

Taguchi experimental design to determine the taste quality characteristic of candied carrot

Y Ekawati and A A Hapsari

Department of Industrial Engineering, Universitas Ma Chung, Malang, Indonesia

yurida.ekawati@machung.ac.id

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 innovative product of candied carrot, robust parameter design is carried out using Taguchi Method. The method is used to determine an optimal quality design. The optimal quality design is based on the process and the composition of product ingredients that are in accordance with consumer needs and requirements. According to the identification of consumer needs from the previous research, quality dimensions that need to be assessed are the taste and texture of the product. The quality dimension assessed in this research is limited to the taste dimension. Organoleptic testing is used for this assessment, specifically hedonic testing that makes assessment based on consumer preferences. The data processing uses mean and signal to noise ratio calculation and optimal level setting to determine the optimal process/composition of product ingredients. The optimal value is analyzed using confirmation experiments to prove that proposed product match consumer needs and requirements. The result of this research is identification of factors that affect the product taste and the optimal quality of product according to Taguchi Method.

1. Introduction

Carrot is an agricultural product that needs to be developed to increase its value. The development of carrot products had been studied to find the carrot products which were preferred by consumers [1]. One of the products preferred was candied carrot. The research also resulted in the attributes of consumer needs for the candied carrot. There are nine attributes of consumer needs for candied carrot. The attributes are grouped into two dimensions of quality, taste and texture. The quality dimension assessed in this research is limited to the taste dimension. Five of the nine attributes of consumer needs are the quality of taste, namely no unpleasant taste, no pungent smell, have about the right sweetness level, have about the right sourness level, and no bitter aftertaste. The product design of candied carrot had been developed to find the critical parts in producing candied carrot [2]. Based on the attributes of consumer needs and the product design, then further research was carried out to determine the optimal process and composition of candied carrot. The optimal process and composition need to be found as there is variation in the performance of a product. The variation degrades the product's quality. One of these approaches to determine the optimum is robust design (also known as parameter design or optimization). In the process of designing and developing the innovation product of candied carrot, robust parameter design is done using Taguchi Method. The method focuses in reducing the influence of factors, called noise, that degrade the performance of a product or process [3]. The Taguchi method achieves the robustness to noise through proper settings of certain parameters, called control factors. The improved



settings of the parameters are obtained through statistically designed experiments that enable one to study a large number of factors with relatively few experiments.

There are several researches in various food products that had been conducted using Taguchi method [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 candied carrot was based on the attributes of consumer needs which the quality response of the product will be measured qualitatively using organoleptic test. The organoleptic test results data on ordinal scale that needs 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.

2. Research Methods

2.1. Experimental Design Planning

The planning stage of Taguchi is done by formulating the problem, determining the experimental objectives, choosing quality characteristics, selecting factors that affect the quality characteristics, identifying controlled and uncontrolled factors, determining the number of levels and factor values, and selecting orthogonal arrays to determine the number of experiments to be performed. All these are done by conducting discussions and brainstorming with the help of experts in the field of food technology.

2.2. Perform Organoleptic Test

The conducting stage is carried out using organoleptic test. The organoleptic test involves 60 - 90 consumer panelists. The consumer panel is selected based on the commodity's marketing target. The panelist is asked for his/her personal response on the products on a scale of 1 (very unsatisfied) to 5 (very satisfied). The results of these organoleptic tests will then be collected for further processing.

2.3. Data Processing

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

1. Generating an appropriate experimental design and collecting data.
2. 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:

$$\text{Link}(P(Y_i \leq j)) = \gamma_j + \beta' X_i \quad (1)$$

$$P(Y \leq j | x) = \frac{e^{(\gamma_j + \beta'_1 x_{1i} + \beta'_2 x_{2i} + \dots + \beta'_k x_{ki})}}{1 + e^{(\gamma_j + \beta'_1 x_{1i} + \beta'_2 x_{2i} + \dots + \beta'_k x_{ki})}} \quad (2)$$

where j is the category ($j = 0, 1, \dots, J-1$), 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.

3. Estimating expected category for each factor combination. 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:

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

$$V(Y_i) = E(Y_i^2) - [E(Y_i)]^2 \quad (4)$$

4. Calculating Taguchi's signal-to-noise 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:

$$SNR_i = -10 \times \log \left[\left(\frac{1}{(E[Y_i])^2} \right) \times (1+3) \times \left(\frac{V(Y_i)}{(E[Y_i])^2} \right) \right] \quad (5)$$

5. Determining the optimal factor level using main effect. Finding the optimal factor levels that maximize SNR, hence achieve the minimum variance.

3. Result and Discussion

The attributes of consumer needs for candied carrot used in this research are the attributes to quality of taste, namely 'no unpleasant taste', 'no pungent smell', 'have about the right sweetness level', 'have about the right sourness level', and 'no bitter aftertaste'. These five attributes become the dependent variable in this study. In addition, this research also consider the Indonesian National Standard (SNI) for candied products, namely SNI 01-4443-1998. SNI 01-4443-1998 is an SNI specifically intended for product of candied nutmeg. This standard is used as there is no SNI for candied carrot. There are two important reasons that make the standard composition of the product should be based on SNI. The first reason is the fulfillment of the SNI quality requirement is an obligation to be followed by the products to be marketed in Indonesia. The second reason is that when it comes to food, the quality aspects, the health standard and the safety become the sensitive aspects that consumers pay attention to. Therefore, the fulfillment of food standards can provide a peace of mind to the consumers which results in the increasing trust to the product. So, based on the two reasons, the fulfillment of SNI quality requirements in the process of determining the standard composition of candied carrot is considered necessary. SNI 01-4443-1998 contains references, definitions, quality requirements, sampling methods, testing methods, marking requirements, and packing methods for candied nutmeg. In the quality requirement section, there is a table of quality requirements specifying the standard conditions, moisture content, sugar level, standard of food additives, metal contamination, arsenic content, microbial contents, and mold. According to SNI 01-4443-1998, the minimum sugar level of candied products is 25% with or without food additives permitted in accordance with applicable regulations.

3.1. Experimental Design Planning

Experimental design planning began with determining the production process of candied carrot. The production process used the process resulted from a research of determining the process quality planning for candied carrot [10]. The planning stage continued with discussion and brainstorming sessions with experts. These are the results of the discussion. Factors that affect the taste of candied carrot are materials, processes, machinery and people. The material factors consist of the amount of sugar, the amount of cinnamon, and the amount of citric acid. Process factors consist of the roasting duration and the marinating duration. Engine factor consists of roasting temperature consistency. As for the human factor consists of the expertise of workers. There are three control factors that can affect the taste of candied carrot. These factors are the amount of sugar (A), the marinating duration (B), and the amount of cinnamon (C). While the uncontrolled factor chosen is the age of carrot (D). Factor A and B will each be given 3 levels, while factor C and D will each be given 2 levels. Based on the discussion, the levels for each factor are as follows:

Table 1. Levels for Each Factor

Factors	Levels		
	1	2	3
Amount of sugar (A)	<ul style="list-style-type: none"> • 15% • 25% • 40% • 50% 	<ul style="list-style-type: none"> • 25% • 40% • 50% • 60% 	<ul style="list-style-type: none"> • 35% • 50% • 60% • 70%
Marinating duration (B)	7 hours	8 hours	9 hours
Amount of cinnamon (C)	10 grams	30 grams	
Age of carrot (D)	3,5 months	5 months	

The attributes of consumer needs included in the experimental design are ‘no unpleasant taste’ (A1), ‘no pungent smell’ (A2), ‘have about the right sweetness level’ (A3), ‘have about the right sourness level’ (A4), and ‘no bitter aftertaste’ (A5). The determination of the number of experiments is determined by orthogonal arrays. Based on the orthogonal array it was found that the number of experiments was 18. Based on those combinations, eighteen candied carrot experimental samples are made and tested on 60 consumers.

3.2. Data Processing

The data obtained from the organoleptic test will then be tested using ordinal logistic regression method with the help of Minitab 17. This test is conducted to all five attributes of consumer needs. As an example, the calculation of the attribute A1 (no unpleasant taste) is shown on this paper. The analysis results of the attribute A1 show that factor A and C are statistically significant. The logistic regression equations for the event probabilities of the categories are given as:

$$\text{Logit } P(Y \leq 1 | x) = -2,9667 - 0,09015A + 0,129529C$$

$$\text{Logit } P(Y \leq 2 | x) = -1,08564 - 0,09015A + 0,129529C$$

$$\text{Logit } P(Y \leq 3 | x) = 0,396992 - 0,09015A + 0,129529C$$

$$\text{Logit } P(Y \leq 4 | x) = 2,47472 - 0,09015A + 0,129529C$$

For each experiment trial, the event probabilities of each category are calculated using equation 2. Using equations 3 and 4, expected category and variance from this category are obtained. Then, SNR can be calculated by using equation 5. Table 2 shows results for each experiment trial.

Table 2. Estimates for Probabilities of Categories, Expected Category, Category Variance and SNR of the attribute A1 (no unpleasant taste)

Factors			P(Y _i = j)					E(Y _i)	V(Y _i)	SNR
A	B	C	j=1	j=2	j=3	j=4	j=5			
1	1	1	0,05082	0,20912	0,34745	0,31773	0,07488	3,15672	1,00507	8,83666
1	2	1	0,05082	0,20912	0,34745	0,31773	0,07488	3,15672	1,00507	8,83666
2	1	1	0,04664	0,19634	0,34272	0,33293	0,08136	3,20604	0,99885	9,00834
2	2	1	0,04664	0,19634	0,34272	0,33293	0,08136	3,20604	0,99885	9,00834
3	1	1	0,04279	0,18399	0,33689	0,34797	0,08836	3,25511	0,99150	9,17677
3	2	1	0,04279	0,18399	0,33689	0,34797	0,08836	3,25511	0,99150	9,17677
1	3	1	0,05082	0,20912	0,34745	0,31773	0,07488	3,15672	1,00507	8,83666
2	3	1	0,04664	0,19634	0,34272	0,33293	0,08136	3,20604	0,99885	9,00834
3	3	1	0,04279	0,18399	0,33689	0,34797	0,08836	3,25511	0,99150	9,17677
1	1	2	0,05744	0,22818	0,35219	0,29580	0,06638	3,08550	1,01198	8,58442
2	1	2	0,05275	0,21484	0,34915	0,31106	0,07219	3,13511	1,00743	8,76066
3	1	2	0,04843	0,20187	0,34493	0,32631	0,07847	3,18452	1,00171	8,93374
1	2	2	0,05744	0,22818	0,35219	0,29580	0,06638	3,08550	1,01198	8,58442
2	2	2	0,05275	0,21484	0,34915	0,31106	0,07219	3,13511	1,00743	8,76066
3	2	2	0,04843	0,20187	0,34493	0,32631	0,07847	3,18452	1,00171	8,93374
1	3	2	0,05744	0,22818	0,35219	0,29580	0,06638	3,08550	1,01198	8,58442
2	3	2	0,05275	0,21484	0,34915	0,31106	0,07219	3,13511	1,00743	8,76066
3	3	2	0,04843	0,20187	0,34493	0,32631	0,07847	3,18452	1,00171	8,93374

3.3. Determining the Optimal Composition

The optimal level is determined by the highest average of SNR on the overall quality attributes.

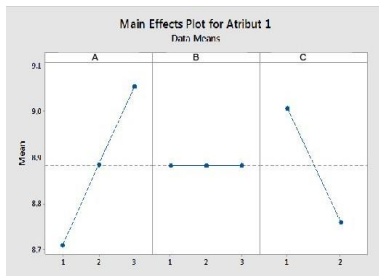


Figure 1. Main effects plot for A1 (no unpleasant taste)

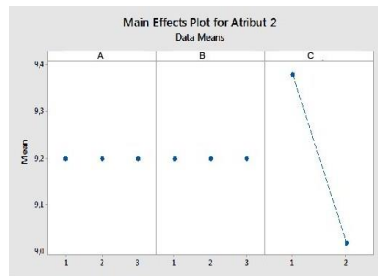


Figure 2. Main effects plot for A2 (no pungent smell)

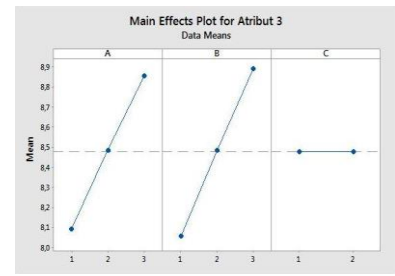


Figure 3. Main effects plot for A3 (have about the right sweetness level)

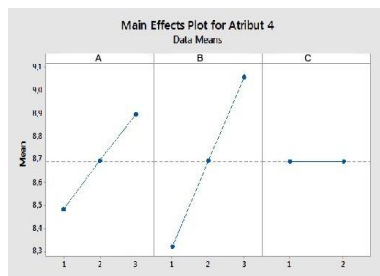


Figure 4. Main effects plot for A4 (have about the right sourness level)

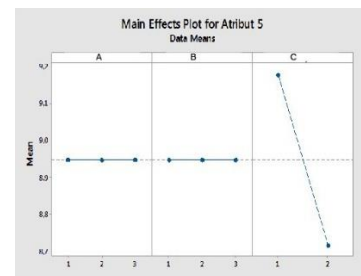


Figure 5. Main effects plot for A5 (no bitter aftertaste)

Based on the optimal level that has been obtained in each attribute, the overall optimal composition then can be determined. The overall optimal composition is determined by the most selected level on each factor. The results are presented in Table 3.

Table 3. The Overall Optimal Composition

Factors	Levels	Composition
Amount of sugar (A)	3	35% (1 st marinade)
		50% (2 nd marinade)
		60% (3 rd marinade)
		70% (4 th marinade)
Marinating duration (B)	3	9 hours
Amount of cinnamon (C)	1	10 grams

Table 3 shows that the optimal combination is the ninth combination in the orthogonal array. Amount of sugar influence the level of sweetness, level of sourness, and able to determine whether or not the product has unpleasant taste. Then based on data analysis known that the amount of cinnamon affects the aroma, the aftertaste of the product, and also can determine whether or not the product has unpleasant taste. While the marinating duration can affect the level of sweetness and sourness of the product. This optimal combination is not only preferred by the consumers, but also technically proven to meet the minimum requirement of sugar level regulated by SNI regardless of the age of carrot used in the process. The sugar level of candied carrots aged 3.5 months using this optimal composition is 31.42%. While the sugar level of candied carrots aged 5 months using the same composition is 49.08%. Both are above 25% therefore meet the criteria made by SNI.

4. Conclusion

Based on the experiment, there are three control factors that can affect the taste of candied carrot. These factors are the amount of sugar (A), the marinating duration (B), and the amount of cinnamon (C). While the age of carrot (D) is used as a noise factor that attempted to be controlled in the study. Factor A and B are given 3 levels, while factor C and D are given 2 levels. The determination of the number of experiments is determined by orthogonal arrays. Based on the orthogonal array it was found that the number of experiments was 18. The results of the organoleptic test are analyzed using ordinal logistic regression analysis to determine the control factors that affect each attribute. Overall there are five attributes studied in this research. The optimal combination obtained is technically proven to meet the minimum requirement of sugar level regulated by SNI regardless of the age of carrot used in the process. Hence the optimal combination is robust to noise and therefore able to produce better quality product.

References

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