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EXPERIMENTAL DESIGN IN DETERMINING QUALITY CHARACTERISTICSOF CARROT SYRUP

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ABSTRACT

One of the strategies to increase the selling price of agricultural products is to diversify the products. This effort had been made on carrots product by diversifying it into carrot syrup. Several previous studies had been done to determine the attributes of consumer needs and product design of carrot syrup using the Quality Function Development method. Based on these studies, this research used experimental design to determine the optimal quality design in the process and ingredients composition of carrot syrup. Utilizing the Taguchi experimental design, this study qualitatively measured the quality response of the product by using organoleptic test. The organoleptic test resulted in ordinal data that needed to be analyzed using an appropriate method to find the robust levels of product and process parameters. Data processing was conducted by planning the experimental design; fitting an ordinal categorical regression model and calculating event probabilities for each category; estimating expected category for each factor combination; calculating Taguchi's signal-to-noise (S/N) ratios; and determining the optimal factor level. At the end of this research, it is concluded that the optimal process and composition of carrot syrup is the duration of heat for 20 minutes and the amount of sugar of 210%.

Keywords: experimental design, ordinal data, carrot syrup.

INTRODUCTION

Diversification is an attempt to make a product or service diverse. Product diversification can increase the value of a product. Diversification of products can also be done on carrots, the agricultural products that have a relatively low durability and cannot be stored for a long time. A previous research had been conducted to find carrot based products preferred by consumers and the attributes of consumer needs for the products [1]. One of the products found in the research was carrot syrup. The research also found that there are six attributes of consumer needs for carrot syrup, namely 'fresh taste', 'flavors that match the taste', 'right level of sweetness', 'does not cause aftertaste', 'color is not flashy', and syrup has a 'clear appearance'. The product design of carrot syrup has been developed to find the critical parts in producing carrot syrup [2]. Based on the attributes of consumer needs and the product design, then further research was carried out to determine the best process and composition of carrot syrup using Taguchi method. The method was used because it is a standardized approach for determining the best combination of inputs to produce a product or service. The best combination is accomplished through design of experiment [3].

The researches using Taguchi method had been conducted for various food products [4], [5], [6], [7]. However, most of the researches conducted using Taguchi method for food products used a quality response of products or processes that typically measured quantitatively on interval or ratio scale. The research conducted on carrot syrup was based on the attributes of consumer needs which the quality response of the product was measured qualitatively using organoleptic test. The organoleptic test resulted data on ordinal scale that needed to be analyzed using an appropriate method to find the robust levels of product and process parameters. The data analysis in this research uses a method proposed by Erdural *et al*. [8] that offers a simple and effective method for the analysis of categorical response data for robust product or process design.

RESEARCH METHOD

Experimental Design Planning

The Taguchi method consists of three main stages: planning stage, conducting stage, and analysis stage. Planning stage in this research began with the identification of quality dimensions to be improved, they were taste and appearance generated from the quality attributes of consumer needs. The next step was determining the levels based on factors that had been determined, followed by the creation of an orthogonal array to determine the number of experiments to be performed. At this stage, a brainstorming process with experts in the field of food technology was carried out to determine the factors that affect the quality of the syrup, the levels of each factor and to give some advice in the process of the making of the carrot syrup being tested to the consumers.

Organoleptic Test to Consumers

After planning stage was completed, the experiments were conducted using organoleptic test. The organoleptic test involved 60 consumer panelists. This type of panel was selected because the research was conducted to determine the composition according to consumer preferences. In this organoleptic test the consumer rated their preferences using Likert scale.

Data Processing

Data processing was done in accordance with the steps of the method proposed by Erdural *et al* [8]. This research used data analysis according to the following steps:

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A. Generating an appropriate experimental design and collecting data.
B. Fitting an ordinal categorical regression model and calculating event probabilities for each category. Ordinal logistic regression method is used to fit a model that estimates the event probabilities for each category. Ordinal regression model is as follows:

$$Link\left(P\left(Y_i \leq j\right)\right) = \gamma_j + \beta' X_i \quad (1)$$

where *j* is the category ($j = 0,1,\ldots,J-1$), γ_j is the cut point (constant), β is the vector of coefficients and X_i is the vector of the control factors' levels at combination *i* of the experiment.

C. Estimating expected category for each factor combination. This step begins by calculating the probability of each rating scale using the formula:

$$P\left(Y_i \leq j\right) = \frac{e^{\left(\gamma_j + \beta_1' x_{1i} + \beta_2' x_{2i} + \ldots + \beta_k' x_{ki}\right)}}{1 + e^{\left(\gamma_j + \beta_1' x_{1i} + \beta_2' x_{2i} + \ldots + \beta_k' x_{ki}\right)}} \quad (2)$$

After that, by using factor level combinations in step 1 and estimated event probabilities for each category in step 2, the expected category and the variance for each factor combination *i* of the experiment are estimated as follows:

$$E\left(Y_i\right) = \sum_{j=0}^{j-1} jP\left(Y_i = j\right) \quad (3)$$

$$V\left(Y_i\right) = E\left(Y_i^{\,2}\right) - \left[E\left(Y_i\right)\right]^2 \quad (4)$$

D. Calculating Taguchi's signal-to-noise (S/N) ratios using $E(Y_i)$ and $V(Y_i)$ calculated in step 3 for each factor combination *i*. This research uses the S/N Ratio for a larger-the-better type of a response and the formula is:

$$\text{S/N } Ratio_{\,i} = -10 \times \log\left[\left(\frac{1}{\left(E[Y_i]\right)^2}\right) \times (1+3) \times \left(\frac{V(Y_i)}{\left(E[Y_i]\right)^2}\right)\right] \quad (5)$$

E. Determining the optimal factor level. By using main effect, the optimal factor levels were taken from each combination. Main effect is used to observe the difference between the average levels for one or more factors.

RESULTS AND DISCUSSIONS

As had been mentioned before, there are six attributes of consumer needs for carrot syrup, namely 'fresh taste', 'flavors that match the taste', 'right level of sweetness', 'does not cause aftertaste', 'color is not flashy', and 'clear appearance'. The six attributes were grouped into two quality dimensions, taste and appearance. Fresh taste, flavors that match the taste, the right level of sweetness and does not cause aftertaste was grouped into taste dimension. Coloris not flashy and clear appearance was grouped into appearance dimension. The experiment used Standar Nasional Indonesia (SNI) as a main consideration in determining the factor and level in the experimental design because the product being tested was a food product. This research used SNI 3544:2013 standard for syrup [9]. SNI 3544:2013 establishes the terms, definitions, quality requirements, sampling, test methods, packaging and labeling syrup. Syrup itself is a beverage product made from a mixture of water and sugar with a minimum sugar content of 65% with or without other food and/or food additives permitted in accordance with applicable regulations.

Experimental Design Planning

Experimental design planning began with determining the production process of carrot syrup. The production process used the process resulted from a research of determining the process quality planning for carrot syrup [10]. The next step was brainstorming with some experts in the field of food technology. The first thing discussed was determining the factors that affect the quality of the syrup. Based on the discussion, those factors that affect the syrup quality were duration of heating, temperature, worker skills, amount and type of sugar, addition of essence, species and age of carrots. Including in the discussion was the determination of the number of factors and levels of each factor, and possible noise factors to be controlled.

The duration of heating and temperature are two things that affect the quality of carrot syrup. The longer the duration of heating and the higher the temperature will make the water content in the syrup decreasing so that the syrup becomes sweeter. The temperature used in the process was 100^o Celcius based on the initial process determined on the previous research [10]. This study used local carrot varieties. The local carrots were chosen as one of the aims of this research was to find carrot based food products that help empowering local carrot farmers. As for the distinctive aroma of carrots, it can be reduced by the addition of essence. However, it got difficulty finding any kind of essence appropriate to reduce the typical aroma of carrots.

One of the steps in making carrot syrup was blanching process [10]. Based on the research the blanching process can be done at a temperature range of 60^{o}C to 100^{o}C within 5 to 10 minutes. The blanching process itself aims to facilitate the process of making carrot juice and to disable the enzyme activity contained in carrots. An experiment was carried out to get the effect of the duration of blanching process on the carrot juice. The temperature used was 80^{o}Ccombined with three selected duration, 5 minutes, 8 minutes, and 10 minutes with equal treatment in the three durations. After the experiment was conducted in the three samples, it was found that there was no difference in terms of filtrate color and filtrate clarity level in the three samples. Based on the experimental result, it was decided that the duration of the blanching process was 5 minutes as it is more advantageous in terms of time when the production of carrot syrup takes place.

Therefore, there were two control factors used in this experiment that can affect the quality attributes of carrot syrup. These factors were the duration of heating and the amount of sugar. Both factors were determined using three levels. Differences in sweetness can be easily distinguished by consumer panellist, so there should be three levels that consider the lower limit, the middle limit, and the upper limit.

The attribute of ‘the right level of sweetness’ was not included in the experiment since the level of sweetness can be more appropriately detected by measuring the content of sugar in the syrup and not based on a hedonic test. Therefore, the attributes of consumer needs included in the experimental design are ‘fresh taste’ (A1), ‘flavors that match the taste’ (A2), ‘does not cause aftertaste’ (A3), ‘color is not flashy’ (A4), and ‘clear appearance’ (A5). Besides the control factors, the discussion also determined the noise factors. The noise factor selected was the age of carrot. This noise factor consisted of two levels, so the replication of the experiment was twice. The levels for each factor are as follows:

Table-1. Levels for Each Factor.

Factors	Levels		
	1	2	3
Duration of heating (A)	20 minutes	30 minutes	40 minutes
Amount of sugar (B)	200%	205%	210%

The percentage of sugar indicates the amount of sugar compared to the amount of carrot filtrate so that the minimum sugar content in the syrup will be 65%.

The final stage of experimental planning was the determination of an orthogonal array. The orthogonal array was based on the number of factors and levels of each factor. This research used two control factors with three levels each, so the number of experiments to be carried out was nine experiments. The combination of the composition level of the experiment to be performed on carrot syrup can be seen on Table-2.

Table-2. Combination of Experiments.

Eksperiment	Factors	
	A (Duration of Heating)	B (Amount of Sugar)
1	1	1
2	1	2
3	1	3
4	2	1
5	2	2
6	2	3
7	3	1
8	3	2
9	3	3

Based on Table-2, it can be seen the composition to be used in each experiment. The combination of compositions used as an experimental sample can be seen on Table-3.

Table-3. The Factor Composition of Each Experimentt.

Experimentt	Factors	
	A (Duration of Heating)	B (Amount of Sugar)
1	20 minutes	200%
2	20 minutes	205%
3	20 minutes	210%
4	30 minutes	200%
5	30 minutes	205%
6	30 minutes	210%
7	40 minutes	200%
8	40 minutes	205%
9	40 minutes	210%

Based on this combination, nine carrot syrup experimental samples that will be tested on consumers were prepared. Consumer panelists for this hedonic test were 60 panelists from various backgrounds. This experiment was conducted twice with the same respondents.

Data Processing

The quality characteristics must be in line with the objectives of the research. The purpose of this research was to determine the optimal quality of carrot syrup products in terms of taste and appearance. Then the quality characteristics used were larger the better because the higher the value obtained from organoleptic tests it meant that the product was preferred by consumers. Factors used in this research were the duration of heating and the amount of sugar as been explained before.

The data obtained from the organoleptic test was then tested using ordinal logistic regression method with the help of Minitab 17 program. This test was conducted to five attributes of consumer needs. An example from calculation of the attribute of ‘ fresh taste’ is given.

The first step was conducting hypothesis testing. The hypothesis test of attribute ‘fresh taste’ is as follows:

1. H_0: There is no effect of factor A (heating duration) and factor B (amount of sugar) when used simultaneously
2. H_1: There is effect of factor A (heating duration) and factor B (amount of sugar) when used simultaneously
3. α = 0.05;
4. CR: p-value<α
5. Statistic test:

```
Log-Likelihood = -1487.919
Test that all slopes are zero: G = 10.351, DF = 2, P-Value = 0.006
```

Figure-1. Likelihood Ratio Test for ‘Fresh Taste’.

6. **Decision:** reject H_0 and conclude that factor A (duration of heating) and factor B (amount of sugar) when used simultaneously affect the attribute of ‘has a fresh taste’.

Ordinal logistic regression calculation can be used to find the significant factors to the attribute by comparing the p-value of each factor (factor A and factor B). The hypothesis test of each factor to attribute ‘fresh taste’ is as follows:

a. Factor A

1. H_0: Factor A (duration of heating) is not significant to the quality attribute ‘fresh taste’.
2. H_1: Factor A (duration of heating) is significant to the quality attribute ‘fresh taste’.
3. α = 0.05
4. **CR:** p-*value*< α
5. Statistic test:

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	95% CI Upper
Const(1)	-3.40545	0.254530	-13.38	0.000			
Const(2)	-1.09297	0.203585	-5.37	0.000			
Const(3)	0.482364	0.201146	2.40	0.016			
Const(4)	2.39794	0.221159	10.84	0.000			
A	0.164530	0.0677389	2.43	0.015	1.18	1.03	1.35
B	-0.138675	0.0676927	-2.05	0.041	0.87	0.76	0.99

Figure-2. Wald Test for Factor A of ‘Fresh Taste’.

6. **Decision:** reject H_0 and conclude that factor A (duration of heating) is significant to the quality attribute ‘has a fresh taste’

a. Factor B

1. H_0: Factor B (amount of sugar) is not significant to the quality attribute ‘fresh taste’.
2. H_1: Factor B (amount of sugar) is significant to the quality attribute ‘fresh taste’
3. α = 0.05
4. CR: p-*value*< α
5. Statistic test:

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	95% CI Upper
Const(1)	-3.40545	0.254530	-13.38	0.000			
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Const(4)	2.39794	0.221159	10.84	0.000			
A	0.164530	0.0677389	2.43	0.015	1.18	1.03	1.35
B	-0.138675	0.0676927	-2.05	0.041	0.87	0.76	0.99

Figure-3. Wald Test for Factor B of ‘Fresh Taste’

6. **Decision:** reject$H_0$and conclude that factor B (amount of sugar) is significant to the quality attribute ‘fresh taste’.

The logistic regression equations for the event probabilities of attribute have a fresh taste are given as:

$$\text{Logit } P(Y = 1|X) = -3.40545 + 0.16453\,A - 0.13868\,B$$
$$\text{Logit } P(Y \leq 2|X) = -1.09297 + 0.16453\,A - 0.13868\,B$$
$$\text{Logit } P(Y \leq 3|X) = 0.482364 + 0.16453\,A - 0.13868\,B$$
$$\text{Logit } P(Y \leq 4|X) = 2.39794 + 0.16453\,A - 0.13868\,B$$

The model is then used to calculate opportunities for each category, expected category, variance, and S/N Ratio for each experiment using the Formula 2 until Formula 4. The calculation of the attribute ‘fresh taste’ can be seen Table-4.

Determining the Optimal Composition

After calculating the value of S/N Ratio to each attribute of quality, the next step was to determine the optimal level setting. The optimal level was determined by the level that has the highest S/N Ratio on the overall quality attributes.

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Table-4. Opportunity Each Category, Expected Category, Variance, and S/N Ratio on Attribute Fresh Taste.

Factors		**$P(Y_i = j)$**					**$E(Y_i)$**	**$V(Y_i)$**	**S/N Ratio$_i$**
A	**B**	**j=1**	**j=2**	**j=3**	**j=4**	**j=5**			
1	**1**	0,0329	0,2230	0,3684	0,2942	0,0814	3,1681	0,9463	8,9343
1	**2**	0,0288	0,2016	0,3609	0,3163	0,0924	3,2418	0,9441	9,1793
1	**3**	0,0252	0,1816	0,3507	0,3379	0,1047	3,3153	0,9394	9,4190
2	**1**	0,0386	0,2499	0,3736	0,2680	0,0699	3,0807	0,9454	8,6373
2	**2**	0,0338	0,2271	0,3695	0,2901	0,0795	3,1544	0,9464	8,8880
2	**3**	0,0295	0,2055	0,3625	0,3122	0,0902	3,2280	0,9447	9,1340
3	**1**	0,0452	0,2782	0,3745	0,2422	0,0599	2,9934	0,9409	8,3341
3	**2**	0,0396	0,2543	0,3740	0,2639	0,0682	3,0669	0,9449	8,5900
3	**3**	0,0346	0,2313	0,3705	0,2860	0,0776	3,1406	0,9464	8,8416

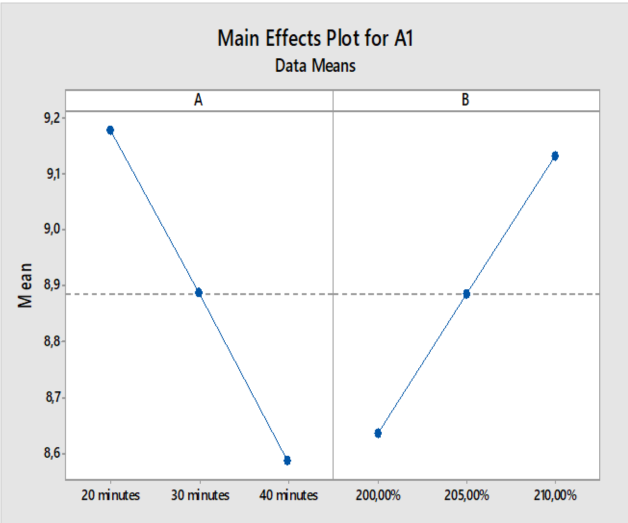

Figure-4. Main Effect Plot For ‘Fresh Taste.

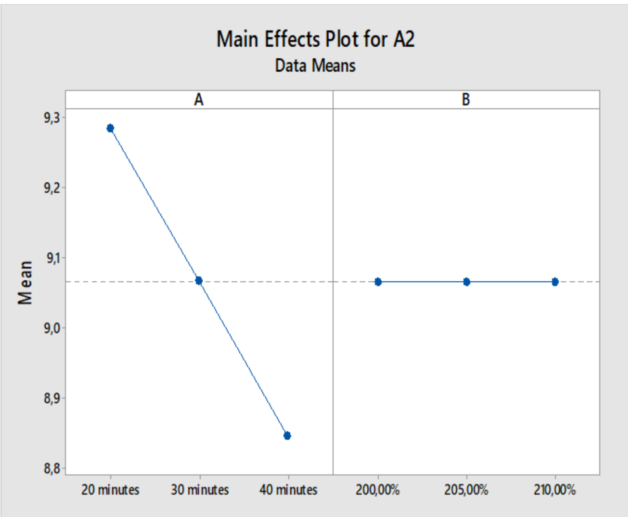

Figure-5. Main Effect Plot for ‘Flavor that Match the Taste.

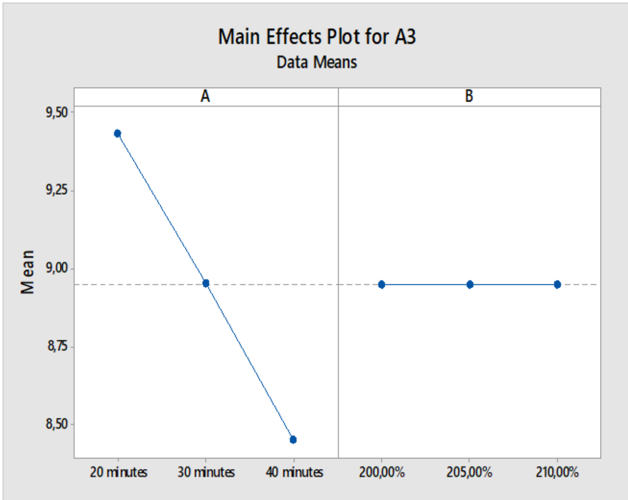

Figure-6. Main Effect Plot for ‘Does Not Cause Aftertaste.

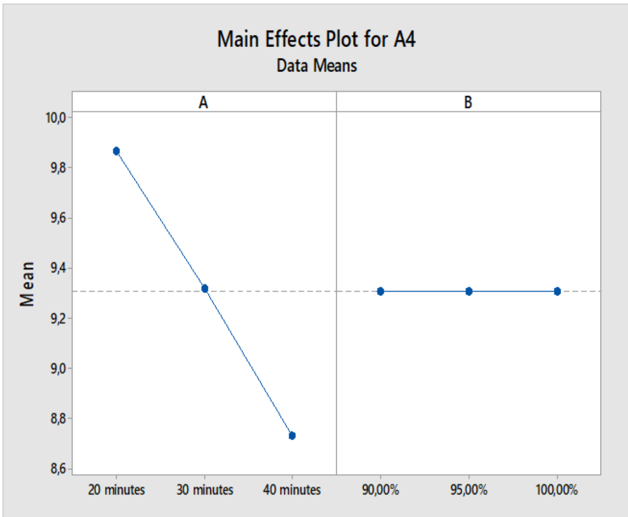

Figure-7. Main Effect Plot for ‘Color Is Not Flashy.

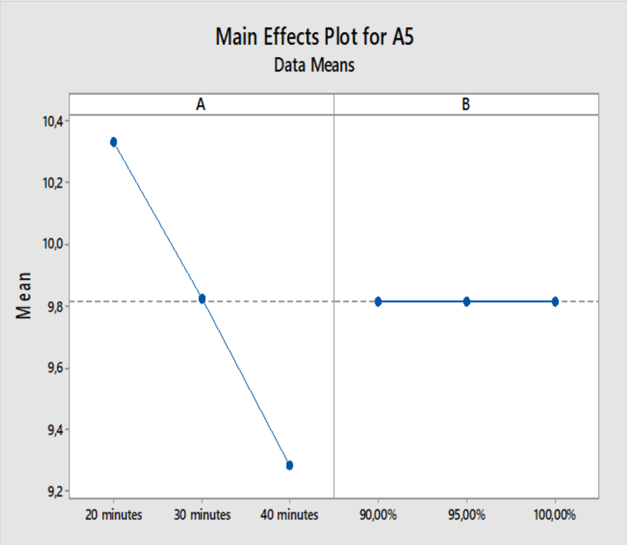

Figure-8. Main Effect Plot for 'Clear Appearance.

Based on all figures above, it can be seen levels with the highest score on each factor. This main effect is done to the five attributes of consumer needs, so it is found the optimal process and composition of carrot syrup is as follows:

Table-5. Optimal Level Result.

Factors	Levels	Composition
Duration of heating	Level 1	20 minutes
Amount of sugar	Level 3	210%

Confirmation Experiment

If the optimal combination is already present in the orthogonal array, then the confirmation experiment does not have to be performed. In this research the optimal combination of composition has been found in orthogonal array, which is found in experiment number 3 with duration of heating 20 minutes and amount of sugar is 210%.

CONCLUSIONS

The research to find the best composition and process of carrot syrup using Taguchi method has found that two factors affected the quality dimension of the carrot syrup. The quality dimensions based on the attributes of consumer needs were taste and appearance. The quality response for the two quality dimensions has to be measured qualitatively. A method for analysis of categorical data for robust product and process design is used to find the robust levels of product and process parameters of carrot syrup. The result of the optimal process and composition of carrot syrup is the duration of heat for 20 minutes and the amount of sugar of 210%.

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