The robust design for improving crude palm oil quality in Indonesian Mill

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Abstract. This research was conducted in palm oil mill in Sumatra Utara Province, Indonesia. Currently, the main product of this mill is Crude Palm Oil (CPO) and hasn’t met the expected standard quality. CPO is the raw material for many fat derivative products. The generally stipulated quality criteria are dirt count, free fatty acid, and moisture of CPO. The aim of this study is to obtain the optimal setting for factor’s affect the quality of CPO. The optimal setting will result in an improvement of product’s quality. In this research, Experimental Design with Taguchi Method is used. Steps of this method are identified influence factors, select the orthogonal array, processed data using ANOVA test and signal to noise ratio, and confirmed the research using Quality Loss Function. The result of this study using Taguchi Method is to suggest to set fruit maturity at 75.4%-86.9%, digester temperature at 95ºC and press at 21 Ampere to reduce quality deviation until 42.42%.

1. Introduction

This research was conducted in palm oil mill in Sumatra Utara Province, Indonesia. Companies engaged in the processing of palm oil especially palm mill is growing rapidly. This development leads to tough competition on each mill [1,2]. Every company has to achieve standard quality so that the product’s quality can meet the customer requirements [1,3,4]. The effort to achieve expected standard quality by using quality control. Quality of CPO is one of the main factors for a customer to make purchasing decisions especially standard stated in Indonesia National Standard SNI 01-2901-2006. The maximum quality requirements of CPO stated are dirt count, free fatty acid, and moisture at 0.5%, and Iodine number at 55 grams Iodine per 100 grams [5].

Several researchers researching about the improvement of CPO’s quality through Six Sigma, Seven Tools of Quality improvement or even using Design of Experiment in Laboratory scope. The improvement obtained from that method usually high cost and Improvement of quality using Taguchi method is simpler and lower cost [1,2,5].

Moisture in CPO greatly affects the free fatty acid content. Increased water content causes free fatty acids to increase. This results in the hydrolysis reaction to oils or fats in the presence of water.
The presence of high fatty acid will result in the quality problem [1,2]. Quality is often referred as conformance to specifications. Taguchi, however, proposes a different view of quality, which links it to costs and losses in money value, not only to producers at the time of production but to consumers and society as a whole [2,6,7,8,9].

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2. Method and equipment

The Taguchi method uses the Loss Function approach which describes the costs that arise between the producer and the consumer due to the determination of certain quality characteristics of the product [1,2,3,13,14,15]. Loss Function is used in measuring the performance of the quality characteristics in the achievement of the target, i.e. how big is the variation around the target. The use of Taguchi Method in this research is expected to know the factors that influence the quality of CPO and perform CPO quality control analysis so that the factory produces CPO with quality in accordance with the expected target.

Taguchi's define that quality is judged from a product loss to society after the product is delivered. The quality objective of the manufacturing process is to take action to minimize loss to society.

Quality Loss Function provides the basis for the determination of tolerance. In this case, tolerance is not a deviation between products but is defined as the deviation of the target. Loss due to the deviation L (y) can be formulated as follows

\[
L(y) = L(m + y - m)
\]  

(1)

\[
L(y) = L(m) + \frac{L'(m)}{1!}(y-m) + \frac{L''(m)}{2!}(y-m)^2 + \ldots
\]  

(2)

Minimum L value at y = m and Ly (m) = 0 then L (m) = 0. Thus, the third term of Eq. 1 is the main term of the loss function or (y-m) 2 which can then be estimated as follows (assuming L''' (m) and so on is ignored) can be seen in Eq. 3 and the loss function formula can be seen in Eq. 4. Loss function contains a coefficient number k. For products with target value m, to determine the magnitude k, it is necessary to know the magnitude of the losses due to exceeding the tolerance.

\[
L(y) = \frac{L''(y-m)^2}{2!}
\]  

(3)

\[
L(y) = kv^2
\]  

(4)

In this research, Experimental Design with Taguchi Method is used. Steps of this method are identified influence factors, select the orthogonal array, processed data using ANOVA test and signal to noise ratio, and confirmed the research using Quality Loss Function. The conceptual framework build in this research can be seen in Fig. 1.

This research uses associative hypothesis that is a statement about the relation between two variables or more. The character of the relationship between variables is not viewed from the causal point, but only question whether there is a relationship between these variables [16]. The hypothesis build in this research consists of three main hypotheses. They are “H0: There is no significant effect of the variable to CPO Quality” and “H1: There is a significant effect of the variable to CPO Quality” for each variable fruit maturity, digester temperature, and ampere press.

There are 9 steps in this research using Taguchi Method as follow:

- Analyze CPO quality level by using seven tools
• Identification of Quality Factors Against Irregularities
• Determination of Number Level and Level Factor

![Diagram](https://example.com/diagram.png)

**Figure 1.** Conceptual framework in the Taguchi Experimental Design.

- Determine freedom degrees to calculate the minimum number of experiments to be performed to investigate the observed factors.
- Selection of appropriate Orthogonal Matrices depends on the value of the factors and expected interactions and the level values of each factor.
- Assignment of Factors to Orthogonal Matrices. Assignment of factors both control factors and interference factors and their interactions on selected orthogonal arrays with respect to linear graphs and triangular tables.
- Calculation of Main Effect
- Data analysis, calculation, and presentation of data using statistical analysis of variance, hypothesis testing and application of empirical formulas on the data result of combinations of factors.
- Interpretation of results is a step taken after the experiment and analysis have been done.

### 3. Results and Discussions

#### 3.1. Actual Data Analysis

Collected data from current CPO Data can be an indication if the CPO quality problem. Collected CPO Quality for a month can be seen in Fig. 2 till Fig. 4
In order to see CPO of production that suffer from accumulative deviation to quality condition, the nonconformities for CPO quality data was taken for 20 months as can be seen in Figure 5.
The water content in CPO greatly affects the free fatty acid content. Increased water content causes free fatty acids to increase. This is due to the hydrolysis reaction to oils or fats because the presence of a certain amount of water in the oil or fat will change the oil or fat to free fatty acids and glycerol.

3.2. Identification and Discussion

A pooling-up strategy is undertaken to determine which factors have the most significant effect on product quality. To show it in Variant Analysis, the pool and pooled error pools are used. The smallest variant pool is marked Y to indicate the source is pooled into pooled E. Next is calculated F-ratio based on pooled E. Then factor A is the factor with least squares. Pooling factor is done on factor A by marking Y and adding the sum of squares to pooled E. Variance Analysis results for the pooling up strategy can be seen in Table 1.

Table 1. Variance analysis.

| Source | Pool | Sq  | v  | Mq  | F-ratio | Sq* | p%   |
|--------|------|-----|----|-----|---------|-----|------|
| A      | Y    | 0.0105 | 1  | 0.0105 | -       | -   | -    |
| B      |      | 0.0218 | 1  | 0.0218 | 2.6954  | 0.0137 | 7.57 |
| C      |      | 0.0541 | 1  | 0.0541 | 6.6971  | 0.0460 | 25.44 |
| E      | Y    | 0.0944 | 12 | 0.0079 |         |      |      |
| Pool E |      | 0.1049 | 13 | 0.0081 | 1.0000  | 0.1211 | 66.99 |
| St     |      | 0.1807 | 15 | 0.0120 | -       | 0.1807 | 100.00 |
| Mean   |      | 2.0378 | 1  | -    | -       | -    |      |
| ST     |      | 2.2185 | 16 | -    | -       | -    |      |

Based on F distribution, with significance level at 5%, degree of freedom for variable 1 is 1 and variable 2 is 13, \( F_{(0.05;1,13)} = 4.6672 \). Hypothesis testing and conclusion obtained from variance analysis table after pooling of Factor A. For Factor B, F calculated is 2.6954 and receive \( H_0 \) because calculated F is less than F table (4.6672). This means there’s no impact on Digester temperature to CPO quality. For Factor C, calculated F is 6.6971 more than F table (4.6672), so there’s an impact of ampere press to CPO quality. From the contribution percentages in Table 5.17, the significant factors are B and C. These factors amount to 33.01% of the sum of the total squares. The sum of squares pooled error is 66.99%.

Based on Taguchi Experimental Design, the result of this research can be seen in Table 2. From Table 2, we can see that there’s a need to set fruit maturity at 75.4-86.9% and press at 21 amperes so that signal to noise ratio can be increased and can reduce quality deviation to 42.42%.

Table 2. Setting recommendation based on Taguchi.

| Factor            | Level Setting | Current Setting | Recommendation setting |
|-------------------|---------------|-----------------|------------------------|
| Fruit Maturity    |               | Maturity Level 2 | Maturity Level 1       |
| Maturity          | 87.0-98.5%    |                 | 75.4-86.9%             |
| Digester Temperature | Level 2     |                 | Level 2                |
|                   | 95°C          |                 | 95°C                   |
| Ampere            | Level 1       |                 | Level 2                |
The result of this study using Taguchi Method is to suggest the setting of fruit maturity at 75.4-86.9%, digester temperature at 95°C and press at 21 Ampere. This setting expected to reduce quality deviation by 42.42%. Implementing Taguchi Method is expected to get suitable CPO criteria based on SNI 01-2901-2006.

### 4. Conclusions

The result of this study using Taguchi Method is to suggest the setting of fruit maturity at 75.4-86.9%, digester temperature at 95°C and press at 21 Ampere. This setting expected to reduce quality deviation by 42.42%. Implementing Taguchi Method is expected to get suitable CPO criteria based on SNI 01-2901-2006.

#### References

[1] Iwan Nauli D, Dedy N, Veni A 2013 J. Ekonomi, Analisis Taguchi dalam meningkatkan utilisasi produksi pada industri crude palm oil (CPO), Taguchi analysis in enhancing production utilization on CPO industry 21(2) 34-38

[2] Candra B, Rodhi A 2011 J. Riset Industri, Setting Parameter Mesin Press dengan Metode Respon Permukaan Pada Fabrik Kelapa Sawit, Setting Parameter in Press Machine using Surface Response Method in Palm Mill V 102-105

[3] Fatemeh A 2013 Iranica J. Energy & Environment, Production of Mycophenolic Acid by Penicillium brevicompactum in a Submerged Batch Culture: Optimization of Culture Conditions Using Taguchi Approach 4(4) 330-335

[4] Elham G, Abdollah A, Elizabeth A C 2015 Int. J. Quality & Reliability, Mahalanobis Taguchi System: a review 32(3) 291-307

[5] National Standardization Bodies of Indonesia 2006 Crude Palm Oil SNI 01-2901-2006

[6] Sreenaj P, Kannan T, Subbasis M 2014 World J. Eng., Analysis of flux cored arc welding process parameters by hybrid Taguchi approach 11(6) 575-588

[7] Periyanan P R, 2014 Int. J. Quality & Reliability, Optimization of multiple-quality characteristics in micro-WEDG process using Taguchi technique 31(3) 205-219

[8] Donny Hidayat A J, Tung K L 2016 Kybernetes, Path optimization of CNC PCB drilling using hybrid Taguchi genetic algorithm 45(1) 107-125

[9] Rahim A, Sharma U, Murugesan K, Sharma A, Arora P 2012 J. Structural Fire Eng., Optimization of Post-Fire Residual Compressive Strength of Concrete by Taguchi Method 3(2) 169-180

[10] Jenarthanan M P, Jeyapaul R 2013 Pigment & Resin Technology, Evaluation of milling characteristics of resin hybrid GFRP laminates using Taguchi approach 42(5) 288-297

[11] Satyendra Kumar S, Vinod K 2015 Benchmarking: An Int. J., Optimal selection of third-party logistics service providers using quality function deployment and Taguchi loss function 22(7) 1281-1300

[12] Abbas Khammas H 2017 Multidiscipline Modeling in Materials and Structures, Parametric optimization of wt.% Y2O3 modified chromium-aluminide coatings using utility concept-based Taguchi approach 13(3) 448-463

[13] Roma Mitra D, Ravi S 2014 The TQM J., Emerging trend of customer satisfaction in academic process: An application SPC and Taguchi’s robust parameter design 26(1) 14-29

[14] Naresh N, Jenarthanan M P, Prakash R H 2014 Multidiscipline Modeling in Materials and Structures, Multi-objective optimisation of CNC milling process using Grey-Taguchi method in machining of GFRP composites 10(2) 265-275
[15] Ali A, Mansour Z, Nima S 2016 J. Enterprise Information Management, Supplier selection in closed loop supply chain by an integrated simulation-Taguchi-DEA approach 29(3) 302-326
[16] Sukaria S 2011 Metode Penelitian, Research Methodology, 1st Ed. (Indonesia: USU Press)

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