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Research paper



Identify the Influence of Ingredients and Cake Baking for Cupcake using Design of Experiments

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Abstract

This experiment purpose is to determine the best recipe for cupcakes, what factors that can affect the taste of cupcake and to identify the main factors which influential significantly to the best recipe of cupcake. The parameter of the best cupcake is judged on taste, moistness, and smoothness. Taste and smoothness is rated by expert, then the moistness is measure by gram. Taguchi's experimental design method, orthogonal arrays of Taguchi, overall evaluation criteria, design of experiments, ANOVA analysis, and S/N-ratio analysis are used to evaluate the significance influence of ingredients and cake baking for cupcake. Confirmation experiments with the significantly effect of ingredients levels was carried out in order to illustrate the effectiveness of the Taguchi's design of experiments method. The factors which have significantly influence is the combination between sugar and fluid milk with the highest contribution i.e. 58.06%. The high amount of sugar and the use of fluid milk can affect the texture of cupcake became not good or became coarse.

Keywords: *Taguchi Method, OEC, DOE, Analysis of Variance, Cupcake*

1. Introduction

At this time cupcake is one of cake type that has been favored by many Indonesian people. There are several courses that provide recipes for making various kind of cupcake creations. Thus, we can enjoy the cupcake by making it ourselves. However, because of the many recipes available, author sometimes confuse which recipes can produce good and delicious flavors. The delicious taste of cupcake is influenced by the combination ingredients used in cupcake making. In addition, there are several supporting factors that can affect the quality of the cupcake, for example the method of cupcake cooking using an electricity oven or steamed.

Recently, Joiner and Brewster (2017) demonstrated that oven temperature, pan fill and cook time, oven setting, and size of pan are the factors that can influences the taste of cupcake. Heenan et al. (2010) says that sweetener type, fat type and time for baking also can influences the product appearance, odour, flavor, texture, and after-flavour characteristics of model cakes. In another way, sugar is not only affect the sweetness of cupcake, sugar also can be serves to soften gluten, so author have a soft cake. In addition, the process of caramelization of sugar can give a good color to the cake. The other ingredients such as flour, eggs, and the addition ingredients also can affect the taste and quality of the cupcake. To get the good taste and quality of the cupcake, we must combine a variety of cupcake ingredients in balance.

This experiment purpose is to determine the best recipe for cupcakes, what factors that can affect the taste of cupcake and to identify the main factors which influential significantly to the best recipe of cupcake. The traditional approach has been to decide the recipe based on one criterion (i.e., Taste) at a time. But, when the ingredients differ, selection of a compromised final recipe becomes a difficult task. The recipes have not brought the desired customer satisfaction. The group decided to follow a path of consensus decision, and carefully devise a scientific scheme to incorporate all criteria of evaluations simultaneously into the analysis process.

In this experiment, design of experiments (DOE) technique, overall evaluation criteria (OEC), and ANOVA used to analyse the results. Design of experiments (DOE) can conveniently study the effects of ingrediants in a cake baking process and determine the optimum recipe with a smaller number of experiments. DOE is among the many techniques used in the practice of quality improvement. Furthermore, ANOVA is used to know the significance level of factors and interaction influence. The parameter of the best cupcake is analyzed by taste, moistness, and smoothness.

2. Methodology

2.1. Overall Evaluation Criteria (OEC)

Flavor of the cupcake can be influenced from the composition of ingrediants. Composition of ingrediants must be balanced to obtain the good taste. However, in addition to ingrediants, there are also any other factors that can affect the flavor of the cupcake. Some of the factors are step, oven type, kitchen temperature, roasting time, skill of operator, oven temperature, etc. The quality of cupcake can be measured by taste, moistness, smoothness, and colour (burn or not). According to Ranjit (1987), taste can used to evaluate the subjective

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criteria, the criteria was be evaluated using a number between 0 and 12. The number 12 being assigned to the best tasting cake. The Moistness was to be measured by weigthing a standard size cake and by noting its weight in grams. Based on the study, the weight of about 40 grams represents the most desirable moistness, and indicates that its Quality Characteristic is of Nominal type. In this evaluation, both results above and below the nominal are considered equally undesirable. Smoothness was measured by counting the number of voids in the cake, which made this evaluation of type Smaller is better (QC). The relative weights were assigned such that the total was 100.

2.2. Design of Experiments (Taguchi's)

Sometimes, the experiments design is having experimental design procedures which are too complicated and not easy to use. If the number of process parameters increase, then the number of experimental works increase too. Because of that, in Taguchi methods a special design of orthogonal arrays (OA) is used to solve that problem. The design of orthogonal arrays studies the entire parameter space with only a small number of experiments [1]. To improve the performance of the product, the producer can analyze the customer needs and expectations [10].
The advantage of Taguchi Methods such as saving of effort in conducting experiments, saving experimental time, reducing the cost and discovering significant factors quickly [3]. Furthermore, the S/N ratio and ANOVA (a statistical analysis of variance) are used to indicate the impact of process parameters on baking cupcake. The resume of methods that used in this experiment are as follows:
DOE:
Statistically technique
Studies effects of multiple variables simultaneously
Determine the factor combination for optimum result
How does DOE Technique Work:
An experimental strategy that determine the solution with minimum effort
Determine the recipe for baking the best pound cake with 5 ingredients, and with the option to take high and low values of each.
DOE is an experimental strategy in which effects of multiple factors are studied simultaneously by running tests at various levels of factors. What levels should author take, how to combine them, and how many experiments should author run, are subjects of discussion in DOE.
ANOVA offers the following statistics:
Relative influence of factors and interactions
A level of confidence on the estimated performance at optimum condition and main effects
Significance of factor and interaction influence
Steps involved in Taguchi Method such as follows:Plan:

1) Identify project and select project team (identify the project-select it based on higher probability of success and higher return on investment)
2) Define project objectives evaluation criteria
3) Determine system parameters (control factors, noise factors, ideal function, etc)

b. Design:

1) Select array and assign factors to the columns (inner and outer arrays)
2) Factors are synonymous to input, ingredient, variable, and parameter
3) Levels are the values of the factors used to carry out the experiment (descriptive & alphanumeric)
4) Five factors at two levels each can produce $2^5 = 32$ different cake recipes
5) Only 8 experiments are carried out in the Taguchi approach

c. Conduct experiments and experiments confirmation

3. Factors and Interactions

In this section, author determine the control and noise factor for this experiment. Cause-effect diagram used to determine that factors. The cause-effect diagram presented in Fig. 1.

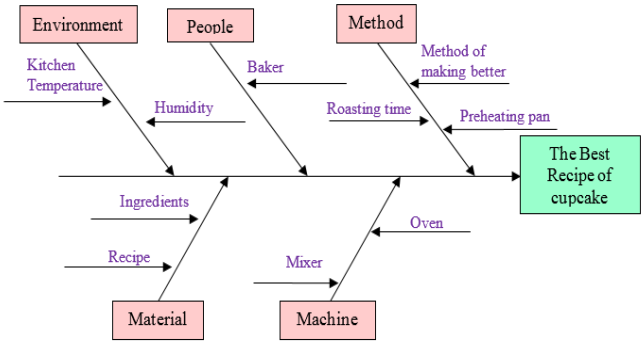


Fig. 1: The cause effect diagram

Author have inner array and outer array. Inner array used to control of average. Outer array used to control of variance. In this experiment, author using five control factors, three noise factor and two levels for each factors. Some ingrediants used to define the inner array. Each cupcake has same ingrediants, so that author can have the best taste of cupcake.

This experiment using outer noise categories. The outer noise factors such as oven type (electric and manual oven), mixer speed, and people (operator). People (operator) have two levels skill such as slow and fast skills to do this experiment. Control and noise factors which influence the best recipe of cupcake presented in Table 1 and Table 2.

Table 1: Control factors

	Control Factors	Levels 1	Levels 2
A	Egg (unit)	1	2
B	Sugar (gr)	30	50
C	Milk	Fluid (13 ml)	Powder (6 gr)
D	Vegetable oil (tbsp)	2	3
E	Flour (gr)	50	60

Table 2: Noise factors

	Noise Factors	Levels 1	Levels 2
A	Mixing time (min)	10	15
B	Type of oven	Steam	Electric
C	Dragon fruit extract	Yes	No

Process diagram in this experiments presented in Fig. 2.

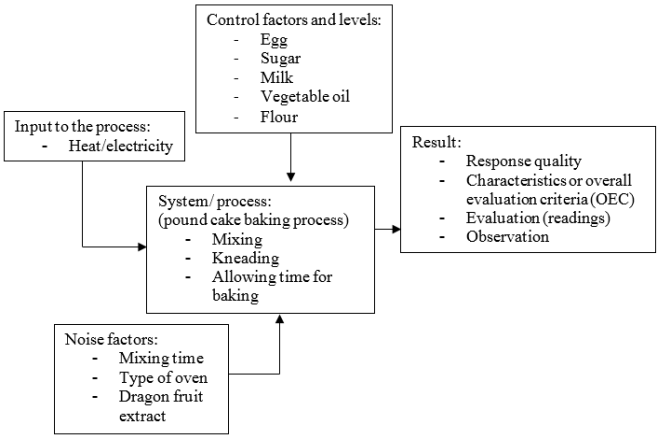


Fig.2: Diagram process of cake baking

4. The Orthogonal Arrays

In this step, author determine which the orthogonal array that appropriate for this experiment. Orthogonal array is one of methodology to design an experiment. L_8 standard array (OA) used to control factors, because author have five control factors and two interactions. The first interaction is between egg and milk, and the second interaction is between egg and vegetable oil. L_4 standard array (OA) used to noise factors, because author have three noise factors.

Complete randomization used to conducting this experiment. Complete randomization means any test has an equal chance of being selected for the first test, (Ross, 1996). The L_8 OA and L_4 OA presented in Table 3 and Table 4.

Table 3: The L_8 standard array

Trial	A	B	E	C	A x C	A x D	D
	1	2	3	4	5	6	7
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

Table 4: The L_4 standard array

Trial no	Column no 1	2	3
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

5. Result and Discussion

The result and discussion are as follows.

5.1. The Evaluation Criteria

In this experiment the evaluation criteria are selected also according to literature review and previous casting experiences. The evaluation criteria for cake baking experiments given in Table 5.

Table 5: The evaluation criteria

Criteria description	Worst value	Best value	Quality control (QC)	Relative weighting
Taste	0	12	H_B	55
Moistness (gr)	25	40	N_B	20
Smoothness	8	2	L_B	25

In this experiment, author using higger is better or H_B of quality control. So, before all criteria of evaluations can be combined their QC's must be the same. The second expression is modified to change the nominal QC to bigger (H_B) and the third expression is modified to change the smaller QC to bigger (H_B). To modified that QC, author must calculate the OEC value use Equation (1).

$$OEC=\left(\frac{C1}{C1_{rang}}\right)xWt_1+\left(1\frac{|C2\text{-}C2}{|C2_b\text{-}C2|}\right)x\left(1\frac{C3}{C3_{rang}}\right)xWt_3 \quad (1)$$

With the use of Eq.(1) the result of measurement shown in Table 6 (author show only one sample data).

Table 6: The results of measurement

Trial no	Taste	Moistness	Smoothness	OEC
1	2	54	8	48
2	6	38	4	62
3	8	47	4	83
4	3	47	7	47
5	2	42	7	36
6	5	44	5	61
7	10	32	3	76
8	7	31	2	65

In this experiment, author conduct 4 sample for each trial, so author have 32 data. The inner/ outer OA parameter design experiment for this experiment presented in Table 7.

Table 7: Inner/ outer OA parameter design experiment

L_4 OA outer array (noise factor)				
Z	1	2	2	1
Y	1	2	1	2
X	1	1	2	2

L_8 OA inner array (control factors)													
Trial no	A	B	E	C	Ax C	Ax D	D	R1	R2	R3	R4	Total	Mean
	Column no												
	1	2	3	4	5	6	7						
1	1	1	1	1	1	1	1	48	45	45	43	181	45
2	1	1	1	2	2	2	2	62	72	67	66	266	67
3	1	2	2	1	1	2	2	83	81	81	81	325	81
4	1	2	2	2	2	1	1	47	37	37	33	154	38
5	2	1	2	1	2	1	2	36	37	29	35	137	34
6	2	1	2	2	1	2	1	61	71	55	59	245	61
7	2	2	1	1	2	2	1	76	71	71	76	294	74
8	2	2	1	2	1	1	2	65	67	64	64	261	65

5.2 Results and Analysis of Experiments

In this section, author conducting the experiment with two analysis. The first analysis is only analysis of variance for inner array. And the second analysis is analysis of inner/outer array. So, in this experiments we will have two results for data analysis. The first is ANOVA for inner array. And the second is S/N-ratio analysis. In this experiments, author conducting the experiments with four repetitions for each trial. The measurements are based on taste, moistness, and smoothness. The taste and smoothness are evaluated by expert. The moistness is measure in gram.

5.2.1 ANOVA and Mean-effect Analysis

The ANOVA for an inner/outer OA experiment can be somewhat more complex than for an inner OA only because of the additional sources of variation [2]. The difference in the average performance of groups of items tested can be detected by using ANOVA (analysis

of variance). ANOVA is a statistically based method. The significance of all main factors and their interactions can test by ANOVA. ANOVA can be comparing the mean square against an estimate of the experimental errors at specific confidence levels. The results of ANOVA inner array (control factors) and S/N-ratio used to analysis which factor that influence the recipe of cupcake. The formula for calculate the results is presented in Equation (2). The ANOVA results are shown in Table 7.

$$SSA_1 = \frac{(A_1 - A_2)^2}{N} \quad (2)$$

Table 7: ANOVA results

ANOVA summary					
Source	SS	v	V	F	P (%)
A	3.78	1	3.78	0.23	0.04
B	1313.28	1	1313.28	80.42	15.48
E	621.28	1	621.28	38.04	7.32
C	3.78	1	3.78	0.23	0.04
A x C	810.03	1	810.03	49.60	9.55
A x D	4925.28	1	4925.28	301.60	58.06
D	413.28	1	413.28	25.31	4.87
e	391.93	24	16.33		4.62
T	8482.65	31			100.00

According to Table 7, the first large-factor that influence is factor A x D (interaction between egg and vegetable oil) with SS value is 4925.28, with contribution 58.06% from the total sum of square. The second factor is factor B (sugar) with SS value 1313.28 and the contribution is 15.48%. The combination between egg and vegetable oil can affect the results or the taste of cupcake.
Then, author conduct the mean effect analysis. The mean effect analysis is the analysis of value of the effect on each factor. Then, to get the effect value for each factor, author calculate the high average response minus the small response. Level means for significant factors and interactions presented in Table 8. The graphic of mean effect analysis is shown in Fig 3.

Table 8: Mean effect of control factors

	A	B	E / C x D	C	A x C	A x D	D
Level 1	57.92	51.88	62.67	58.63	63.27	45.83	54.64
Level 2	58.57	64.61	53.82	57.86	53.22	70.66	61.85
Effect	0.65	12.73	8.84	0.76	10.04	24.83	7.22
Rank	7	2	4	6	3	1	5
Optimum	A2	B2	E1	C1	A x C (1)	A x D (2)	D2

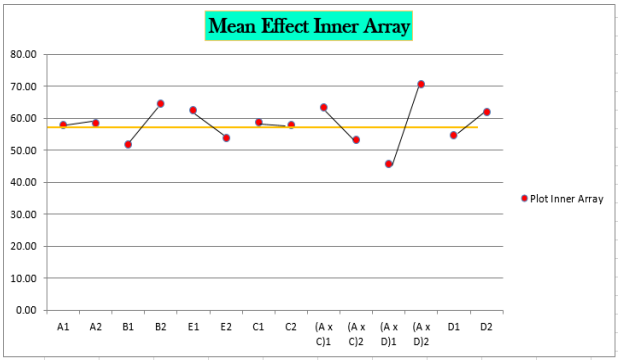


Fig. 3: The graph of mean-effect analysis

Based on the calculations, the high average response used to suggested as a proposed of experiment. This is because the characteristics in this experiment is higher is better. Table 8 showing the large mean effect is the interaction between factor A and D (egg and vegetable oil) and small mean effect is egg. Respons Table for mean show the high factor for cake baking is 10.04 for factor A x D and the small factor is 0,65 for egg. Thus it can be said that the interaction between egg and vegetable oil is a factor that greatly affect the taste of cupcake. Also, the egg was not affecting the taste of cupcake.
In this study, higher the better category is used to performance characteristics. Therefore, the high effect level of the factors is the level with greatest mean value.

5.2.2 S/N ratio and Mean-effect Analysis

The S/N-ratio analysis is to find the factors which significantly influences respons. The larger the better is presented in Equation (3).

$$S/N_{HB}=-10 \log\left(\frac{1}{r}\sum_{i=1}^{r}\frac{1}{y_i^2}\right) \quad (3)$$

The S/N-ratio analysis is presented in Table 9. Table 10 shown the rank of effect level.

Table 9: S/N-ratio analysis

Trial no	1/r * sigma 1/y^2	Log	S/N
1	0.00049	-3.31157	33.11572
2	0.00023	-3.64283	36.42831
3	0.00015	-3.81996	38.19961
4	0.00071	-3.14658	31.46579
5	0.00087	-3.06006	30.60060
6	0.00027	-3.56247	35.62472
7	0.00019	-3.73132	37.31320
8	0.00024	-3.62797	36.27971

Table 10: The rank effect

	A	B	E	C	A x C	B x C	D
Level 1	34.80	33.94	35.78	34.80	35.80	32.86	34.37
Level 2	34.95	35.81	33.97	34.94	33.95	36.89	35.37
Effect	0.15	1.87	1.81	0.142	1.85	4.027	0.99
Rank	6	2	4	7	3	1	5
Optimum	A(2)	B(2)	E(1)	C(2)	A x C(1)	B x C(2)	D(2)

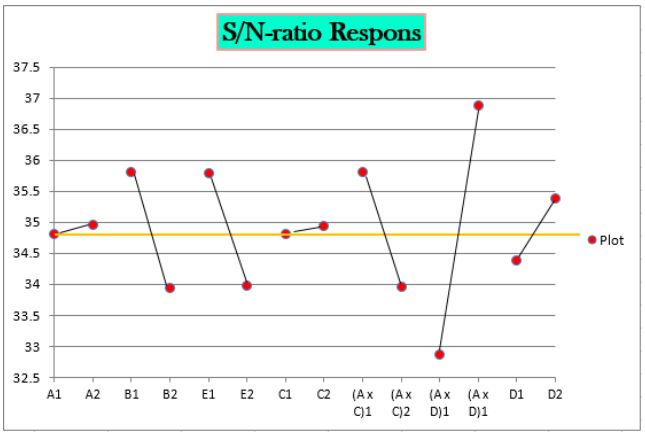


Fig. 4: S/N ratio response

The high effect level of the factors is the level with greatest S/N value. Based on the analysis of S/N ratio, the high effect for cake baking was obtained at factor A x D (B x C) as factor interactions. The interactions are between factor A and factor D or between factor B and factor C (level 1). The value are 1 unit egg and 2 tbsp vegetable oil or 30 gr sugar and 13 ml fluid milk. Fig. 4 shows the main effect of the influence of ingredients on cake baking process. This explain, if sugar and fluid milk used the cupcake became not well cooked. Also, if we use only 1 egg with 2 tbsp vegetable oil the texture of cupcake became not good or became coarse. Thus it can be said that the interactions between egg and vegetable oil or sugar and fluid milk is a factor that greatly affect the baking of cupcake and also the taste of cupcake.

5.3 Confirmation Tests

The final step in Taguchi method is the experimental confirmation. The experimental confirmation used to verify the result drawn based on Taguchi's design approach. In this study, a confirmation experiment was conducted by utilizing the factors that significantly influences to the greatest cake baking and taste of cupcake. These factors are:

1) Factor B x $C_{(2)}$: factor B and C level 2
2) Factor $B_{(2)}$: factor B level 2
3) Factor A x $C_{(1)}$: factor A and C level 1
4) Factor $E_{(1)}$: factor E level 1
5) Factor $D_{(2)}$: factor D level 2
6) Factor $A_{(2)}$: factor A level 2
7) Factor $C_{(2)}$: factor C level 2

The interaction level combination is used as an estimate of the mean. B (sugar) x C (milk) interaction level combination is:

$\overline{B_1C_1}$ = 39.84
$\overline{B_1C_2}$ = 63.91
$\overline{B_2C_1}$ = 77.40
$\overline{B_2C_2}$ = 51.81

An estimate of the mean is:

$$\hat{\mu}\, B_2C_1D_2E_1 = \overline{D_2} + \overline{E_1} + \overline{B_2C_1} - 2\,(\overline{T}) = 85.44 \quad (4)$$

Author conducting four sample verification axperiments.The data of verification experiments results as shown in Table 11.

Table 11: Verification experiments

Sample no	Taste	Moistness	Smoothness	OEC
1	9	37	2	82
2	9	38	3	79
3	10	39	2	90
4	11	38	2	93
		Total		344
		Mean		86

$$CI_3 = \sqrt{F_{\alpha;1;ve} V_{ep} \left[\left(\frac{1}{neff}\right) + \left(\frac{1}{r}\right)\right]} \quad (5)$$

$$CI_3 = \sqrt{F_{0.5;1;2} V_{ep} \left[\left(\frac{1}{neff}\right) + \left(\frac{1}{r}\right)\right]}$$

$$CI_3 = \sqrt{18.5*0.04 \left[\left(\frac{1}{8}\right) + \left(\frac{1}{4}\right)\right]}$$

$$= 0.53$$

The confidence interval for the estimated mean using the CI_3 value is:

$\hat{\mu} - CI < \mu < \hat{\mu} + CI$

$85.44 - 0.53 < \mu < 85.44 + 0.53$

$84.91 < \hat{\mu}\, B_2C_1D_2E_1 < 85.97$

Based on confidence interval with 95% confidence level, the mean of confirmation experiments or verification experiment is inside the confidence interval.

6. Conclusions

By using Taguchi method, this experiment have been run with eight trials. This study has discussed an influence of ingredients in cake baking with the parameters measure are taste, moistness, and smoothness. From the analysis of the results using the ANOVA, S/N-ratio and mean effect analysis, the following can be concluded that the optimal design parameter combination are factor B x $C_{(2)}$, B_2, A x $C_{(2)}$, $E_{(1)}$, and $D_{(2)}$ that are the interactions between sugar (50 gr) and milk (powder 6 gr), sugar (50 gr), interaction between egg (2 units) and milk (powder 6 gr), flour (50 gr), and vegetable oil (3 tbsp). And the factors which have significantly influence is the combination between sugar and fluid milk with the highest contribution i.e. 58.06%.

As a result of conducting this research, the author proposes that the ingredients and cake baking process are can influence the quality of cupcake. This study can used as reference to conduct another research about quality pf product.

Acknowledgement

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