model was not significant (Zhang *et al.* 2024).

The suggested prediction model pattern is quadratic (Table 10). The *R*² value (0.9779) suggests that the effect of microwave power, blanching duration, and blanching water on the response of total carotene value is 97.79%, with the remaining 2.21% owing to unaccounted-for factors. The *R*² value indicates how much the combination of independent factors influences the response value. The model improves as the *R*² value approaches 1. The mathematical model equation for the relationship between the three variables to optimize the total carotene value as a response is shown below.

$$\begin{aligned} \text{Total carotene (mg/100 g)} = & 2,82 + 0,65*A + 0,93*B - \\ & 0,22*C + 0,21 *AB - \\ & 0,09*AC - 0,025*BC + \\ & 0,027*A^2 - 0,04*A^2 + \\ & 0,46 C^2 \end{aligned}$$

where
A = Microwave power

Table 9 ANOVA response of total carotene

Source	Sum of squares	df	Mean square	F-value	P-value		
Model	11.96	9	1.33	34.38	< 0.0001	Significant	
A: Microwave power	3.46	1	3.46	89.44	< 0.0001		
B: Blanching time	6.96	1	6.96	179.91	< 0.0001		
C: Blanching water	0.414	1	0.414	10.71	0.0136		
AB	0.1849	1	0.1849	4.78	0.065		
AC	0.0361	1	0.0361	0.9336	0.3661		
BC	0.0025	1	0.0025	0.0647	0.8066		
A ²	0.0031	1	0.0031	0.0794	0.7863		
B ²	0.0078	1	0.0078	0.2013	0.6672		
C ²	0.8987	1	0.8987	23.24	0.0019		
Residual	0.2707	7	0.0387				
Lack of fit	0.2229	3	0.0743	6.23	0.0547		Not significant
Pure error	0.0477	4	0.0119				
Cor total	12.23	16					

Table 10 Model summary statistics of total carotene response

Source	Std. dev.	R ²	Adjusted R ²	Predicted R ²	PRESS	
Linear	0.3288	0.8852	0.8586	0.7807	2.68	
2FI	0.3437	0.9034	0.8455	0.5916	5	
Quadratic	0.1966	0.9779	0.9494	0.7023	3.64	Suggested Aliased
Cubic	0.1092	0.9961	0.9844		*	

B = Blanching time
C = Blanching water

The above equation has positive coefficient values for variables A and B and negative coefficients for variable C. This indicates that the higher the power, the longer the blanching time, and the less water utilized, the higher the total carotene content.

The 3D response plot of total carotene demonstrates that the higher the microwave power and the longer the blanching time, the higher the total carotene content (Figure 4). Treatment 8 (400 W, blanching period 120 sec, blanching water 150 mL) had the highest total carotene content (4.6 mg/100 g). Meanwhile, treatment 9 (200 W, 20 sec, and 300 mL water) had the lowest total carotene level, measuring 1.63 mg/100 g. Lycopene is among the most abundant carotenoids found in tomatoes. Heating damages cell walls and plastid membranes, namely chromoplasts, which store carotenoid compounds like lycopene and β -carotene, leading to an increase in carotene concentration. This technique allows carotenoids to be released from the lipid matrix and measured in their free form. According to Salingkat *et al.* (2020), carotenoid content rises during respiration and ripening but tends to plateau at advanced maturity. However, excessive heating might result in carotenoid loss via isomerization and oxidation (Hasri 2015), therefore temperature and duration control are critical.

Water volume is inversely related to heat transfer from water to material. This can be observed in treatment 16, which had the maximum power combination of 600 W for 120 sec, yet consumed less

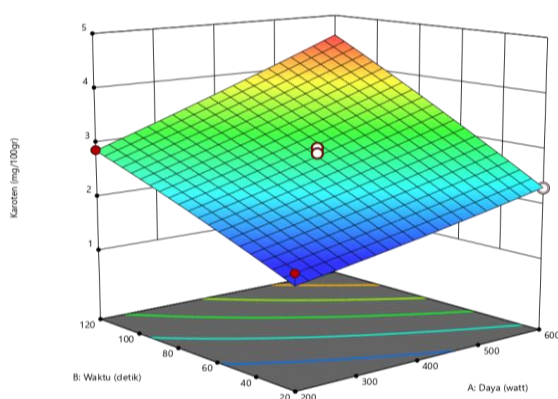


Figure 4 3D Plot of total carotene.

water than treatment 8. The more blanching water is used, the more energy is necessary to heat the material. This is consistent with Rosari *et al.* (2014), that using less water reduces the necessary heat capacity and causes the water temperature to rise faster. Blanching treatment reduces total carotene levels, indicating a decline in tomato quality. Carotene, particularly lycopene, is a significant red color as well as a bioactive molecule with antioxidant activity; thus, a decrease in carotene content affects the visual, nutritional, and functional quality of tomatoes.

Blanching Optimization

The DX-13 optimization results showed that the anticipated most optimal parameters for tomato blanching were 200 W, 120 sec, and 450 mL of water. This formula solution was chosen based on the highest attractiveness value, 0.716 (71.6%). This is consistent with Prabudi *et al.* (2018) finding, that the desirability value shows the amount to which specified criteria are met, resulting in a product of expected quality. The optimization model will be more accurate as the value approaches one.

Verification of Optimum Blanching

The adjusted formulation was then confirmed by two repetitions. The verification results under optimal conditions showed a yield response value of 100.01%, a TSS response value of 3.6 °Brix, a vitamin C content response value of 154 mg/100 g, and a total carotene content response value of 3.3 mg/100 g. All microwave blanching verification data remained within the 95% confidence interval (CI) low to high (Table 11).

The optimal condition was achieved through a combination of microwave power, time, and water volume, which collectively regulate the intensity of heating: appropriate power accelerates heat penetration to inactivate enzymes such as polyphenol oxidase and peroxidase; controlled time prevents vitamin C degradation; and water volume keeps the temperature stable. Overall, this approach preserves yield, reduces nutrient loss, and maintains tomato quality.

CONCLUSION

The optimal treatment solution found by RSM utilizing DX-13 software was 200 W, 120 sec, and 450 mL water. Following the validation process, the optimal

Table 11 Verification of optimum formula solution

Response	Prediction	Verification	95% CI		95% PI	
			Low	High	Low	High
Yield (%)	100	100.01	99.93	100.07	99.76	100.25
TSS (°Brix)	3.62	3.6	3.59	3.66	3.51	3.74
Vitamin C (mg/100 g)	157.39	154	148.06	166.71	133.64	181.35
Total carotene (mg/100 g)	3.17	3.3	2.59	3.75	1.69	4.65

values were yielding response of 100.01%, vitamin C response of 154 mg/100 g, and total carotene response of tomatoes of 3.3 mg/100 g. All these results fell within the 95% confidence intervals for low and high. This suggests that the DX-13 solution can be used for tomato blanching to reduce the potential impact of quality deterioration.

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