Optimization of Treated Chicken Breast Meat Color Components Using Ultrasound

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Abstract

The study was conducted at the laboratories of the Food Science, College of Agriculture, University of Basrah, started from 1/10/2019 until 12/1/2020 to investigate the effect of ultrasound on the color components of chicken breast using independent variables (power from 4.4-66 W, ultrasound treatment time from 10-30 minutes, storage period from 0-60 days). The response surface method was used to obtain optimal conditions for the independent variables and to optimize the dependent variables (L *, a *, b *, h and ΔE). Quadratic polynomial regression models were used to predict color components. Optimization results were compared with the traditional method and fresh meat. The results showed that the optimum conditions were at 66 W, ultrasound treatment time of 24.07 minutes and storage period of 40 days. The values of L *, a * and Δ E, of the ultrasound treated breast meat were higher by 16.46, 24.26 and 122.26, respectively, while the values of b * and h decreased by 7.79 and 20.63 degrees, respectively. Significant differences (p <0.05) appeared between ultrasound, conventional method and fresh breast meat in color components.

Key words: Ultrasound, Chicken breast meat, Color components, Optimization process.

Introduction:

Color plays an important role in the quality of meat and the consumer depends on the color of the meat to reject or accept it because it is an important sensory property. Colorimetry is important in assessing the commercial quality of the meat (Peña-Gonzalez *et al*., 2019). The color of the meat depends on the chemical condition and the amount of myoglobin in the meat muscle (Patist & Bates, 2008). The purple color of fresh meat belongs to deoxymyoglobin and myoglobin. deoxyomiglobin is oxidized into oxyhemoglobin when exposed to environmental air for a few minutes making a cherry red color meat, Also, the meat can turn brown when exposed to environmental air for a few hours or days due to the oxidation of oxyoglobin into meteoglobin. There are other pigments present in meat in small amounts that can be an indication of deterioration. Moreover, aging time, hardness, shelf life, and juiciness effect of flesh color and outward appearance. (Patist and Bates, 2008; Alarcon-Rojo *et al*., 2018).

Ultrasound is one of the modern technologies that has many applications in food processing, and it is a sound wave with a frequency higher than that which a human being is able to hear (Alarc´on-Rojo *et al.*, 2015).The frequencies at which ultrasound operates are greater than 20 kHz. Usually, sounds at those frequencies cannot be heard by humans. The energy density of ultrasound ranges from 10-1000 W / cm^2 at frequencies between 20-100 kHz and its effect is clear on the chemical and physical properties of liquids (Dhankhar, 2014). There is a very important role for ultrasound in food processing because the consumer is very interested in consuming processed foods that have very little quality.

When the sound travels to a certain medium, it generates pressure waves and breaks down the fine portions in the medium (Povey and Mason, 1998), resulting in the formation of cavities and / or bubbles, and the cavities grow in successive cycles of ultrasound and eventually become unstable, then collapse and generate high temperature and pressure. Their effect on biological materials and tissues is at the micro and macro levels, and their effect on food is positive and increases the quality and safety of food (Alarc´on-Rojo *et al*., 2015). The range of ultrasound used is high-frequency, low-intensity (> 1 MHz, <1 Wcm^{-2}) and low-frequency, high-intensity (20-100 kHz with10-1000 Wcm^{-2}). and that both types are useful in food processing (Mason *et al*., 1996; Mason *et al*., 2011). The traditional methods of treating meat include mechanical, chemical, enzymatic and electrical stimulation methods, while modern methods include shock waves, hydrostatic pressure, flash electric field (Bhat *et al*., 2018), and ultrasound. Some research indicates that ultrasound has no effect on meat color because heat generation is insufficient for denaturation of proteins and pigments (Sikes *et al*., 2014). Conversely, in assessing the effect of ultrasound (22 W / cm^2) on meat, it was found that the color changed to a lighter color and less red and more yellowish (greater gradation angle), which was less bright than the standard treatment (untreated meat) (Stadnik *et al*., 2011; Xiong *et al*., 2012). Ultrasound speeds accelerate overall color changes, reduces oxymyoglobin formation, and slows myoglobin formation (Stadnik and Dolatowski, 2011). However, when the meat is cooked, the judges do not discover the differences between the ultrasound-treated and non-treated meats (Peña-González *et al*., 2017; González-González *et al*., 2017). Recently, some studies have been conducted on the effects of high-intensity ultrasound on the color of fresh meat, Khalaf *et al*., (2019) showed that the color components represented by L *, a *, b *, and h for fresh chicken breast were 41.76, 17.41, 12.71 and 0.75, respectively. Al-Hmedawy *et al*., (2019) mentioned that the values of color components for fresh chicken carcass meat (L *, a *, and b *) were 44.78, -22.84 and 19.66, respectively, as a result of the difference of researchers about the effect of ultrasound, as well as the importance of meat color in attracting the consumer, as well as the lack of studies, therefore, the present study aims to investigate the effect of ultrasound on the color components of chicken breast meat and to find the optimal conditions in terms of power, time of ultrasound treatment and storage period to improve the color components of chicken breast meat.

Materials and methods:

Sample preparation:

The experiment was conducted at the laboratories of the Food Science - College of Agriculture - University of Basrah started from 1/10/2019 until 12/1/2020. Laying hens at the age of 1-1.5 years were purchased from the local market of Basrah Governorate. Chickens were manually slaughtered, cleaned and cut into pieces and the breast cut was taken and placed in a low-density Polyethylene bags, with a density of 0.93 g / cm^3, a thickness of 0.03 mm, and a type of BFI-NA345 (Smallman and Ngan, 2007).

Pelvic ultrasound device:

The pelvic ultrasound device was used (Model LUC-405) made in Korea equipped by Dai han Lab Tech.co, LTD, which has a capacity of 5 liters and internal dimensions of 150 x 155 x 300 mm ^{3} and a power of 350 W. The device works with a voltage of 220 V and a frequency of 50Hz. The frequency of ultrasound in the device is 40kHz.

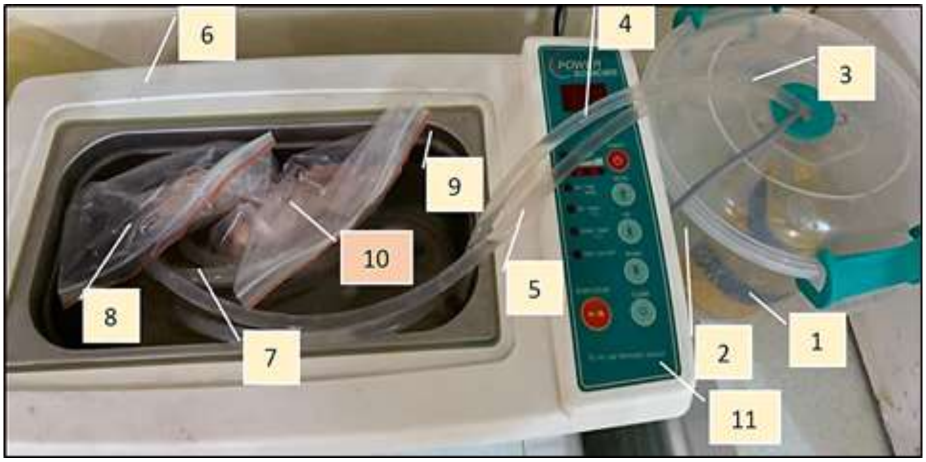


Figure 1. pelvic ultrasound device provided with a heat exchanger.

1. Pump, 2. Cold water level, 3. Cold water tank 4. Water pipe leaving the heat exchanger, 5. Cold water tube entering the heat exchanger 6. Equipment basin, 7. Heat exchanger 8. & 10. Chicken breast, 9. Water level 11 Control panel.

Four pieces of chicken breast were placed in the basin, then both treatment time of ultrasound and power were determined based on initial experiments. The temperature was also fixed by means of a tube heat exchanger (a 10-liter water tank, a submersible pump, a plastic tube, and ice water). The effect of power, ultrasound treatment time and storage period on the meat quality were studied. The treatment of chicken breasts was carried out in the traditional way by following the method described by Levie (1970) in the Meat Science Laboratory of the College of Agriculture, University of Basra, by taking a chicken breast cut using the method of grilling in an electric oven at a temperature of 200 ° C for 30 minutes.

The color evaluation was conducted with Experience in animal production department to evaluate samples in term of color. The power (amplitude) (%) was converted to the values in W by measuring the current and voltage difference supplied to the ultrasound device at each power percentage and plotted the relationship between power (W) and the percentage of power (%) and obtaining the linear equation P = 0.6816 P - 1.1541% which shows the relationship between them, with a determination factor of 0.9959 (Figure 2).

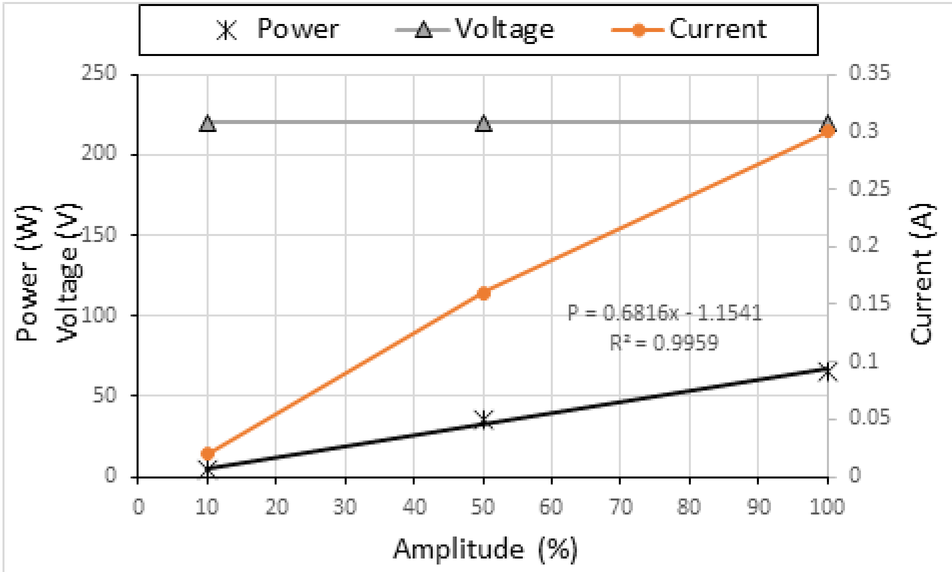


Figure 2. The relationship between power (W), voltage difference, current, and percentage of power (%).

Color Measurement:

An image processing method was used to analyze the color characteristics of the breast segment. The images of the breast for all parameters were captured by a high-resolution digital camera (6 megapixels) at suitable lighting by an image capture device according to Al-Essa (2020). Image J software was used instead of Photoshop to analyze images and find ranges of values of L*, a*, and b* according to Yam and Papadakis (2004). The change in color was calculated from the following equation (Wrolstatad and Smith, 2017):

$$\Delta E = \sqrt{(L_o^* - L^*)^2 + (a_o^* - a^*)^2 + (b_o^* - b^*)^2} \qquad (1)$$

Where :

ΔE: The total change in color, L_o* : Lightness, a_o* : Redness, b_o* : Yellowing of untreated meat, L *, a *, b * are for ultrasound processed meat .

Hue angle was calculated according to Equation 2 as according to Wrolstatad and Smith, (2017):

$$h = tan^{-1}\frac{b^*}{a^*} \qquad (2)$$

Where h: is the hue angle (degree).

Experimental design and statistical analysis:

Three independent factors (power, treatment time by ultrasound, and storage period) were used to improve the qualitative characteristics of poultry breast cuts using Design Expert v.7 by Response Surface methodology using the central composite design (CCD). Table (1) shows the maximum, median and minimum values. For independent factors (power, treatment time by ultrasound, and storage period) in the CCD. There are twenty-one randomly distributed treatments. Then, the quadratic polynomial regression model was used to predict the color characteristics (L *, a *, b * , ΔE, ΔC and h) of poultry breast pieces (Equation 3):

$$Y = \beta_\circ + \sum_{i=1}^{2} \beta_i X_i + \sum_{i=1}^{2} \beta_{ii} X_i^2 + \sum \sum_{i<j=1}^{2} \beta_{ij} X_i X_j \qquad (3)$$

Where : Y : response (color compounds), β° : a constant, βi : a constant related to the linear portion of the equation, βii : a constant related to the nonlinear part of the equation, βij : a constant related to the interference portion of the equation.

Table 1. The experimental ranges of the independent factors (power, ultrasound treatment time, and storage period) in the CCD of the qualitative characteristics of poultry breast pieces.

Factors	Symbol	Levels		
		-1	0	+1
Power (Watt)	X_1	4.4	35.5	66
Ultrasound treatment time (min)	X_2	10	20	30
Storage period (day)	X_3	0	30	60

Statistical analysis was performed with Design Expert v.7. The measured and predicted values were compared with the t-test at 0.05 level using SPSS software version 7.

Results and discussion:

Lightness (Luminosity) :

The results showed in Table (2) that the highest value of luminance (L *) was 74.11 when the power was 66 W, the ultrasound treatment time was 30 minutes and the storage period was 60 days. As for the lowest value of L *, it was 26.86 when the power was 35.2 W, the ultrasound treatment time was 10 minutes, the storage period was 30 days, and the power was 35.2, and the ultrasound treatment time was 20 minutes and the storage period was 30 days. The results showed that the value of L * varies with the change of power. When the power was 4.4, 35.2 and 66 W, the value of L * was 50.78, 49.80, 50.19, respectively, when the ultrasound treatment time was 20 minutes and the storage period was 30 days. When increasing the ultrasound treatment time from 10-30 minutes, it increased the L * value from 43.72-55.88, respectively, at 66 W and 30 days of storage period. When storage period increased from 0-60 days, L * increased from 43.72-70.58, respectively, at 66 W power and 10 minutes ultrasound treatment time. The results of the statistical analysis (table 3) showed that the reduced quadratic model and the square of the storage period had a significant effect ($p < 0.05$) on the value of L * while the effect of each of the power and the ultrasound treatment time and the interference between power and storage period, as well as the interference between Ultrasound treatment time, storage period, power squared, ultrasound treatment time squared and lack off it were insignificant ($p > 0.05$). In addition, the descriptive statistic values for model were R^2 = 0.6417, Adj. R^2 = 0.4327, Pred R^2 = 0.0752 and Adq precision = 6.714. Equation 4 describe L* depending coded factors (X_1 (-1, 0, +1); X_2 (-1, 0, +1); X_3 (-1, 0, +1)):

$$L^* = +40.27 + 4.80X_1 + 4.20X_2 + 6.27X_1X_3 - 1.13X_2X_3 + 10.57{X_1}^2 - 9.14{X_2}^2 + 13.21{X_3}^2 \quad (4)$$

Where, X_1: power (W), X_2: ultrasound treatment time (min.) and X_3:storage period (day).

Table 2. Matrix of central composite design for capacity, ultrasound treatment time, storage period, and color components response to chicken breast cuts.

Runs	P (W)	t (min.)	SP (day)	L*	a*	b*	h (degree)	ΔE
1	66	10	0	43.72	17.88	16.47	42.67	7.48
2	4.4	10	60	43.13	21.64	20.70	43.75	11.69
3	35.2	20	30	49.80	13.64	12.70	42.98	4.19
4	66	30	60	74.11	9.882	16.47	59.07	25.61
5	35.2	20	0	66.27	12.23	21.64	60.55	18.40
6	4.4	10	0	45.49	16.94	16.94	45.02	5.68
7	35.2	10	30	26.86	18.82	14.11	36.89	22.86
8	66	30	0	55.88	15.05	20.23	53.37	8.66
9	35.2	20	30	49.80	13.64	12.70	42.98	4.19
10	35.2	20	30	35.86	13.82	14.11	36.89	22.86
11	4.4	20	30	50.78	13.64	14.58	46.93	3.20
12	35.2	20	60	40.00	17.88	15.05	40.12	10.40
13	35.2	20	30	49.80	13.64	12.70	42.98	4.19
14	4.4	30	60	52.15	24.00	24.47	45.58	14.66
15	35.2	20	30	30.86	13.82	14.19	36.89	22.86
16	35.2	20	30	26.86	15.82	14.11	36.89	22.86
17	35.2	30	30	34.70	21.64	16.00	36.49	16.81
18	66	10	60	70.58	27.76	24.47	41.41	28.07
19	4.4	30	0	54.90	16.47	18.35	48.12	7.81
20	66	20	30	50.19	10.82	10.35	43.75	6.47

P: power, t: ultrasound treatment time, SP: storage period

Table 3. Analysis of variance of color components for chicken breast meat and descriptive statistics.

Source	L*		a*		b*		h		ΔE	
	SS	P-value	SS	P-value	SS	P-value	SS	P-value	SS	P-value
Model	2114.9	0.042	384.1	0.0001	291.6	0.0001	805.4	0.002	14.3	0.216
X_1	230.78	0.151	12.76	0.0019	8.97	0.0065	11.8	0.323	1.9	0.211
X_2	176.07	0.205	3.99	0.0346	-	-	0.08	0.933	0.001	0.973
X_3	-	-	51.02	0.0001	21.7	0.0004	208.7	0.001	0.57	0.484
X_1X_2	-	-	63.78	0.0001	11.07	0.0036	68.62	0.032	0.091	0.777
X_1X_3	314.95	0.098	7.09	. 0009	3.99	0.0435	8.51	0.398	0.85	0.394
X_2X_3	10.17	0.753	18.71	0.0006	11.07	0.0036	-	-	-	-
X_1^2	307.11	0.102	11.93	0.002	8.63	0.0072	34.53	0.107	3.93	0.083
X_2^2	229.64	0.152	96.28	0.0001	77.99	0.0001	71.79	0.03	4.35	0.070
X_3^2	480.24	0.047	1.51	0.1565	24.91	0.0002	200.5	0.002	-	-
$X_1X_2X_3$	-	-	39.97	0.0001	40.95	0.0001	-	-	-	-
$X_1^2X_2$	-	-	22.68	0.0003	4.98	0.0276	30.42	0.128	-	-
$X_1^2X_3$	-	-	-	-	-	-	169.5	0.003	3.03	0.122
Re	1180.9	-	4.93	-	6.51	-	97.48	-	11.91	-
LoF	620.86	0.625	1.2	0.6773	3.42	0.3603	41.89	0.509	0.71	0.998
PE	560.05	-	3.73	-	3.1	-	55.59	-	11.21	-
CT	3295.8	-	389.1	-	298.1	-	902.9	-	26.21	-
R-Sq	0.6417	-	0.987	-	0.978	-	0.892	-	0.545	-
Adj R-Sq	0.4327	-	0.969	-	0.953	-	0.772	-	0.215	-
Pred R-Sq	0.0752	-	0.801	-	0.919	-	0.145	-	0.319	-
Adeq Pr.	6.714	-	29.39	-	21.43	-	9.861	-	4.734	-
Std. Dev.	9.92	-	0.79	-	0.85	-	3.29	-	-	-

X_1: Power, X_2: Time, X_3: Storage period, Re: Residual, LoF: Lack of Fit, PE: Pure Error, CT: Cor Total, R-Sq: R-Squared, Adj R-Sq: Adj R-Squared, Adeq Pr.: Adeq Precision, L*: lightness, a*: redness-blueness, b*: yellowness-greenness, h: hue angle and ΔE: total color deference.

The three-dimensional figure (Figure 3) shows the effect of overlapping independent factors on the L * value. The results showed that the L * value was 52.97 at the power 4.4 W and the storage period was 60 days and increased to 75.12 at 66 W power and 60 days of storage period. At the center point, 20 minutes of ultrasound treatment time (Figure A-3) was L * 65.52 at 4.4 W and 0 days of storage period. It decreased to 62.58 at 66W and 0 days of storage period. Both power and storage period are two factors that mainly affect the value of L * . MacDougal (1982) showed that the reason for increasing the value of L * when increasing the storage period is due to the presence of high oxidation conditions and possibly due to changes in the composition of meat such as changes in protein shape and these changes may produce high light scattering and give a large L * value.

The results in Fig. (B-3) showed that the L * value increased from 39.02 to 49.66 when increasing the ultrasound treatment time from 10-30 minutes respectively, and the L * value reached 41.27-47.41 when increasing the ultrasound treatment time from 10-30 minutes respectively, slight differences occurred when the storage period changed, and it was clear from the results that the effect of the ultrasound treatment time was greater than the effect of the storage period. Peña-Gonzalez *et al*., (2019) found out that the L * value of beef increased when treated with ultrasound (48.21) compared to the standard treatment (39.50).

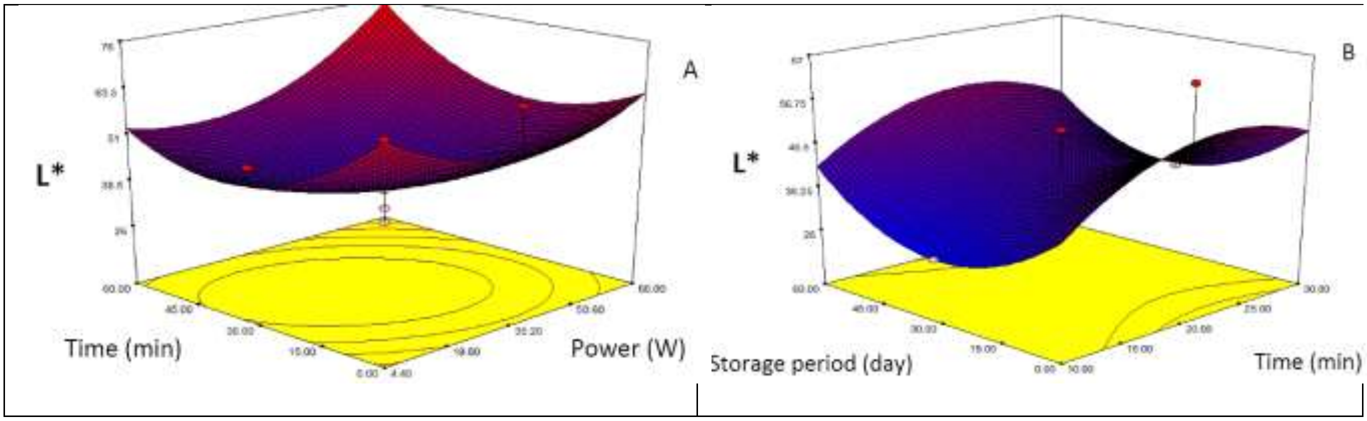


Figure 3: Effect of power, ultrasound treatment time, and storage period in L * at central points A: 30 days and B: 35.2 W.

Redness-yellowing (a *):

The results have showed in Table (2) that the highest value of a * was 27.76 when the power was 66 W, the ultrasound treatment time was 10 minutes, the storage period was 60 days. The lowest value was 9.882 when the power was 66 W, and the ultrasound treatment time was 30 minutes and the storage period 60 days. This decrease in the a * value may be attributed to the effect of the ultrasound treatment time, which directly affected the a * value. The value of a * increased from 17.88 at 66 W and ultrasound treatment time 10 minutes at 0 days storage period to 18.82 at 35.2 W power and ultrasound treatment time 10 minutes and 30 days storage period. This is because the decrease in power and the increase of the storage period led to a decrease in the value of a *, and the value of a * increased from 16.47 at a power of 4.4 W, and the ultrasonic treatment time was 30 minutes and the storage period was 0 to 24.00 days at the power of 44 W and the ultrasound treatment time was 30 minutes. The storage period was 60 days. Peña-Gonzalez et al. (2019) found that the redness value of the ultrasound treated beef was lower compared to the standard treatment.

The results of the analysis of variance (Table 3) showed that the reduced cubic model and all the interactions and factors squares had a significant effect (P <0.05) while the effect of lack of fit was insignificant (P> 0.05) and that R^2 = 0.9873 and Adj R^2 = 0.9699 and Pred. R^2 = 0.80149 and Adq Precision = 29.394. As well as, a standard deviation of 0.79 and a coefficient of variation of 4.77%. These statistical indications show that the reduced cubic model can be used to predict the values of a *.

$$a^* = +36.42080 - 0.37211X_1 - 2.49722X_2 - 6.57513E - 003X_3 + 0.026029X_1X_2 + 3.81971E - 003X_1X_3 + 3.41737E - 003X_2X_3 + 5.74141E - 003{X_1}^2 + 0.059171{X_2}^2 + 8.22937E - 004{X_3}^2 - 2.41915E - 004X_1X_2X_3 - 3.96853E - 004{X_1}^2X_2 \quad (5)$$

Where, X_1: power (W), X_2: ultrasound treatment time (min.) and X_3:storage period (day).

The results in the three-dimensional figure (A-4), which was drawn by the response surface methodology, showed that the value of a * increased from 19.60 at 4.4 W and the ultrasound treatment time was 30 minutes to 21.64 at the power of 35.2 W and the ultrasound treatment time was 30 minutes and then decreased to 11.69 at 66 W. It also increased from 18.66 at 4.4 W and the ultrasound treatment time of 10 minutes to 22.04 at 66 W at the same ultrasound treatment time. Here it is evident that when increasing the power and the ultrasound treatment time, it led to a decrease in the value of a *, but when increasing the power and reducing the ultrasound treatment time, it led to an increase in the value of a *.The results in the three-dimensional figure (B-4) showed that the value of a * reached 10.75 at the power of 4.4 W and the period of storage is 0 day, and it increased to 31.01 at the power of 66 W and the period of storage was 60 days, as well as increased to 17.15 at the power of 4.4 W and the period of storage of 60 days. Here, it appears from the results that the interference between the power and the storage period played an important role in changing the value of a *. The results in the three-dimensional (Fig. C-4) showed that the value of a * increased from 15.62-21.52 when the ultrasound treatment time increased from 10-30 minutes. When the storage period is 0 day. The results also showed that the a * value increased from 23.20 to 22.96 at the ultrasound treatment time of 10 minutes to 30 minutes, respectively, at the centre point of 35.2 W.

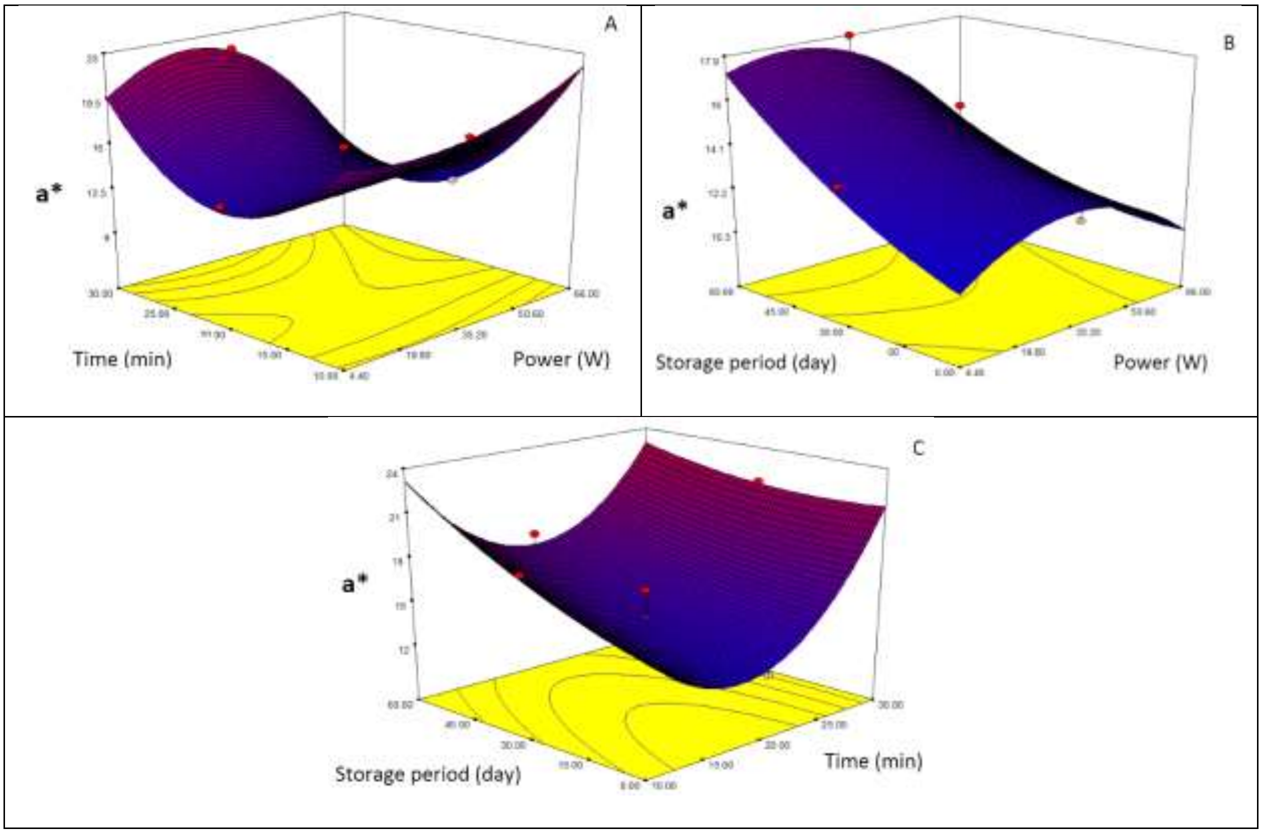


Figure 4. The effect of power, ultrasound treatment time and storage period in the value of a * at the central points A: 20 minutes, B: 30 days, and C: 35.2 W

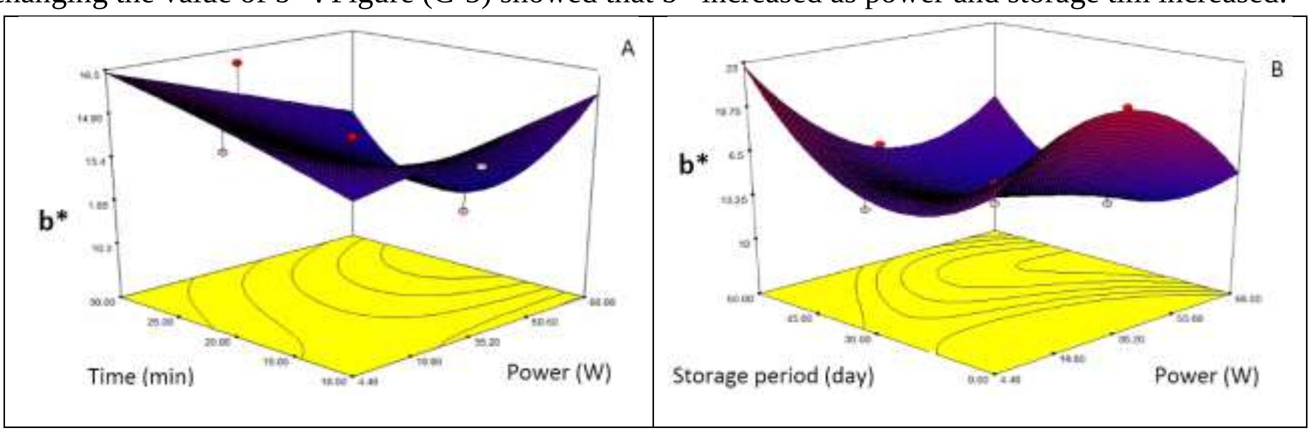
Yellowness-blueness (b *):

The results showed in Table 2 that the highest value of b * was 24.47 when the power was 4.4 W, the ultrasound treatment time was 30 minutes, and the storage period was 60 days. The power was 66 W, the ultrasound treatment time was 10 minutes, and the storage period was 60 days. The lowest value for b * was 10.35 when the power was 66 W, the ultrasound treatment time was 20 minutes, and the storage period was 30 days. The power was 35.2 W, the ultrasonic treatment time was 10 minutes, the storage period was 30 days, the value of b * was 14.11, which is equal to the value of b * when the power was 35.2 W, the ultrasound treatment time is 20 minutes and the storage period was 30 days. The results showed that the value of b * decreased from 16.47 at 66 W, ultrasound treatment time 10 minutes, storage period 0 day, to 20.23 at 66 W power, ultrasound treatment time 30 minutes, storage period 0 day, and this is due to an increase in the ultrasound treatment time. Peña-Gonzalez et al. (2019) disclosed that the value of b * was not significantly affected by ultrasound-treated beef compared to the standard sample. The results of the statistical analysis (Table 3) showed that the reduced cubic model, the independent factors, and all the interactions and squared factors have a significant effect ($P < 0.05$). The effect of lack of fit was not significant ($P > 0.05$). The statistical indicators for the mathematical model were $R^2 = 0.9782$, Adj $R^2 = 0.9539$, Pred $R^2 = 0.9190$, and Adq Precision = 21.433. as well as the standard deviation of 0.85 and a coefficient of variation of 5.15%. These statistical indications showed that the reduced cubic model can be used to predict b * values. . Equation 6 describe L* depending coded factors (X_1 (-1, 0, +1); X_2 (-1, 0, +1); X_3 (-1, 0, +1)):

$$b^* = +13.23 - 2.12X_1 - 3.29X_3 - 1.18X_1X_2 - 0.71X_1X_3 - 1.18X_2X_3 + 1.64{X_2}^2 + 4.94{X_3}^2 - 1.76X_1X_2X_3 + 13.21{X_1}^2X_3 + 1.76X_1{X_2}^2 \quad (6)$$

Where, X_1: power (W), X_2: ultrasound treatment time (min.) and X_3:storage period (day).

The results are shown in the three-dimensional figure (A-5), which was plotted by surface response methodology at the central point for 30 days. The overlap between the power and the ultrasound treatment time had a clear effect on the value of b *, when the power was 4.4 W and the time of the ultrasound treatment was 10 minutes, the value of b * was 14.05 and it increased to 15.69 when the power was 66 W and the treatment time was 10 minutes and it increased to 16.40 at the power 4.4 W and the ultrasound treatment time was 30 minutes, and the lowest value of b * was observed at 66 W and the ultrasound treatment time was 30 minutes, reaching 13.34. Chang et al. (2012) showed that the b * value of beef was significantly decreased upon ultrasound treatment. The results are shown in the three-dimensional Figure (B-5), which showed the interference between power and storage period. The highest value for b * was 22.75 when the power was 4.4 W and the storage period was 60 days. The lowest value for b * was 14.99 when the power was 66 W and the storage period was 0 days. Peña-Gonzalez et al. (2019) showed that the b * value of ultrasound treated beef increased with increasing storage period compared to the standard sample. The results also showed that the power 35.2 W and the two storage periods 0 and 60 days then reached the value of b * 21.64 and 15.0 respectively. Here it was observed from the results that both the power and the storage period play an important role in changing the value of b *. Figure (C-5) showed that b* increased as power and storage tim increased.



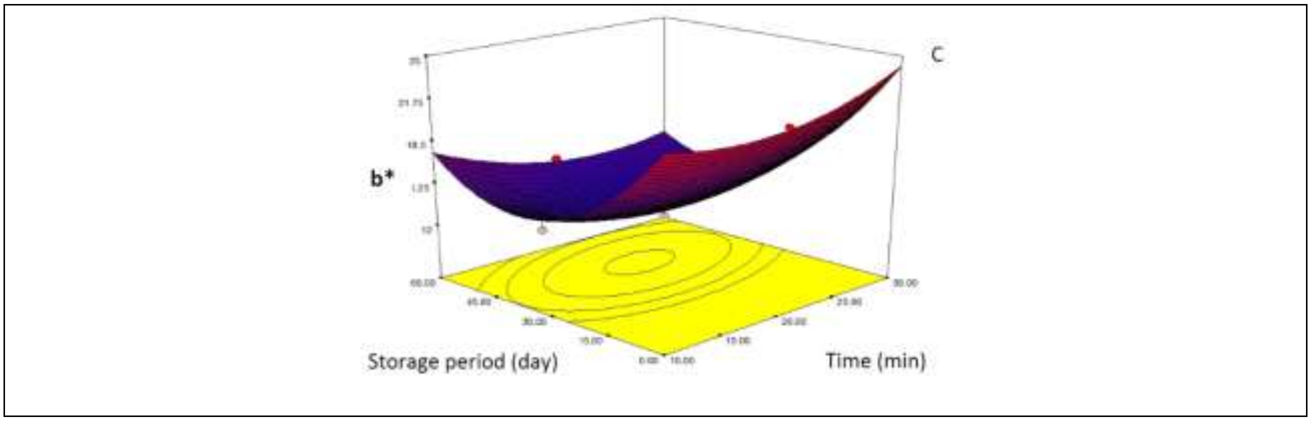


Figure 5. The effect of power, ultrasound treatment time, and storage period in the value of b * at the central points A: 20 minutes, B: 30 days, and C: 35.2 W

Hue angle (h):

The results showed in Table (2) that the highest value of h reached 60 degrees at the power 35.2 W, the ultrasound treatment time was 20 minutes, and the storage period was 0 days. The lowest value was 36.49 degrees at the power of 35.2 W, the ultrasound treatment time was 30 minutes, and the storage period was 30 days. Peña-Gonzalez *et al.,* (2019) found that h was increased in ultrasound treated beef. The results of the analysis of variance (Appendix 15) showed that the effect of the reduced cubic model, the storage period, the interference between power, ultrasound treatment time, the square of the ultrasound treatment time, the square of the storage duration, and the interference between the power square and the storing period were significant ($p < 0.05$) while there wasn't a significant effect ($p > 0.05$) for the power, the ultrasound treatment time, the interference between the power, the storage duration, the power square, and the interference between the power square and the ultrasound treatment time. The results also showed that the effect of lack of fit was not significant as well.

The statistical indicators of the match between the model and the measured data were R^2 = 892, Adj R^2 = 0.7721, pred R^2 = 0.1452, and Adeq precision = 9.861, and the standard deviation was 3.29. These indicators showed that the reduced cubic mathematical model can predict h values with high efficiency.

$$h = +25.82136 + 2.25853X_1 - 2.49722X_2 - 0.50101X_3 - 0.022852X_1X_2 - 0.024351X_1X_3 - 0.016311{X_1}^2 - 0.051093{X_2}^2 + 9.48958E - 003{X_3}^2 + 3.61750E - 004{X_1}^2X_3 + 4.59678E - 004{X_1}^2X_2 \quad (7)$$

Where, X_1: power (W), X_2: ultrasound treatment time (min.) and X_3:storage period (day).

The results are shown in the three-dimensional figure (A-6), which shows the effect of the interference between power and the ultrasound treatment time in h at the central point for a 30-day storage period. The highest value of h was 47.28 degrees at 66 W and the ultrasound treatment time was 30 minutes, while the lowest value was 33.11 at 66 W and the ultrasound treatment time was 10 minutes. The results also showed that the differences in h were small during the ultrasound treatment time of 10 and 30 minutes at the power of 4.4 W, as it reached 36.79 degrees and 39.25 degrees (the difference of 2.46 degrees), while the difference was most severe at the power of 66 W, as it reached the maximum difference of 28.83 degrees. It may be due to increased yellowing and decreased redness, i.e. there is a change in some color components as a result of some chemical changes such as oxidation.

As for the effect of the interference between the power and the storage period, the results showed in Figure (B-6) that the value of (h) is variable with the change of the power and the storage period. At the power 4.4 W and the storage period of 60 days, h was equal to 50.72 degrees at the power 66 W and the storage period was 0 days. The lowest value of h was 39.11 degrees at the power of 35.2 W and the storage period was 60 days. While the value of h reached its maximum value at 35.2 W and the storage period was 0 days, as it reached 60.55 degrees, and this may be due to the increase of b *. Ayala-Silva et al. (2005) and Pedisic *et al.*, (2009) showed that the color angle describes the relative amounts of redness and yellowness, where 50/360 represents red / magenta, 90 is yellow, 180 is green, and 270 is blue, purple, or mid-tones between close pairs of those primary colors. They also showed that the lowest value of the hue angle indicates that the color of the product is reddish, the hue angle depends on the color components a * and b *, which represents the angle between the pure red color (color angle = 0 degrees) and pure yellow (hue angle = 90 degrees). When the hue angle is high it indicates browning of meat or an increase in yellowness on the redness within the flesh color range due to the formation of metmyoglobin.

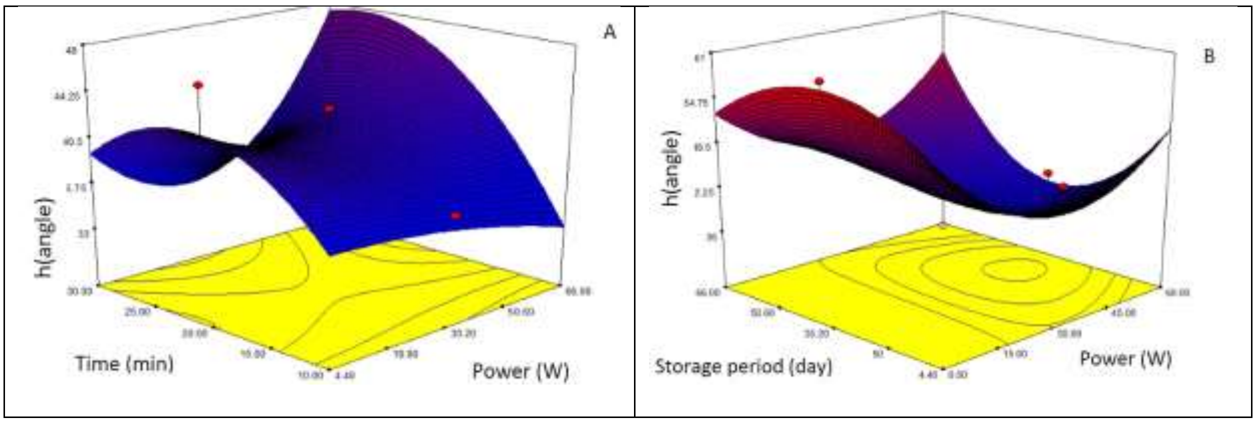


Figure 6. The effect of power, ultrasound treatment time, and storage period in the value of h at central points A: 20 minutes, B: 30 days, and C: 35.2 W

Total color difference (ΔE):

The results are shown in Table (2), which shows the central composite design of power, ultrasound treatment time, storage period, and response to the total color difference of chicken breast pieces. The highest ΔE value was 28.07 at 66 W, the ultrasound treatment time was 30 minutes, the storage period was 0 days, the lowest value was 3.20 at the power 4.4 W, the ultrasound treatment time was 20 minutes, and the storage period was 30 days. The results also showed that the ΔE value increased from 7.48-28.07 at 66 W power, the ultrasound treatment time was 10 minutes, and the storage period increased from 0 days - 60 days and when the power increased from 4.4 to 66 W,. This may be due to increase of storage period that led to change in the chemical characteristic such as development of peroxide as value. when the ultrasound treatment time was 10 minutes and the storage period was 60 days, it increased ΔE from 11.69-28.07, respectively. These results were in agreement with Pohlman *et al.*, (1997) who showed that the color of the ultrasound-treated meat changed to less red, less shiny, lighter, and increased yellowish-orange, while the results were not in agreement with Stadnik and Dolatowski (2011); Sikes et al. (2014) who showed that ultrasound did not significantly affect the color of chicken meat and the reason for this is that the heat generation in ultrasound is small and does not affect the pigments and denaturation of proteins.

The results of the statistical analysis (Table 3) showed that the reduced cubic model and the interactions between independent factors did not significantly affect ($p > 0.05$) the value of ΔE even though the value of lack of fit was not significant ($p > 0.05$). The value of $R^2 = 0.5455$ and the difference between Adj R^2 and pred R^2 was 0.104, which is less than 0.2. In addition to Adq precision was greater than 0.4. The insignificance of the model effect may be due to the dispersion in the value of ΔE because it is a value computed from the values of L*, b*, and a* and that the effect of color components overlapping with different factors led to that. Equation 8 describe the effect of independent variables and their interactions on the ΔE:

$$Sqrt(\Delta E) = +5.01333 + 0.19486X_1 - 0.45302X_2 + 0.029752X_3 - 3.46068E - 004X_1X_2 - 3.05092E - 003X_1X_3 - 2.61880E - 003X_1{}^2 + 0.011658X_2{}^2 + 9.48958E - 003X_3{}^2 + 4.83525E - 005X_1{}^2X_3 \quad (8)$$

Where, X_1: power (W), X_2: ultrasound treatment time (min.) and X_3:storage period (day).

The results in the 3D figure (A-7) plotted by the response surface methodology showed that increasing the power from 4.4-66 W at the ultrasound treatment time of 10 min and 30 min led to an increase of ΔE from 8.75-16.35 and 10.19-14.84 respectively. From this, it is evident that the effect of the power to change ΔE is more important than the effect of the ultrasound treatment time, and this led to an increase in the values of L *, a * and b * of the ultrasound-treated chicken breasts compared to the untreated samples. The results showed that increasing the power from 4.4-35.2 W led to an increase in ΔE, and the latter decreased when the power increased to 66 W at the 60 days storage period at the central point of 20 minutes of ultrasound treatment time. The results also showed an increase in ΔE when increasing the power during the 60 days storage period (Figure B-7). The highest value of ΔE was 15.63 when the power was 66 W and the storage period was 60 days. This may be due to the occurrence of some chemical changes to the chicken breast when the storage period increased.

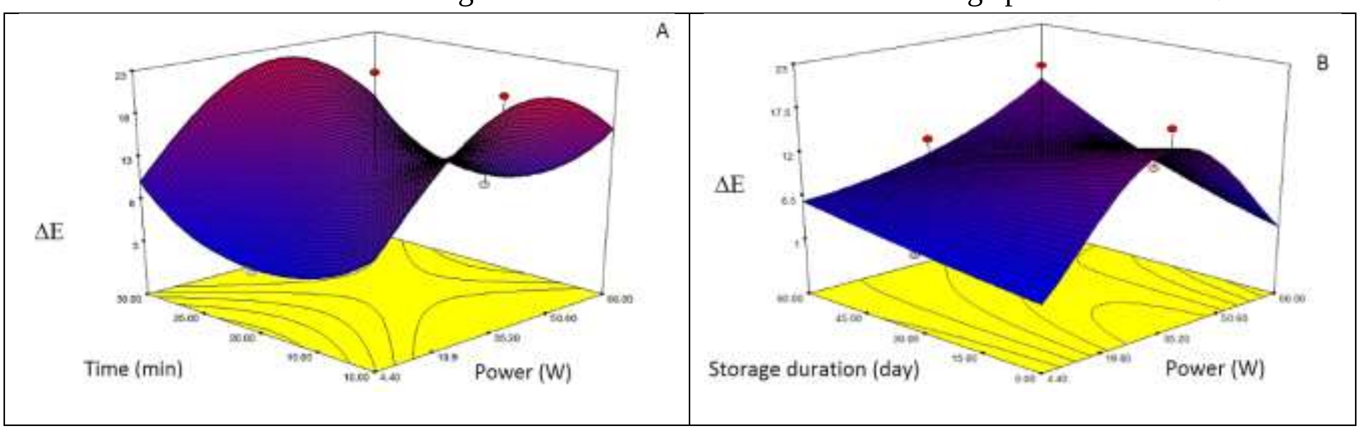


Figure 7. The effect of power, ultrasound treatment time, and storage period in the value of ΔE at the central points A: 20 minutes, B: 30 days, and C: 35.2 W.

Optimization process:

The results of the optimization process for the performance of the ultrasound device for the color compounds of the ultrasound-treated breast meat are shown in Table 4. The results showed that the optimal conditions for the performance of the device were the power of 66 W, the ultrasound treatment time of 24.07 minutes and the storage period of 40 days, which led to the improvement of the color components. The results also showed that the differences between the predicted and practical values were not significant ($p > 0.05$) for all color components.

There were significant differences ($p < 0.05$) between the conventional method and the standard treatment (untreated). Regarding the color components, the results showed that the values of L * and a

* were significantly higher ($p < 0.05$) than the standard treatment (untreated chicken breast meat). This is due to the fact that the ultrasound treatments stopped the spoilage changes and thus improved the color. Better despite the length of the storage period. Morbiato *et al.*, (2019) found that the values of L *, a *, and b * for fresh chicken meat (untreated) were 48.6, 7.8, and 11.2, respectively. The results showed that the value of b * was significantly lower when using ultrasound compared with the conventional method. The total change in color was significantly higher ($p < 0.05$) when using the ultrasound treatment than the conventional method because the color brightness (L) increased when using ultrasound as the meat color was bright compared to the conventional method. As for the color intensity, the results showed that it was significantly affected ($p < 0.05$) by the two factors (ultrasound and the traditional method) as the color intensity was higher when using ultrasound compared to the traditional method. While Lee, Park et al. (2004) and (Seo *et al*., 2019) showed that ultrasound-treated chickens did not show changes in skin color.

Table 4. Results of the optimization process for color components for ultrasound-treated breast meat under optimal conditions of ultrasound treatment time, power and storage period.

Independent variables			Dependent variables			Conventional method	Raw chicken breast meat (untreated)
P (W)	T (min.)	St (day)	Color components	Predicted values	Experimental values		
66	24.07	40	a*	13.969±0.54 [a]	14.032±0.86 [a]	11.294[b]	9.882[c]
			b*	12.981±0.63 [b]	13.011±0.97 [b]	14.117[a]	8.941[c]
			L*	57.204±6.63 [a]	58.003±6.94 [a]	49.803[c]	50.392[b]
			ΔE	10.950±0.99 [a]	10.980±1.98 [a]	4.94724[b]	-
			h (angle)	44.010±2.26 [b]	43.410±2.03 [b]	54.705[a]	42.158[c]

Conclusions:

A pelvic ultrasound device has been used to treat chicken breast at a power of 44 - 66 W, an ultrasound treatment time of 10-30 minutes, and a storage period of 0-60 days, using the central composite design. Optimum process conditions were power of 66 W, ultrasound treatment time of 24.07 minutes, and storage period of 40 days were used to optimize the dependent variables (color components). The color components of the ultrasound-treated chicken breast were better than the conventional method, and the color components of the untreated chicken breast were less than the ultrasound and the conventional method excluding L* value, as the differences between them were significant.

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تحسين مكونات لون صدور الدجاج المعالجة باستخدام الموجات فوق الصوتية

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الملخص

أجريت الدراسة لمعرفة تأثير الموجات فوق الصوتية على المكونات اللونية لصدور في مختبرات قسسم علوم الاغذية، كلية الزراعة، جامعة البصرة من 2019/10/1 إلى 2020/1/12 باستخدام متغيرات مستقلة (الاستطاعة من 4.4–66 واط، زمن المعاملة بالموجات فوق الصوتية من 10–30 دقيقة، مدة التخزين من 0–60 يوماً). تم استخدام طريقة سطح الاستجابة للحصول على الظروف المثلى للمتغيرات المستقلة ولتحسين المتغيرات التابعة (* L و * a و * b و h و ΔE). تم استخدام نماذج الانحدار التربيعي متعدد الحدود للتنبؤ بمركبات اللون. تمت مقارنة نتائج التحسين بالطريقة التقليدية واللحوم الطازجة. أظهرت النتائج أن الظروف المثلى كانت عند 66 واط، ووقت المعالجة بالموجات فوق الصوتية 24.07 دقيقة، وفترة التخزين 40 يومًا. كما كانت قيم * L و * a و Δ E للحوم صدور الدجاج المعاملة بالموجات فوق الصوتية أعلى بمقدار 16.46 و24.26 و122.26 على التوالي، بينما انخفضت قيم * b و h بمقدار 7.79 و20.63 درجة على التوالي. ظهرت فروق معنوية ($p < 0.05$) بين الموجات فوق الصوتية والطريقة التقليدية ولحوم صدور الدجاج الطازجة في مركبات الملون.

الكلمات المفتاحية: الموجات فوق الصوتية، لحم صدور الدجاج، مكونات اللون، عملية التحسين.