Taguchi Experimental Design to Optimize the Sugar Content of Candied Carrot

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Taguchi Experimental Design to Optimize the Sugar Content of Candied Carrot

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Abstract. Robust parameter design is used to design product that is robust to noise factors so the product's performance fits the target and delivers a better quality. In the process of designing and developing the innovation product of candied carrot, robust parameter design is done using Taguchi Method. The performance of the candied carrot is evaluated in terms of its percentage of sugar. Orthogonal Array (OA) of Taguchi, Analysis of Variance (ANOVA), signal-to-noise (S/N) ratio, and main effect were employed to analyze the effect of parameters on the percentage of sugar in the candied carrot. The optimal level is determined based on the highest signal-to-noise (S/N) ratio. The analysis of the results shows that the optimal composition for candied carrot are the amount of sugar of 25%, 40%, 50%, 60%, the soaking duration for 8 hours, the amount of cinnamon of 10 grams and the age of carrot of 5 months.
Keywords: robust parameter design, Taguchi method, candied carrot

1. Introduction

Carrot is an agricultural product that can be easily found in Indonesia. Although it has abundant harvest, the price of carrots is cheap because carrots are usually sold as a raw commodity. To increase the price of carrot, carrot can be made into processed products which desired by the customers. One of the product that was preferred by customers was candied carrot [1]. The design of candied carrot product had been developed to determine the critical parts while producing candied carrot [2]. Based on the design of candied carrot product, further research was carried out to determine the optimal production process and composition of candied carrot using Taguchi method. This method was used because it can determine the best combination through design of experiment [3]. Additionally, the researches using Taguchi experimental design had been conducted for many kind of food products [4], [5], [6] and [7].

This study attempts to determine the optimization of the production process and composition parameters for optimal percentage of sugar in candied carrot. Parameters have to be optimized to make the candied carrot with highest percentage of sugar.

2. Methods

Robust parameter design (RPD) is a method to product realization activities which focuses on choosing the controllable factors or parameters and their levels in a product. The objectives of RPD are to ensure that the mean of the product output is at target and to ensure that the variability around this target value

is small. The general RPD problem was developed by Genichi Taguchi. Taguchi proposed an approach to solve the RPD problem based on designed experiments and some novel methods for analysis of the resulting data [8].

2.1 Experimental design

The experimental design of Taguchi is conducted by stating the problems of concern, stating the objectives of the experiment, selecting the quality characteristics and measurement systems, selecting the factor which may influence the selected quality characteristics, identifying control factors and noise factors, selecting levels for the factors, and selecting the appropriate orthogonal array (OA) [3].

2.2 Perform the experiment and Anthrone test

The experiment was done by making the combination of factor and level as described in OA. In this study, the percentage of sugar in candied carrot is measured using Anthrone test.

2.3 Data processing

Data processing is done by calculating the Signal-to-Noise (S/N) ratio and Analysis of Variance (ANOVA). S/N ratio is a transformation of the repetition data to another value which is a measure of the variation present in Taguchi method. The S/N ratio consolidates several repetitions into one value which reflects the variation of the result. The S/N ratio for larger the better quality characteristic can be defined as [3]:

$$S/N_{LTB} = -10\log\left(\frac{1}{r}\sum_{i=1}^{r}\frac{1}{y_i^2}\right) \quad (1)$$

where r is the number of repetitions or observations i and y is the observed data.

ANOVA is a predominant statistical method that is used to interpret experimental data and make the necessary decisions. The determination of influential factors and the relative strengths is based on their levels. ANOVA is an objective decision making tool for detecting any differences in performance of a product. The decision on ANOVA calculation takes variation into account [3]. The purpose of ANOVA is to find how much variation for each factor affecting the total variation in the final result [9].

3. Result and Discussion

3.1 Experimental design planning

Experimental design planning started by determining the production process of candied carrot which had already conducted [10]. The planning stage was continued by selecting the parameters and their levels. Percentage of sugar in the candied carrot parameters and their levels were discussed with some experts in food technology. The experts said that there are three control parameters affecting the percentage of sugar. The parameters are amount of sugar, soaking duration in sugar solution, and amount of cinnamon. The experts also said that age of carrot also affecting the percentage of sugar. But the age of carrot in the market can't be controlled. So in this study, the age of carrot is set as a noise factor that is tried to be controlled. The level of each parameters is shown in Table 1.

Table 1. The Level of Each Parameters

Factor	Parameter	Unit	Level 1	Level 2	Level 3
A	Amount of Sugar	Percentage	-15 (1st soaking) -25 (2nd soaking) -40 (3rd soaking) -50 (4th soaking)	-25 (1st soaking) -40 (2nd soaking) -50 (3rd soaking) -60 (4th soaking)	- 35 (1st soaking) - 50 (2nd soaking) - 60 (3rd soaking) - 70 (4th soaking)
B	Soaking Duration	Hour	7	8	9
C	Amount of Cinnamon	Gram	10	30	
D	Age of Carrot	Months	3.5	5	

The next step was selection of orthogonal array (OA). The selection of OA depends on the parameters and their levels. In this section, there are one parameter that has two levels and two parameters that have three levels. Therefore, the OA that is appropriate is L_{18} ($2^1 \times 3^7$).

3.2 Data processing for each age of carrot

The percentage of sugar data resulted from Anthrone test then transformed into S/N ratio. To obtain the optimal percentage of sugar in candied carrot, larger the better quality characteristic must be taken. Table 2. shows the results for percentage of sugar and the S/N ratio for each age of carrot.

Table 2. Percentage of Sugar and S/N Ratio for Each Age of Carrot

Experiment	Parameters			Percentage of Sugar		S/N Ratio	
	A	B	C	3.5 months	5 months	3.5 months	5 months
1	1	1	1	26.19	53.81	28.3627	34.6173
2	2	1	1	35.52	54.97	27.7014	33.6284
3	3	1	1	34.70	51.66	31.0095	34.8025
4	1	2	1	24.27	48.02	26.7092	34.8608
5	2	2	1	21.65	55.34	30.8066	34.2631
6	3	2	1	25.02	53.17	27.9657	34.5133
7	1	3	1	39.71	40.98	31.9780	32.2514
8	2	3	1	29.51	44.29	29.3994	32.9261
9	3	3	1	31.42	49.08	29.9441	33.8181
10	1	1	2	16.73	37.52	24.4699	31.4853
11	2	1	2	19.58	41.20	25.8363	32.2979
12	3	1	2	18.88	40.27	25.5200	32.0996
13	1	2	2	33.95	46.35	30.6168	33.3210
14	2	2	2	30.16	50.84	29.5886	34.1241
15	3	2	2	28.82	50.77	29.1939	34.1121
16	1	3	2	21.21	44.55	26.5308	32.9770
17	2	3	2	27.62	43.03	28.8245	32.6754
18	3	3	2	27.47	39.15	28.7772	31.8546

The result of the S/N ratio is converted into a main effect plot by calculating the mean of S/N ratio. The main effect plot shows the effect of each parameter at different levels. The main effect plot was conducted using Minitab 17 software. The main effect plot for each age of carrot is shown as follows:

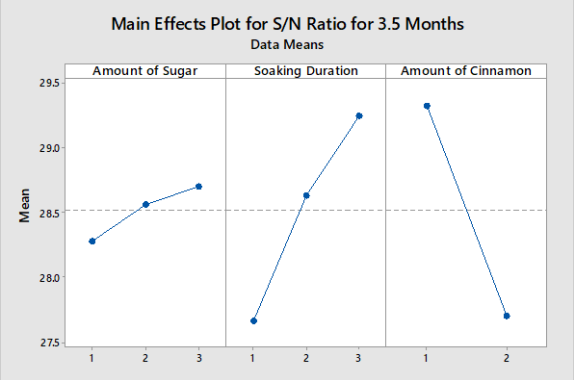

Figure 1. Main Effects Plot for 3.5 Months Carrot

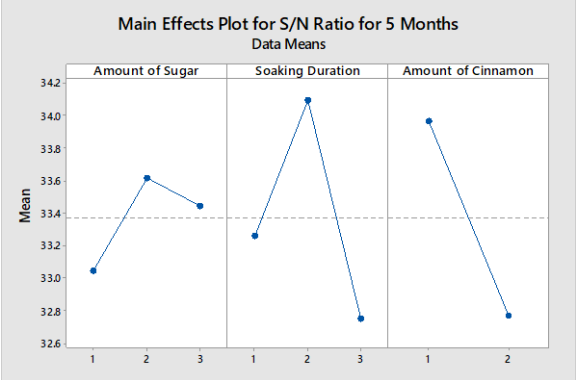

Figure 2. Main Effects Plot for 5 Months Carrot

To determine the optimal combinations of the parameter levels, the relative importance amongst the parameters for percentage of sugar had to be known using ANOVA. The test of hypothesis was conducted for all factors for 95% confidence level. The hypothesis for each factor is described as follows:

1. Factor A
H_0: there is no effect of factor A to percentage of sugar
H_1: there is an effect of factor A to percentage of sugar
2. Factor B
H_0: there is no effect of factor B to percentage of sugar
H_1: there is an effect of factor B to percentage of sugar
3. Factor C
H_0: there is no effect of factor C to percentage of sugar
H_1: there is an effect of factor C to percentage of sugar

The ANOVA calculation was conducted using Minitab 17 software. ANOVA for each age of carrot is shown as follows:

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Amount of Sugar	2	1.508	0.754	0.02	0.983
Soaking Duration	2	53.527	26.764	0.62	0.555
Amount of Cinnamon	1	105.464	105.464	2.44	0.144
Error	12	519.325	43.277		
Total	17	679.824			

Figure 3. ANOVA for 3.5 Months Carrot

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Amount of Sugar	2	29.82	14.91	0.91	0.429
Soaking Duration	2	158.29	79.14	4.82	0.029
Amount of Cinnamon	1	184.58	184.58	11.24	0.006
Error	12	197.02	16.42		
Total	17	569.70			

Figure 4. ANOVA for 5 Months Carrot

Based on the hypothesis test, the factor A, factor B, factor C for the 3.5 months carrot and factor A for the 5 months carrot accept the H_0, that means these factors didn't affect the percentage of sugar. But the factor B and factor C for the 5 months carrot reject the H_0, that means these factors affect the percentage of sugar. Because the result of ANOVA for each age of carrot is different, so the calculation using age of carrot factor is conducted to find the effect of age of carrot.

3.3 Data processing for all factors

In this section, there are two parameters that have two levels and two parameters that have three levels. The OA that is suitable for this section is L_{36} (2^3x3^{13}). The next step is to calculate the S/N ratio and to conduct the main effect plot by calculating the mean of S/N ratio. Table 3. shows the results for percentage of sugar and the S/N ratio.

Table 3. Percentage of Sugar and S/N Ratio

Exp.	A	B	C	D	Percentage of Sugar	S/N Ratio	Exp.	A	B	C	D	Percentage of Sugar	S/N Ratio
1	1	1	1	1	26.19	28.3627	19	2	1	1	2	54.97	34.8025
2	1	2	1	1	24.27	27.7014	20	2	2	1	2	55.34	34.8608
3	1	3	1	1	39.71	31.9780	21	2	3	1	2	44.29	32.9261
4	1	1	2	1	16.73	24.4699	22	2	1	2	2	41.20	32.2979
5	1	2	2	1	33.95	30.6168	23	2	2	2	2	50.84	34.1241
6	1	3	2	1	21.21	26.5308	24	2	3	2	2	43.03	32.6754
7	1	1	1	2	53.81	34.6173	25	3	1	1	1	34.70	30.8066
8	1	2	1	2	48.02	33.6284	26	3	2	1	1	25.02	27.9657
9	1	3	1	2	40.98	32.2514	27	3	3	1	1	31.42	29.9441
10	1	1	2	2	37.52	31.4853	28	3	1	2	1	18.88	25.5200
11	1	2	2	2	46.35	33.3210	29	3	2	2	1	28.82	29.1939
12	1	3	2	2	44.55	32.9770	30	3	3	2	1	27.47	28.7772
13	2	1	1	1	35.52	31.0095	31	3	1	1	2	51.66	34.2631
14	2	2	1	1	21.65	26.7092	32	3	2	1	2	53.17	34.5133
15	2	3	1	1	29.51	29.3994	33	3	3	1	2	49.08	33.8181
16	2	1	2	1	19.58	25.8363	34	3	1	2	2	40.27	32.0996
17	2	2	2	1	30.16	29.5886	35	3	2	2	2	50.77	34.1121
18	2	3	2	1	27.62	28.8245	36	3	3	2	2	39.15	31.8546

The result of the S/N ratio is converted into a main effect plot. The main effect plot was conducted using Minitab 17 software. The main effect plot for S/N ratio for all factors are used is shown in Figure 5.

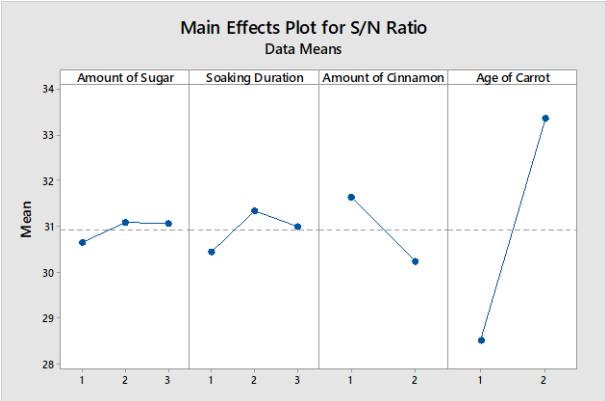

Figure 5. Main Effects Plot

To determine the optimal combinations of the parameter levels, the relative importance amongst the parameters for percentage of sugar had to be known using ANOVA. The test of hypothesis was conducted for all factors for 95% confidence level. The hypothesis for each factor is described as follows:

1. Factor A
H_0: there is no effect of factor A to percentage of sugar
H_1: there is an effect of factor A to percentage of sugar
2. Factor B
H_0: there is no effect of factor B to percentage of sugar
H_1: there is an effect of factor B to percentage of sugar
3. Factor C
H_0: there is no effect of factor C to percentage of sugar
H_1: there is an effect of factor C to percentage of sugar
4. Factor D
H_0: there is no effect of factor D to percentage of sugar
H_1: there is an effect of factor D to percentage of sugar

The ANOVA calculation was conducted using Minitab 17 software. ANOVA is shown as follows:

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Amount of Sugar	2	20.03	10.01	0.33	0.721
Soaking Duration	2	65.64	32.82	1.08	0.352
Amount of Cinnamon	1	284.54	284.54	9.38	0.005
Age of Carrot	1	3453.33	3453.33	113.89	0.000
Error	29	879.32	30.32		
Total	35	4702.85			

Figure 6. ANOVA

Based on the hypothesis test, the factor A and factor B accept the H_0, that means these factors didn't affect the percentage of sugar. But the factor C and factor D reject the H_0, that means these factors affect the percentage of sugar. In addition, percentage contribution of each parameter was also calculated. The percentage contribution of each parameter is shown as follows:

Table 4. Percentage Contribution of Each Parameter

Parameter	Percentage Contribution
Amount of Sugar	0.86%
Soaking Duration	0.11%
Amount of Cinnamon	5.41%
Age of Carrot	72.79%

3.4 Comparison and analysis of the result
Optimal composition was determined by choosing the highest mean of S/N ratio from each parameter which are shown in the main effects plot. The optimal composition for each age of carrot and for all factors is shown in Table 5.

Table 5. Optimal Composition of Each Parameter

Factor	Optimal Level		
	3.5 Months Carrot	5 Months Carrot	All Factors
A	3	2	2
B	3	2	2
C	1	1	1
D	-	-	2

Based on Table 5 the optimal composition for 3.5 months carrot was the amount of sugar is 35%, 50%, 60%, 70%, the soaking duration is 9 hours and the amount of cinnamon is 10 grams. The optimal composition for 5 months carrot was the amount of sugar is 25%, 40%, 50%, 60%, the soaking duration is 8 hours and the amount of cinnamon is 10 grams. Based on Table 4. the age of carrot has a huge contribution for percentage of sugar in candied carrot (72.79%).

Therefore, it is better to use the 5 months carrot with less amount of sugar and less soaking duration, but has a higher percentage of sugar. Also, the percentage of sugar in the optimal composition for 5 months carrot is higher percentage of sugar (55.34%) than in the optimal composition for 3.5 months carrot (31.42%). Therefore, the optimal composition for candied carrot is shown in Table 6.

Table 6. The Level of Each Parameters

Factor	Parameter	Level 2
A	Amount of Sugar	-25% (1st soaking)
		-40% (2nd soaking)
		-50% (3rd soaking)
		-60% (4th soaking)
B	Soaking Duration	8 hours
C	Amount of Cinnamon	10 grams
D	Age of Carrot	5 months

4. Conclusion

Percentage of sugar in the candied carrot was affected by the amount of sugar (factor A), the soaking duration in sugar solution (factor B), the amount of cinnamon (factor C) and the age of carrot (factor D). The experiment was done by making the combination of factor and level as described in OA. The percentage of sugar data that was tested using Anthrone test then transformed into S/N ratio. The result of the S/N ratio is converted into a main effect plot. Next, the hypothesis test was conducted to determine the optimal combinations of the parameter levels using ANOVA. Because the result of ANOVA for each age of carrot is different, so the calculation using age of carrot factor is conducted to find the effect of age of carrot. The result showed that the age of carrot has a huge contribution for percentage of sugar in candied carrot. The optimal composition for candied carrot are the amount of sugar of 25%, 40%, 50%, 60%, the soaking duration for 8 hours, the amount of cinnamon of 10 grams and the age of carrot of 5 months.

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5. References

[1] Halim V and Ekawati Y 2014 Perencanaan Produk Olahan Wortel Menggunakan Metode Quality Function Deployment *Symbol* **1** pp 57-67
[2] Ekawati Y and Bazarado M 2016 Designing Food Products Based on Carrots Using the Product Design Phase of Quality Function Deployment *ARPN Journal of Engineering and Applied Science* **11** pp 3109-16
[3] Ross, P J 1996 *Taguchi Techniques for Quality Engineering* (New York: Mc Graw-Hill)
[4] Sihombing H, Hafiz M K, Yuhazri M Y and Kannan R 2012 Taguchi's Quality Improvement Analysis of the SME Bread Manufacturing *Global Engineers & Technologists Review* **2** pp 6-13
[5] Habibi N, Soleimanian-Zad S and Zeinoddin M S 2011 Optimization of Kefir Grains Production by Using Taguchi Technique and Mini-Fermentation *World Applied Sciences Journal* **12** pp 613-18
[6] Noorwali A 2013 Apply Lean and Taguchi in Different Level of Variability of Food Flow Processing System *Procedia Engineering* **63** pp 728-34
[7] Naik E K M and Bala E K L 2013 Study on Optimization of Microwave Frying of Potato Slices by Using Taguchi Design *International Journal of Engineering Research & Technology* **2** pp 141-8
[8] Montgomery D.C 2013 *Design and Analysis of Experiments* (New York: John Wesley and Sons)
[9] Roy R K 2001 *Design of Experiments Using The Taguchi Approach* (New York: John Wiley & Sons, Inc)
[10] Noya S, Ekawati Y and Utami N 2017 Quality Function Deployment for Candied Carrots Process Planning *International Journal of Engineering and Advanced Technology Studies* **5** pp 1-7