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Optimization of Hot Water Treatment in Red Dragon Fruit Using Response Surface Methodology

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ABSTRACT

Red-fleshed dragon fruit is recognized as a superfruit because of its betacyanin content, a natural pigment with antioxidant properties. However, the fruit is highly perishable after harvest, requiring effective postharvest handling, such as Hot Water Treatment (HWT). This study aimed to determine the optimum combination of temperature, immersion time, and maturity index using Response Surface Methodology (RSM) with a Box-Behnken Design. The optimized quality parameters included lightness value (L*), total soluble solids (TSS), betacyanin content, and vitamin C content. The optimum conditions were found to be 50°C for 15 min at maturity index IV, achieving a desirability of 0.885. The predicted model values were 28.40 (L*), 13.5 °Brix (TSS), 56.44 mg/L (betacyanin), and 3.53 mg/100 g (vitamin C). Validation of the optimal treatment revealed that only the quality attributes of total soluble solids (13.1 °Brix) and vitamin C (3.36 mg/100 g) were in close agreement with the predicted model values. In contrast, the model demonstrated lower predictive accuracy for lightness *(L*)* and betacyanin content.

Keywords: **Box-Behnken Design, dragon fruit, hot water treatment, response surface methodology**

INTRODUCTION

Dragon fruit is a tropical plant classified as a horticultural commodity that grows well in Indonesia and is widely cultivated. Consumer interest in dragon fruit has increased owing to its rich nutritional composition and high antioxidant content. According to Lata *et al.* (2022), dragon fruit can be considered a superfruit because the red flesh is rich in betalain compounds, which act as both natural pigments and valuable sources of antioxidants. Dragon fruit is categorized as a non-climacteric fruit because it produces relatively low amounts of ethylene and CO_2 (Nerd *et al.* 1999). The maturity stage at harvest significantly influences postharvest quality; therefore, dragon fruit should ideally be harvested at physiological maturity. One of the criteria commonly used to determine the appropriate harvest time is the number of days post-anthesis. To *et al.* (2002) reported that dragon fruit can be harvested 25 days after anthesis, with the optimal harvest time being 28–30 days after anthesis. Physiological maturity can also be determined using physical parameters such as fruit diameter, weight, shape, peel color, and firmness (Ortis & Takahashi 2020b). Among these, peel color is the most practical maturity indicator, as it signals fruit readiness for commercialization and directly influences consumer preference for brightly colored fruit.

Dragon fruit has a relatively short shelf life after harvest due to respiration, transpiration, and postharvest disease. To maintain postharvest quality, it is essential to implement strategies that can control these sources of deterioration in the fruit. One such approach is the application of heat treatments, such as Hot Water Treatment (HWT), which is widely used to control postharvest diseases and preserve fruit quality. This study combined HWT and fruit maturity index to predict the quality responses of dragon fruit using Response Surface Methodology (RSM). This method helps analyze and select process conditions, such as water temperature, immersion time, and maturity index, in relation to the responses observed during the cold storage. This study aimed to determine the optimum combination of temperature, immersion time, and fruit maturity index using RSM to maintain the postharvest quality of dragon fruit during cold storage.

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METHODS

Time and Place

The research was conducted from March to May 2025 at the Post-Harvest Agricultural Instrumentation Standardization Agency, Ministry of Agriculture, and at the Food and Agricultural Product Processing Engineering Laboratory, Faculty of Agricultural Engineering and Technology, IPB University, Indonesia.

Materials and Tools

The material used in this study was red-fleshed dragon fruit harvested from the orchard of PT Trisna Naga Asih, located in Subang, West Java, Indonesia. The dragon fruits used had maturity indices III, IV, and V, as specified by Marlina *et al.* (2020) (Table 1). Fruits were harvested and sorted based on their maturity index, transported from the orchard to the laboratory using plastic baskets, and stored at room temperature overnight before undergoing hot water treatment the following day. Before HWT, the fruits were washed with tap water to remove dirt and insects from their surfaces. The fruits were then subjected to HWT according to the experimental design, followed by cooling in water at 25±2°C for 15 minutes. After cooling, the fruits were air-dried to remove excess water. Once dried, each fruit was wrapped in paper and placed in cardboard boxes (58 × 35 × 12 cm), with 12 fruits per box separated by cardboard partitions. Eight ventilation holes (2.5 cm in diameter) were placed on the longer (three holes each) and shorter sides (one hole each). The packaged fruits were stored in cold storage at 10±3°C and 89% relative humidity for 21 days. Quality analyses were performed at 3-day intervals.

The equipment used for HWT included a water bath, a thermometer, and a thermocouple. At the same time, laboratory analyses employed a digital scale, CR-300 rheometer, DS-200 spectrocolorimeter, refractometer (Atago), Jenway 7315 UV-VIS spectrophotometer, and standard laboratory glassware such as measuring cylinders, volumetric flasks, test tubes, and pipettes.

Experimental Design

The experimental design for HWT was based on Response Surface Methodology (RSM), using a Box-Behnken Design (BBD) with three factors: temperature, immersion time, and fruit maturity index. The software used for data analysis was Design Expert Stat-Ease version 22.0.3.0 (serial number 0958-7468-5785-1549). The treatment combinations and coded factors are presented in Table 2, and the complete experimental design is presented in Table 3. The measured quality parameters included weight loss, firmness, lightness, total soluble solids (TSS), betacyanin content, and vitamin C content, which were measured every three days over 21 days for all treatments. The obtained response values were used to develop mathematical models and are presented in contour and 3D surface plots.

Weight Loss Measurement

Table 1 Dragon fruit maturity index

Maturity index	Criteria
Index I	Green fruit skin with a red tinge (green 90–99% and red 1–10%), green scales
Index II	Green>red fruit skin (green 60–89% and red 11–40%), green scales
Index III	Green< red fruit skin (green 11–40% and red 60–89%), green scales
Index IV	Bright red fruit skin (green 0–10% and red 80–100%), green scales
Index V	Dark red fruit skin, green scales

Source: Marlina *et al.* 2020.

Table 2 Treatment and treatment code

Treatment factors	Unit	levels		
		-1	0	+1
A (temperature)	°C	40	45	50
B (immersion time)	Minute	5	10	15
C (maturity index)		III	IV	V

Table 3 Experimental design with a coding system

code	Run	A	B	C	Temperature (°C)	Immersion time (minute)	Maturity Index
P1	1	+1	-1	0	50	5	IV
P2	2	-1	0	+1	40	10	V
P3	3	-1	-1	0	40	5	IV
P4	4	0	0	0	45	10	IV
P5	5	+1	+1	0	50	15	IV
P6	6	-1	+1	0	40	15	IV
P7	7	+1	0	-1	50	10	III
P8	8	0	-1	+1	45	5	V
P9	9	0	0	0	45	10	IV
P10	10	0	+1	+1	45	15	V
P11	11	0	0	0	45	10	IV
P12	12	0	+1	-1	45	15	III
P13	13	0	0	0	45	10	IV
P14	14	0	-1	-1	45	5	III
P15	15	+1	0	+1	50	10	V
P16	16	-1	0	-1	40	10	III

Fruit weight was measured on the first day and every three days during storage at 10±3°C. The percentage of weight loss (WL) was calculated using the following equation:

$$WL = (A-B)/A \times 100$$

Where:
WL = Weight loss (%),
A = Initial weight (g)
B = Final weight (g)

Firmness

Fruit firmness was measured using a digital rheometer (CR 300 model) at three different points along the equatorial axis of each fruit. The measurement results were expressed in kilograms (kg).

Total Soluble Solids (TSS)

The total soluble solids content of the fruit was determined using a refractometer (Atago), and the results were expressed in degrees Brix (°Brix).

Color

The skin color of the fruit was measured using a spectrocolorimeter (DS-200, China) based on the CIELAB color system. Measurements were taken at three points along the equatorial axis to obtain the L*, a*, and b* values.

Betacyanin

Sample preparation was performed according to Naderi *et al.* (2012). A total of 100 g of homogenized fruit pulp was shaken with 100 mL of a 50:50 ethanol–aqueous ethanol solution for 15 minutes using a shaker. The mixture was then left at room temperature for 48 hours to allow the color to stabilize. The solution was filtered through gauze, and the filtrate was concentrated using a rotary evaporator to obtain a solid extract. The solid extract (100 mg) was diluted with 0.5 M phosphate buffer to a final volume of 10 mL, and the solution was analyzed using a spectrophotometer at 500 nm. The betacyanin content (BC, mg/L) was calculated using the equation from Cai *et al.* (1998).

$$BC = (A \times DF \times MW \times 1000) / (\varepsilon \times L)$$

Where:
A = Absorbance at 500 nm
DF = Dilution factor
MW = Molecular weight of betanin (550 g/mol)
ε = Molar extinction coefficient of betanin (60,000 L/mol·cm)
L = Path length of the cuvette (1 cm)

Vitamin C

Sample preparation was performed according to Arel *et al.* (2017). A total of 2.5 g of homogenized fruit pulp was placed in a 50 mL volumetric flask. Distilled water was added to the mark, the mixture was homogenized, and then filtered through filter paper. A 35 mL aliquot of the filtrate was transferred to another 50 mL volumetric flask, diluted to volume with distilled water, and the absorbance was measured at the maximum wavelength for ascorbic acid (266 nm).

RESULTS AND DISCUSSION

Weight Loss

The analysis of variance (=5%) for the weight loss response indicated a non-significant model. All factors—temperature, immersion time, and maturity index—along with their interactions, had no significant effect on the weight loss of dragon fruit. Lestari *et al.* (2017) reported that Vapor Heat Treatment had no significant effect on weight loss in mangoes. Similarly, Lopez-Lopez *et al.* (2023) found that HWT at 46°C for 75 minutes and 55°C for 5 minutes had no significant effect on weight loss. However, sequential HWT was more effective in reducing mango weight loss during cold storage. Heat treatment can reduce weight loss by modifying the epicuticular wax structure; however, excessive heat can increase weight loss owing to wide cuticular cracking (Lestari *et al.* 2017).

Weight loss during storage is an important quality parameter associated with fruit freshness. The results (Figure 1) showed a progressive increase in weight loss over the 15-day storage period. This increase was not caused by heat treatment damage but rather by water loss due to metabolic processes during the storage. Linear regression analysis predicted the weight loss as a function of storage duration. The regression equation y = ax + b indicates that the coefficient (a)represents the direction and magnitude of the effect of storage duration on the weight loss. As shown in Table 4, the highest slope value (a) was found in the treatment at 45°C for 5 min with maturity index V, indicating that each additional storage day increased the weight loss by 0.625%. The increase in weight loss is attributed to respiration and transpiration, where transpiration reduces the water content in the fruit by releasing moisture through stomata, lenticels, and other epidermal tissues.

Fruit Firmness

Firmness is a primary factor that influences postharvest fruit quality. The analysis of variance indicated that the model for fruit firmness was insignificant. None of the factors—temperature, immersion time, or maturity index— or their interactions significantly affected dragon fruit firmness. The changes in firmness during storage are shown in Figure 2. Heat treatment may slow down pectin hydrolysis, thereby reducing the activity of enzymes involved in cell wall degradation (Rohaeti *et al.* 2010). Lestari *et al.* (2017) also reported that VHT did not significantly influence mango firmness at ambient (28°C) or refrigerated storage (13°C). Thus, the observed reduction in firmness was not induced by heat treatment but instead reflected the natural softening process that occurs during fruit storage.

Peel Lightness

Color is a crucial quality parameter that significantly influences the visual appeal of dragon fruits. The L*

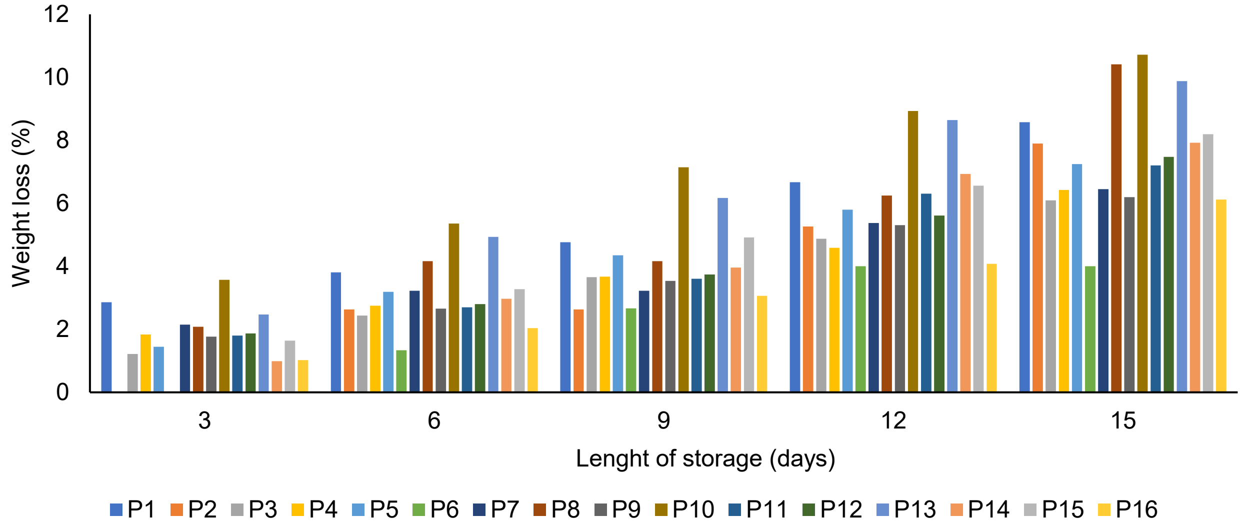


Figure 1 Percentage value of weight loss during storage at 10°C±3°C.

Table 4 Coefficient a value and R^2 in weight loss response of dragon fruit under hot water treatment

Treatment	a value	R^2
P1	0.476	0.970
P2	0.614	0.942
P3	0.407	1
P4	0.367	0.973
P5	0.473	0.997
P6	0.356	0.941
P7	0.358	0.926
P8	0.625	0.880
P9	0.384	0.983
P10	0.595	1
P11	0.481	0.955
P12	0.467	0.970
P13	0.617	0.987
P14	0.594	0.976
P15	0.492	0.921
P16	0.408	0.973

Note: Treatments with codes P1 to P16 are presented in Table 3.

value represents the lightness of the peels. Based on the analysis of variance, the lightness value on the 9th day of storage produced a significant model using a quadratic regression. The coefficient of determination (R^2) for the lightness response was 0.9396 (93.96 %). The equation used to predict the lightness response is as follows:

$$L^* = +29.30-3.06A-1.33B-1.02C-0.9625AB-0.3375AC+3,13BC+0.7675A^2+3.91B^2+0.9475C^2$$

Where:
A = Temperature
B = Immersion time
C = Maturity index

In this equation, variables A, B, and C, as well as interactions AB and AC, indicate inverse relationships with the response. The contour and surface plots (Figures 3a and 3b) describe the predicted response pattern, higher regions indicate lighter peel color, while increasing the temperature and immersion time reduced the lightness of the peel. Factors A (temperature) and B (immersion time) were identified as the main factors influencing lightness. In the surface plot (Figure 3b), the highest L* value (38.17) was obtained at a treatment combination of 40°C for 5 minutes with maturity index IV. The lightness response in the graph indicates that the higher the temperature and the longer the immersion time, the lower the lightness value. This finding is consistent with the results of Miao *et al.* (2025), who reported that HWT of citrus fruits at a higher temperature of 60°C resulted in lower L* values compared to treatments at 50°C and 55°C. Overall, the study concluded that higher HWT temperatures reduced citrus peel lightness more significantly than treatments conducted at 50°C and

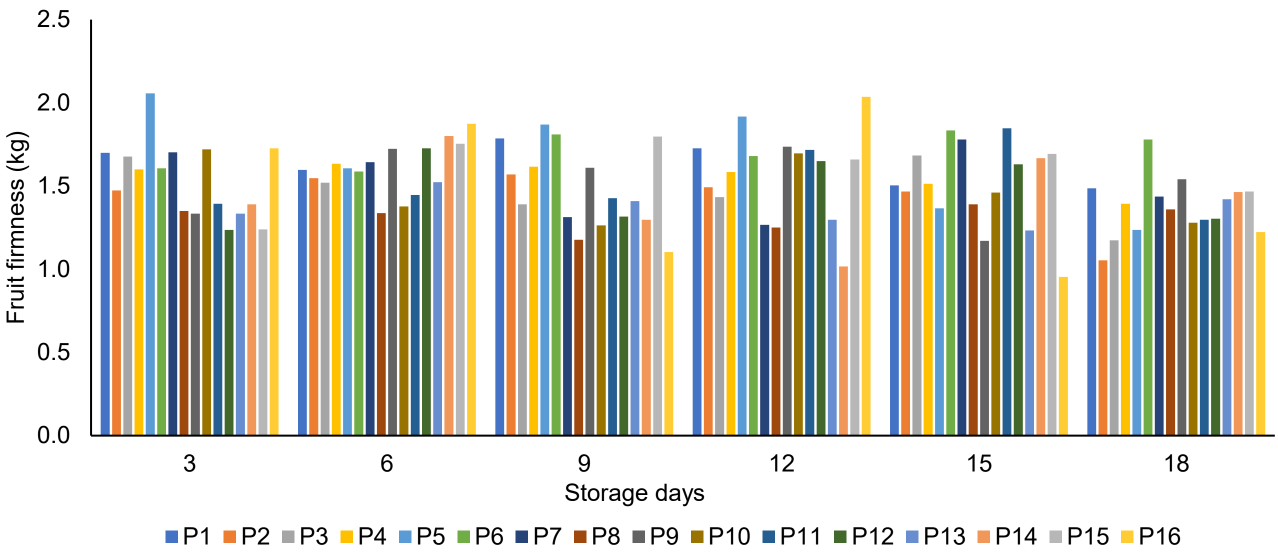
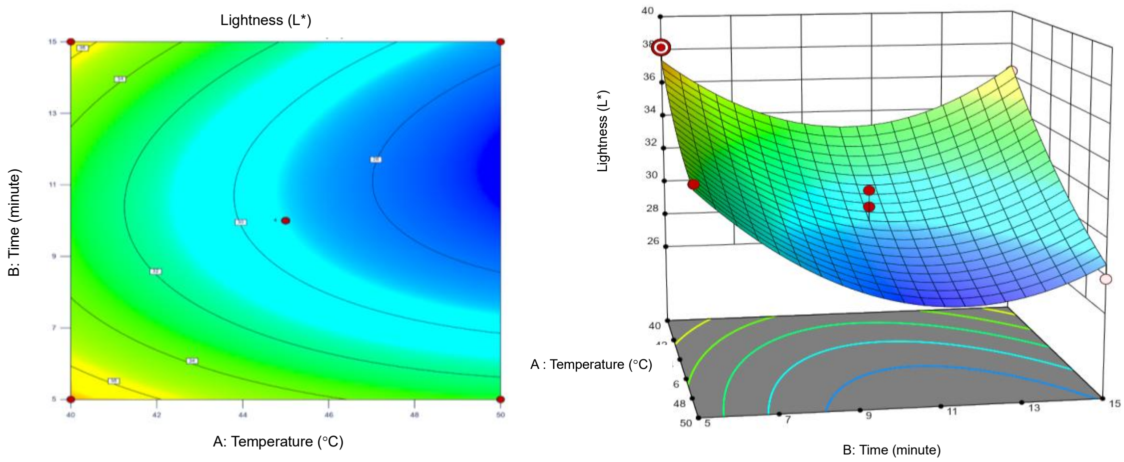


Figure 2 Dragon fruit firmness value during storage at 10°C±3°C.



(A) (B)

Figure 3 (A) Contour graph of L* value and (B) Surface response graph of L* value.

55°C. Yulianti *et al.* (2022) also reported in their study that HWT treatment in Arumanis mangoes significantly increased peel color changes during the ripening process. Thus, our results are in agreement with their findings, who found that Hot Water Treatment at 47°C for 65 minutes with a six percent beeswax coating produced higher peel lightness in Arumanis mangoes than a longer immersion time of 75 minutes. Shorter immersion durations effectively maintained lightness in the fruit peel after HWT. Heat treatment can trigger gas exchange on the surface of the fruit peel, leading to reduced oxygen (O_2) consumption, which subsequently contributes to chlorophyll degradation. According to Lopez-Lopez *et al.* (2023), heat treatment may enhance cell membrane stability, thereby reducing respiration rate and the activity of ripening-related enzymes, which ultimately delays the ripening process and, in turn, reduces changes in peel color.

Total Soluble Solids (TSS)

The total soluble solids (TSS) in fruit determine the total sugar content; therefore, the sweetness level of the fruit depends on the total sugars. The TSS value indicates the concentration of sugars and other soluble components present in the fruit. Based on the analysis of variance, the TSS value on the 12th day of storage produced a significant model using a quadratic regression. The coefficient of determination (R^2) for the TSS response was 0.9576 (95.76 %). The equation used to predict the TSS response is as follows:

$$TSS = +12.80-0.4250A-0.1625B+0.0625C+0.7750AB-0.0250AC-0.2000BC-0.6000A^2+1.07B^2+1.2C^2$$

Where:
A = Temperature
B = Immersion time

C = Maturity index

According to the regression model, variables A and B and the interactions AC and BC had negative effects on the response. However, the interaction of A and B increased TSS, indicating that a balance between temperature and immersion time is required to maintain TSS values. Based on the resulting model, the contour and surface plots for TSS are shown in Figures 4a and 4b, respectively; these plots visualize low and high TSS regions across treatment combinations. The analysis of the TSS response produced a saddle-point optimization model (Figure 4b). Sutrisno *et al.* (2013) stated that saddle point optimization indicates that the minimum region cannot yet be considered an optimum region because almost all areas within the experimental treatment range fall into this minimum region. From the graphs, the highest TSS value, 14.7°Brix, was obtained at a treatment of 40°C for 5 minutes with a maturity index of IV. According to Nguyen *et al.* (2020), dragon fruit subjected to HWT at 50°C for 5 minutes had a lower TSS value than fruit without HWT treatment (control and coating treatments) on the 6th day of storage. This is also consistent with the findings of Malek *et al.* (2024), who reported that HWT at a higher temperature of 50°C for 10 minutes reduced TSS in bananas compared with a lower temperature of 45°C at the same immersion time on the 9th day of storage. Caleb *et al.* (2016) also reported that strawberries treated with HWT at 45°C for 5 minutes had higher TSS values compared with longer immersion times of 10 minutes. According to Jacobi *et al.* (2001), heat treatment may also reduce the enzymatic hydrolysis of carbohydrates into simple sugars, thereby disrupting the conversion of starch to sugars during the ripening process.

Betacyanin

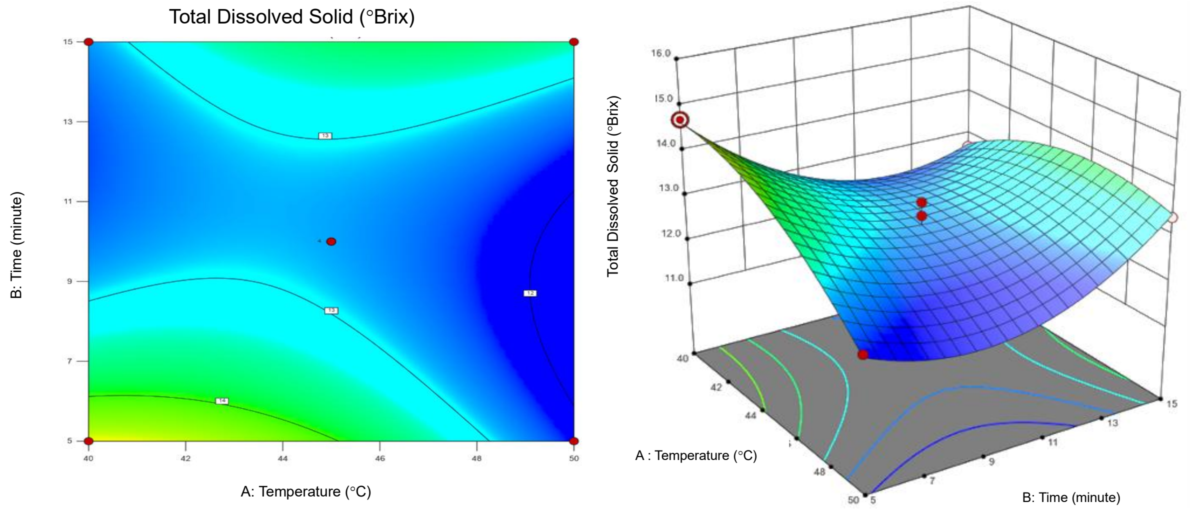
The most essential pigment in red-fleshed dragon fruit is betacyanin, which is responsible for the red–purple coloration. Betacyanin is a water-soluble pigment belonging to the betalain group of nitrogen-containing pigments. Betalains are divided into two subgroups: betacyanins, which are red–purple in color, and betaxanthins, which are yellow–orange (Mello *et al.* 2015). According to Huang *et al.* (2021), betacyanin compounds in red dragon fruit contribute to the red–purple pigment and exhibit anti-inflammatory and antioxidant activities.

Based on the analysis of variance, the betacyanin response on the 9th day of storage produced a significant model using a quadratic regression. The coefficient of determination (R^2) for the betacyanin response was 0.9840 (98.40 %). The equation used to predict the betacyanin response was as follows:

$$\text{Betacyanin} = +51.91+7.64A+2.29B+1.44C+3.45AB+0.9625AC+4.13BC-2.41A^2-5.37B^2-9.55C^2$$

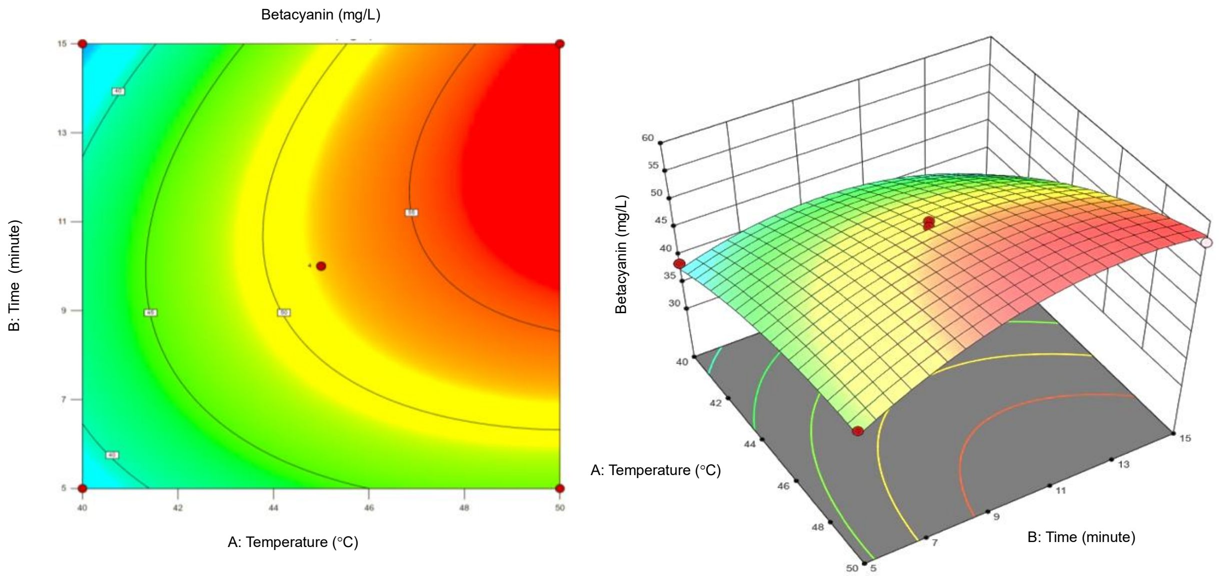
Where:
A = Temperature
B = Immersion time
C = Maturity index

According to the regression model, variables A, B, and C and interactions AB, AC, and BC exerted positive effects on the response. In contrast, the quadratic terms of the independent variables have adverse effects. This can be observed from the contour and surface response plots of betacyanin (Figures 5a and 5b), where higher regions indicate greater predicted pigment content. From the surface response graph (Figure 5b), the highest betacyanin content, 56.44 mg/L, was obtained at the treatment combination of



(A) (B)

Figure 4 (A) Contour graph of total soluble solids (TSS) value and (B) Surface response graph of total soluble solids (TSS) value.



(A) (B)

Figure 5 (A) Contour graph of betacyanin value; and B) Surface response graph of betacyanin value.

50°C for 15 minutes with maturity index IV. According to Ortiz and Takahashi (2015a), the red coloration of dragon fruit results from the accumulation of betacyanin compounds. The synthesis of betacyanin pigments is triggered by the availability of sugars and light, among other factors. As the fruit ripens, the amount of soluble sugars increases, leading to enhanced betacyanin production and a reduction in peel lightness. Lata *et al.* (2022) also noted that the peel lightness of dragon fruit gradually decreased when the fruit reached full maturity and became constant at the overripe stage. In the present study, increasing the HWT and immersion time enhanced betacyanin levels on the 9th day of storage; however, higher temperatures and longer immersion times reduced the lightness of the peel. The regression model revealed nonlinear quadratic effects of temperature and immersion time, indicating the presence of optimum points for both factors in influencing the betacyanin response. When the optimum temperature and duration were reached, further increases in these factors decreased the betacyanin content.

Vitamin C

The analysis of variance for vitamin C showed a significant model on the 9th day of storage, with a coefficient of determination (R^2) of 0.9501 or 95.01%. The equation used to predict the vitamin C response is as follows:

$$\text{VitaminC}=+2.76+0.0450A+0.2675B-0.5025C+0.3700AB+0.3100AC+0.2700BC-0.1850A^2+0.2750B^2+0.4550C^2$$

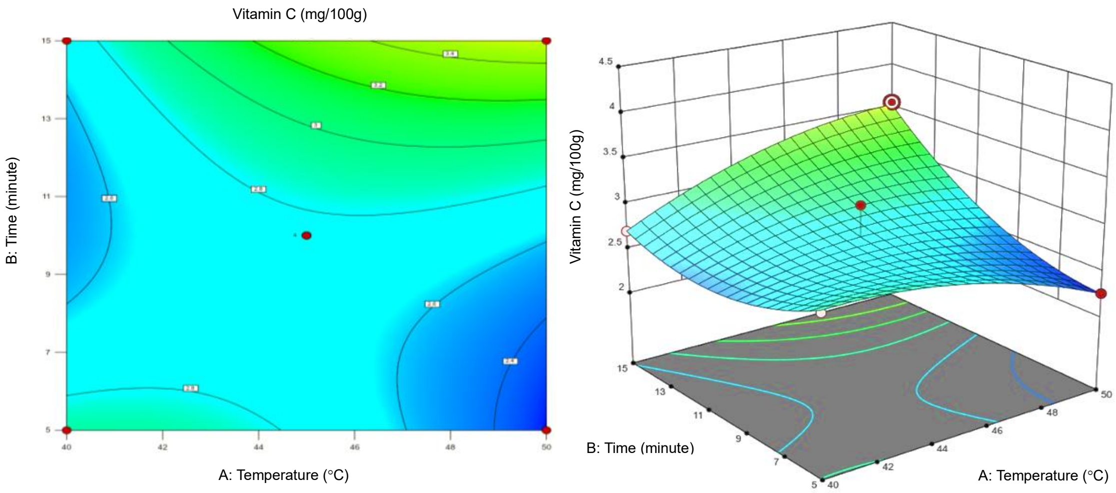
Where:

A = Temperature

B = Immersion time

C = Maturity index

From the regression equation, it can be observed that only the independent variable C (maturity index) and the quadratic term of A (temperature) had negative effects on the response variable. This indicates that the more mature the fruit, the lower the vitamin C content, which shows a linear decline. According to Lestari *et al.* (2017), the vitamin C content increases as the fruit reaches optimal maturity but then gradually decreases when the fruit becomes overripe or enters the senescence phase. For the other independent variables, vitamin C content increased as their values increased; however, the analysis of variance showed that temperature did not have a significant effect on vitamin C. Similar to the other responses, the vitamin C response is represented by contour and surface plots (Figures 6a and 6b), which show the treatment region with higher predicted vitamin C content. The highest vitamin C content, 3.56 mg/100 g, was obtained at a treatment of 50°C for 15 minutes with a maturity index of IV. Nguyen *et al.* (2020) reported that HWT at 50°C for 5 minutes, either with or without coating, was able to maintain vitamin C in dragon fruit for up to 18 days of storage. After 30 days of storage, the vitamin C content decreased, but the value remained higher than that of the control. In contrast, Pholoma *et al.* (2020) reported that water and storage temperatures affected the vitamin C content of mangoes during storage, whereas immersion duration did not significantly affect it. HWT at 55°C significantly reduced the vitamin C content in mangoes compared to treatment at 50°C. Vitamin C loss is influenced by both pH and temperature, indicating that vitamin C degradation



(A) (B)

Figure 6 (A) Contour graph of vitamin c value and (B) Surface response graph of vitamin c value.

Table 5 Criteria and limit values for the Response Surface Methodology (RSM) optimization process of Hot Water Treatment (HWT) in dragon fruit

Variable	Goal	Lower limit	Upper limit	Importance level
Temperature (°C)	In range	40	50	
Immersion time (minute)	In range	5	15	
Maturity index	In range	3	5	
Response				
L* value	minimum	26.85	39.38	+++++
TSS (Brix)	In range	12.3	15.6	
Betacyanin (mg/L)	maximum	31.78	56.44	+++++
Vitamin C (mg/100 g)	maximum	2.26	4.12	++++

proceeds more rapidly at higher fruit pH and temperature.

Optimum Combination and Validation

The optimization stage of the HWT process was conducted to determine the temperature, immersion time, and maturity index that provided optimal response values according to the established criteria. After obtaining models from the various observed responses, optimization was performed only for those responses that produced significant models. The responses that yielded significant models were peel lightness (L*), total soluble solids (TSS), betacyanin, and vitamin C, which were simultaneously optimized u sing the desirability function (Montgomery 2013). Meanwhile, the responses of weight loss and firmness were not optimized, as these were not affected by the treatments, as indicated by the absence of significant models across all observation days. The optimization objectives for each response were determined. The lightness value (L*) was minimized, with the understanding that the minimum lightness value should remain within an acceptable level to maintain fruit quality. Betacyanin and vitamin C responses were maximized, as the optimization target was to increase these two parameters. For the TSS response, the “in range” option was applied, which meant that the TSS value was constrained to fall within the range of values obtained in the experiments. This was necessary because maximizing the TSS did not yield a selected model. After determining the optimization goals for each response, weighting was applied to indicate the relative importance of each response variable. The optimization objectives and importance levels for each response are listed in Table 5.

Based on the optimization process performed using the software, the optimum combination was obtained at a temperature of 50°C, an immersion time of 15 minutes, and a maturity index of IV. This condition was recommended as the optimal HWT process for dragon fruit, with a desirability value of 0.855. The desirability value indicates that applying HWT at 50°C for 15 minutes to dragon fruit at maturity index IV would achieve a storage quality target of 85.5%. The predicted values for peel lightness (L*), TSS, betacyanin, and vitamin C after optimization were 28.40, 13.5°Brix, 56.44 mg/L, and 3.53 mg/100 g, respectively. The optimization results were subsequently validated by conducting measurements and comparing the experimental and model-predicted values. The validation results showed that only the values of TSS (13.1°Brix) and vitamin C (3.36 mg/100 g) closely matched the predicted values. These results indicate that the model was reliable for predicting TSS and vitamin C quality attributes in dragon fruit treated with HWT, but less accurate for predicting peel lightness (L*) and betacyanin content.

CONCLUSION

The combination of HWT treatment at 50 °C for 15 minutes applied to dragon fruit at maturity index IV provided the optimum condition, with a desirability value of 0.855. The predicted values generated by the model for lightness (L*), total soluble solids (TSS), betacyanin, and vitamin C were 28.40, 13.5°Brix, 56.44 mg/L, and 3.53 mg/100 g, respectively. The direct measurements obtained from the same treatment (HWT at 50°C for 15 minutes, maturity index IV), which served as validation of the model, resulted in values of 13.1 °Brix for TSS and 3.36 mg/100 g for vitamin C. These validation results demonstrated that the model was sufficiently accurate for predicting TSS and vitamin C, but less accurate for predicting lightness (L*) and betacyanin.

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