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Research Article

Recycling Solid Waste of Coconut Oil Industry: A Response Surface-Goal Programming Approach

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A B S T R A C T

Waste minimization is a key success factor to achieve sustainability, including in the edible oil industry. One type of solid waste produced substantially in this industry is spent bleaching earth (SBE), which comes from a mixture of bleaching earth (BE) and activated carbon (CA) used in the edible oil refining process. SBE that is recycled through a heating process is known as heat regenerated SBE (HRSBE). The process is influenced by two factors as stated in previous studies: temperature and time. In the current study, we report the results of experiments to find the optimal combination of temperature and time in restoring the absorbent quality of SBE by observing four quality parameters: colors (red and yellow), Free Fatty Acid (FFA), and Peroxide Value (PV). The current study uses Response Surface Methodology (RSM) to design the experiments and to find the equations of the relationship between the factors for each response; as well as Goal Programming (GP) to find the most optimal combination of factors in order to achieve aggregated quality targets. The findings show that 3.414 hours of heating at a temperature of 151.64oC allow HRSBE to produce coconut oil in accordance with the expected quality targets.

INTRODUCTION

The coconut oil industry is commonplace in tropical countries and Indonesia has many coconut cooking oil industries (refined bleached deodorized coconut oil) spread across the islands of Sumatra, Java, Kalimantan, Sulawesi, and West Nusa Tenggara. The coconut oil industry, just like any other food processing industries, produces large amounts of solid and liquid waste [1]. In coconut cooking oil production, when the raw material, copra, is processed and refined, large amounts of waste is produced, solid and liquid alike, including spent bleaching earth (SBE), which is a used absorbent in the refinery process of bleaching the crude coconut oil color. SBE is the largest solid waste, estimated at 0.5-2.0% of every total mass of crude coconut oil processed. Meanwhile, a coconut oil industry can produce more than 400 tons per day. SBE with 5-10% absorbed oil can lead to the serious fire hazard if disposed to the landfill. This will also deteriorate the land fertility and groundwater quality; and cause air pollution in the form of dust and odor [2].

In brief, the process of producing coconut oil is not sustainable, which not only hurts the environment but also reduces the industry's competitive advantage [3]. Initiatives in the industry does not only cover to Reduce, Reuse, Recycle, and Recover (4R) but also the concept of triple bottom line: people, planet, and profit (3P) [4], Green manufacturing [5], Green productivity [6], and Green innovation [7]. Several studies, such as in [8]-[12], tried to adapt these Green management concepts in the edible oil industry. However, Green agendas will not be achieved without proper waste management. Effective and efficient waste management techniques are needed, including in the oil industry.

Previous studies have contributed greatly to the development of wastewater management in the edible oil industry. Rajkumar et al. [13] proposed an approach to treat the wastewater of soya edible oil industry, which was followed by a comprehensive economic study. Saranya et al. [14] proposed a biocatalytic approach to treat wastewater of edible oil refinery. Gunawan et al. [15] offered a strategy to recover vegetable oil wastewater sludge into biodiesel. Šereš et al. [16] proposed a treatment of oilseed processing plant wastewater using alumina ceramic membrane.

The enthusiasm to conduct studies on the wastewater is high [17], but research in the management of solid waste (SBE) is still lacking. Boukerroui and Ouali [18] regenerated SBE using a thermal process and acid leaching. Tsai et al. [19] did it by using pyrolysis in a rotary furnace. Wambu et al. [20] continued what Tsai et al. [19] had done and tested the effectiveness of heat regenerated SBE (HRSBE) to absorb Cu (II) ions from aqueous solutions. Heat treatment is proven asan efctve method

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for regenerating SBE in order to restore its absorbent quality. Loh et al. [2] proposed to repurpose SBE into bio organic fertilizer. Previous findings have suggested that heating temperature and heating time have an effect on the recovery of SBE's absorbent quality [18], [20]. Therefore, the current study factors in heating temperature and time.

Heat treatment is used to regenerate SBE to recover its function in the bleaching of coconut oil. Heat-treated SBE's effectiveness is then tested in order to meet the quality characteristics of coconut oil: colors (red and yellow), Free Fatty Acid (FFA), and Peroxide Value (PV). Broader than the study by Boukerroui and Ouali [18], which only evaluated the effect of heating temperature, time, and acid concentration by looking at the color, the current experiments examine the effect of temperature and time by looking at the colors (red and yellow), FFA, and PV. The ultimate goal is to find the optimal aggregated factors in recycling the SBE to produce HRSBE suitable for high standard coconut cooking oil production. The acid leaching as in [8] and [18] was excluded from these experiments because the SBE came from a coconut oil refinery, which has different physical properties from the SBE of palm oil refineries. The current research aims to fill the practical-knowledge gap and the population gap from the previous research.

Response Surface Methodology (RSM) is an approach that is widely used researching edible oil processes as in [21] and [22] due to its effectiveness in minimizing the number of trials. Furthermore, RSM can optimized responses by modeling the effects of several factors. Responses in this context means the results of quality characteristics measurement of a product. In this study, RSM will be used to establish the relationship model between heating temperature and heating time and each of the coconut oil quality characteristics. However, RSM can only accommodate a single response. Meanwhile, this study has several responses to assess: colors (red and yellow), FFA and PV. To compensate the limitation of RSM, a multi criteria decision making (MCDM) approach is put in place. Goal programming (GP) is chosen as one of the MCDM approaches to overcome the limitation of RSM in addressing the purpose of this study. The rationale for using GP is its ability to solve optimization problems with more than one objective. GP has also been used in some quality related studies in order to optimize a number of quality characteristics as in [23] and [24]. RSM and GP are integrated in a way that the models generated by RSM for each response will be used as the objective constraints in GP to find the optimal condition covering all factors. The targeted result is optimal and aggregated factors that meet all responses. The integration between RSM and GP in coconut oil quality optimization also provides a methodological insight for future research.

On a pragmatic level, this study is expected to support Green concepts to not only reduce negative environmental impacts, but also to keep the production cost low. The regeneration of SBE can significantly reduce solid waste generated by the coconut oil industry, thus minimizing the impact on the environment.

The Production of Coconut Cooking Oil

Crude coconut oil (CCO) comes from copra or dried coconut, which is produced by sun drying or smoke drying. Copra produced by sun drying is better than copra produced by smoke drying. In the production of CCO, copra is chopped into small pieces by a crushing machine then goes to the expeller pressing machines. The expeller pressing process produces about 60% CCO and 40% copra cake. The CCO will be stored in the storage tank while the copra cake is stored in a warehouse. The CCO in the storage tank is pumped to a refinery to undergo a refining process. In the refining process, supporting materials such as bleaching earth (BE), activated carbon (AC), and phosphoric acid (PA) are added. There are three stages in the refining process: degumming, bleaching, and deodorizing. BE, AC, and PA are used in the degumming and bleaching process. Subsequently, BE and AC will be extracted as SBE or solid waste. The outputs of refining process are 95% refined bleached deodorized coconut oil (RBDCNO) and 4% coconut fatty acid distillate (CFAD) [25]. Both are liquid products so they are stored in storage tanks. In this study, SBE will be recycled through a heating process to become HRSBE for it to be usable in another coconut cooking oil production process.

The observed quality parameters of cooking oil are colors, FFA, and PV. The high level of red and yellow colors will make coconut cooking oil look dark. Therefore, to improve the appearance of coconut cooking oil, the levels of red and yellow must be lowered. High FFA concentration in cooking oil often contributes to the bitter and soapy taste in food so the concentration of FFA in coconut oil must be reduced [26]. Meanwhile, PV refers to the amount of oxygen that reacts with oil and produces hydroxide formation. Simply put, PV shows the level of oxidation experienced by coconut cooking oil so it must be lowered too.

The Integration of Response Surface Methodology and Goal Programming

RSM is best used in the case of single response optimization. However, in real-world problems, a real single response case is very rare. The real-word problems always involve more than one response that needs to be optimized (multi-response problems). In a multi-response optimization, there are complexities that will affect the outcomes. Such complexities may be an optimum level for one response, but not necessarily for another response. In fact, there is often a conflict between these responses. GP can find a solution to satisfy all responses. Therefore, the integration of RSM and GP is required in dealing with multi-response cases [27]. As in the case of SBE regeneration, there is more than one quality characteristic that must be considered in order to determine both the optimal factors and the factor levels. RSM and GP integration is an ideal solution to the problem.

Despite the widespread application of RSM in finding an optimal parameter setting is an ordinary study and the application of GP to find optimal solutions for multi-objective problems, to date, the integration of the two to solve multi-response problems has not been not popular. When applied properly, the integration of RSM and GP is an effective tool to solve multi-response problems. Previous studies such as the optimization of weld pool morphology [28], the optimization of mushroom growing medium [29], and the optimization of physical and mechanical properties of tablets [30] have shown how the integration of RSM and GP was able to tackle multi-response problems effectively. RSM significantly reduces the number of trials required to find the optimal point in single-response cases. Then, GP continues the task by finding the optimal point from the combination of these single-response cases. Therefore, the current study integrates RSM and GP to find the optimum condition of an SBE heating treatment.

METHOD

Determining Factors, Factor levels, and Responses

Previous studies and screening experiments have provided an insight of the factors and the factor levels that influence an SBE regeneration process. Considering the literature review, the preliminary study results and the experimental limitations, the current study scope covers heating temperature and heating time, with quality parameters being colors (red and yellow), FFA, and PV.

Boukerroui and Ouali [18] set the heating temperature between 300-800oC and the heating time between 0.5-3 hours in their experiment. Tsai et al. [19] set the heating temperature between 500-800°C and the heating time between 0.5-2 hours. Wambu et al. [20] set the heating temperature between 50-1000oC and a heating time of 12 hours. In this study, the heating temperature was set between 130-150oC based on the result of the first-order experiment. This temperature range is set lower than previous studies because the sample used in the previous studies is palm oil which has different initial physical properties from coconut oil. Therefore, the first-order experiment showed a significant adjustment from previous studies. Table 1 shows the three levels of the factors expected to affect the responses.

Experimental Procedures

After the factor levels were determined, Central Composite Design (CCD) was chosen as the response surface design. Previous studies have been conducted to compare CCD and other methods such as the full factorial design and the box-Behnken design in chromatographic method development [31], and the optimization of hempseed oil extraction [32] have shown that CCD is a recommended method for the optimization of liquid-solid extraction processes.

CCD contains an embedded factorial or fractional factorial design with center points augmented by a group of 'star points' that allow for the estimation of curvature. In CCD, factors are tested at a minimum of three levels: minimum, middle and maximum, with coded units of −1, 0 and 1 respectively. To obtain design rotatability, each experimental factor must be represented at five-level coded units: −α, −1, 0, 1, α. The value of α depends on the number of experimental runs in the factorial portion, with k: number of factors [33]. So, when the number of factors are two, the value is 1.414.

Table 1. Levels of the Experiment Factors

Factors	Level		
	Low	Medium	High
Heating temperature (^{o}C)	130	140	150
Heating time (hour)	1	2	3

Table 2. Experimental Design

No.	Factors			
	Coded		Uncoded	
	Heating Temp. (^{o}C)	Heating Time (hour)	Heating Temp. (^{o}C)	Heating Time (hours)
1	-1	-1	130	1
2	1	-1	150	1
3	-1	1	130	3
4	1	1	150	3
5	-1.414	0	126	2
6	1.414	0	155	2
7	0	-1.414	140	0.5833
8	0	1.414	140	3.4166
9	0	0	140	2
10	0	0	140	2
11	0	0	140	2
12	0	0	140	2
13	0	0	140	2

This experiment was designed with 13 factor combinations and each factor combination was replicated three times. Since the sample's characteristics are homogeneous, the number of replications used in this experiment is considered adequate (see Table 2).

In detail, the experimental steps were carried out by following the predetermined experimental design, as follows:

1. 50 grams of SBE is weighed in a porcelain cup with a rough balance.
2. SBE is heated in an oven with a heating temperature and a heating time in accordance with the experimental design.
3. After being heated, the SBE is cooled in a desiccator for 1.5 hours.
4. The CCO sample is measured as much as 100 mL with a measuring cup.
5. 1.8 grams of SBE is weighed with a rough balance and then mixed in the CCO while being stirred.
6. The mixture of SBE and CCO is left to stand for 30 minutes to allow the adsorption process to take place.
7. SBE and CCO mixture is filtered with a Buchner funnel and aspirator.
8. The filtered coconut oil is tested for colors, FFA, and PV.

FFA concentration in the coconut oil is tested by the following steps:

1. The coconut oil is weighed as much as 10-20 grams in an Erlenmeyer flask and 50 ml of 95% neutral alcohol is added. Neutral alcohol is used to dissolve the fatty acids.
2. The Erlenmeyer flask is closed with a condenser and the solution is heated on a hot plate for ± 10 minutes (until the solution is boiling) while being stirred using a magnetic stirrer.
3. After cooling, the solution is titrated with 0.1 N NaOH using 2 mL phenolphthalein indicator until the color of the solution is pink.
4. Then, the FFA concentration is calculated by equation (1).

$$\%\text{FFA} = \frac{mL\ NaOH\ x\ N_{NaOH}\ x\ BM_{fatty\ acid}}{sample\ wight\ (gr)} x \frac{1(g)}{1000\ (mg)} x\ 100\% \quad (1)$$

PV in the coconut oil is measured by the following steps:

1. The coconut oil is carefully weighed to reach approximately 5 grams in a 250 mL iodine flask.
2. The coconut oil is added with 30 mL of CH3COOH-CHCl3 (3:2) mixture and then shaken until dissolved.
3. The coconut oil is subsequently added with 0.5 mL of saturated KI solution then allowed to stand for 1 minute with occasional shake, then added 30 mL of distilled water.
4. The coconut oil is titrated with 0.1 N Na2S2O3 solution while being shaken until the oil's yellow color fades.
5. Then, the coconut oil is added with 0.5 mL of 1% starch solution and the titration continues until the blue color

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dissapear.
6. Finally, PV is calculated by equation (2).

$$PV = \frac{mL\ Na_2S_2O_3 x\ N\ Na_2S_2O_3\ x\ 1000}{sample\ weight\ (gr)} \quad (2)$$

The levels of red and yellow in the coconut oil is tested using Lovibond Tintometer. The sample of coconut oil is put into a Lovibond Tintometer glass cuvette until it is almost full. Then, the sample is placed into the Lovibond Tintometer to observe the red (R) and yellow (Y) color index values.

Response Surface Analysis

The responses generated from the experiments is analyzed using response surface method, analysis of variance, and hypothesis testing. The tests were carried out to check whether the regression equation shows a significant relationship between the factors and the responses.

RSM is a collection of mathematical and statistical techniques that not only aims to model and analyze a response influenced by multiple variables but also to optimize the response [34]. In the application of this method, the observed response is often more than one. The independent variable is the quantity controllable by researchers in an experiment. RSM is employed to see the effect or response of several variables simultaneously. According to Myers et al. [35], RSM is useful for solving problems in three categories: (1) mapping the responses' surface over an area; (2) optimizing the responses. In any industry, one key issue is determining conditions that can optimize responses; and (3) selecting the operational conditions to achieve the specifications. In many response-surface problems, there are multiple responses that must be considered all together.

Technically, the stages of analysis using RSM are as follows:
1. Determine the responses and the factors that influence them along with the levels.
2. Conduct experiments to infer the first order model or the second order model by using a CCD.
3. Perform an analysis of variance to see the significance of each parameter in the model.
4. Test the lack of fit.
   H0: There is no lack of fit
   H1: There is lack of fit
   α: 1%
   Test criteria: reject H0 if p-value ≤ α
5. Conduct residual testing of the suitable models.
6. Make contour plots and regression equation functions.

The RSM process was carried out using Minitab 14 software.

Optimizing the Responses with Goal Programming

A Goal Programming (GP) is used to determine the optimal solution of all equations obtained from the response surface analysis. GP is an effective optimization approach to tackle a multi-objective problem [36]. GP plays an important role in this research because there are four objective functions that must be met, namely the specifications of FFA concentration, colors: red and yellow, and PV in the coconut cooking oil. In addition, unlike Linear Programming that uses hard constraints, GP uses soft constraints so that it can produce feasible solutions [37].

The optimization process is done iteratively starting from the most important quality parameter. In this case, FFA is considered as the most important quality parameter and is followed by red, yellow, and PV respectively. The reason for considering FFA concentration as the most important quality parameter in this study is because it determines the price of edible oil, and potentially causes various health and environmental problems [38]. Therefore, the optimization process consists of four steps. The first step is minimizing the deviation variable of the FFA concentration (δ_1^-). The second step is minimizing the deviation of red level (δ_2^-). The value of the variable δ_1^- generated in the first step is included as an additional constraint in the second step. In the third step, the deviation of yellow level (δ_3^-) is minimized and the values of the variables δ_1^- and δ_2^- generated in the second step are included as additional constraints. In the last step, the deviation of PV (δ_4^-) is minimized and the variable values δ_1^-, δ_2^- and δ_3^- generated in the third step are added as the constraints. This optimization process is carried out to find potential combination that are still within the limits of the experiments conducted. The optimization process was done using Lingo 11.

RESULTS AND DISCUSSION

To adjust the technical conditions of the experiments, the analysis in the current study examines the percentage change from the initial condition to the condition after treatment. The initial CCO sample parameters before the experiments include FFA concentration = 3,784%, PV = 0.781 meq/kg of oil, red level = 13.8, and yellow level = 6.0.

Table 3 shows the influence of heating temperature, heating time, and the combination of heating temperature and heating time on the percentage decrease of the FFA concentration, the red color level, the yellow color level, and the PV.

Table 3 shows that: (1) temperature and time have a significant effect on the decreased percentage of the coconut oil's FFA concentration because the p-value obtained is smaller than the alpha used in this study (α: 1%); (2) temperature, time, the quadratic effect of time, and the interaction between temperature and time have a significant effect on the percentage reduction in the red level of the coconut oil; (3) temperature, time, the quadratic effect of temperature, the quadratic effect of time, and the interaction between temperature and time have a significant effect on the percentage decrease in the yellow level of the coconut oil; and (4) temperature, time, and the interaction between temperature and time have a significant effect on the percentage of reduction in the PV of the coconut oil. In addition, the coefficient of determination (R-sq) for each response whose value is from 61.41% to 94.91% indicates that the model can explain the variation of each response variable (percentage decrease in FFA concentration, red level, yellow level, and PV) very well.

Equations 3-6 are compiled from the coefficient values of the factors that significantly influence the decreased percentage of FFA concentration, red color level, yellow color level, and PV. Factors that have no influence will not be included in the equation.

$$Y_1 = 0.012262 + 0.009083\ x_1 + 0.004330x_2 \quad (3)$$

$$Y_2 = 0.045478 + 0.017670x_1 + 0.012339x_2 + 0.005606x_2^2 + 0.010725x_1x_2 \quad (4)$$

$$Y_3 = 0.1 + 0.04440x_1 + 0.03336x_2 - 0.01493x_1^2 - 0.01910x_2^2 + 0.03333x_1x_2 \quad (5)$$

Table 3. The Results of Estimated Regression Coefficients

Term	FFA		RED		YELLOW		PV	
	Estimated Regression Coefficient	Sig	Estimated Regression Coefficient	Sig	Estimated Regression Coefficient	Sig	Estimated Regression Coefficient	Sig
Constant	0.012	0.000	0.045	0.000	0.100	0.000	0.013	0.000
Heating temp.	0.009	0.000	0.018	0.000	0.044	0.000	0.009	0.000
Heating time	0.004	0.005	0.012	0.000	0.033	0.000	0.006	0.000
Heating temp. * Heating temp.	0.000	0.874	0.000	0.769	-0.015	0.003	0.000	0.476
Heating time * Heating time	0.000	0.788	0.006	0.001	-0.019	0.000	0.001	0.240
Heating temp. * Heating time	0.003	0.109	0.011	0.000	0.033	0.000	0.006	0.000
R-Sq	**61.41%**		**90.01%**		**86.40%**		**94.91%**	

Table 4. Goodness of Fit Test

Source	FFA	RED	YELLOW	PV
	Sig.	Sig.	Sig.	Sig.
Regression	0.000	0.000	0.000	0.000
Linear	0.000	0.000	0.000	0.000
Heating temp.	0.000	0.000	0.000	0.000
Heating time	0.005	0.000	0.000	0.000
Square	0.945	0.002	0.000	0.343
Heating temp. * Heating temp.	0.874	0.769	0.003	0.476
Heating time * Heating time	0.788	0.001	0.000	0.240
Interaction	0.109	0.000	0.000	0.000
Heating temp. * Heating time	0.109	0.000	0.000	0.000
Lack-of-Fit	**0.353**	**0.028**	**0.350**	**0.057**

$$Y_4 = 0.013485 + 0.008856x_1 + 0.006231x_2 + 0.005785x_1x_2 \quad (6)$$

Goodness of fit test is conducted using analysis of variance to see whether there is a lack of fit in the model. The result of goodness of fit test can be seen in Table 4. Generally, all p-values for the lack of fit of all responses (percentage decrease in FFA concentration, red level, yellow level and PV) are greater than α: 1%. Therefore, the conclusion is that there is no lack of fit or the regression model is appropriate.

Residual Testing of the Regression Models

To test the regression models, it is necessary to do a residual analysis by paying attention to some residual properties, i.e. the residuals must be identical, independent and normally distributed. The test results are presented in Figure 1-4.

Table 5. The Results of Normality Residual Testing

	FFA	Red	Yellow	PV
KS	0.14	0.145	0.1	0.098
Sig / P-Value	0.053	0.043	> 0.15	> 0.15

Table 5 shows that p-values for all residuals that have been tested for normality are greater than α: 1%, which means that the residuals for the all models are normally distributed, so the assumption of normal distributed residuals has been fulfilled. Figure 5-8 show that the residual correlations of all models are still within the interval, so the independent residual assumption has been fulfilled.

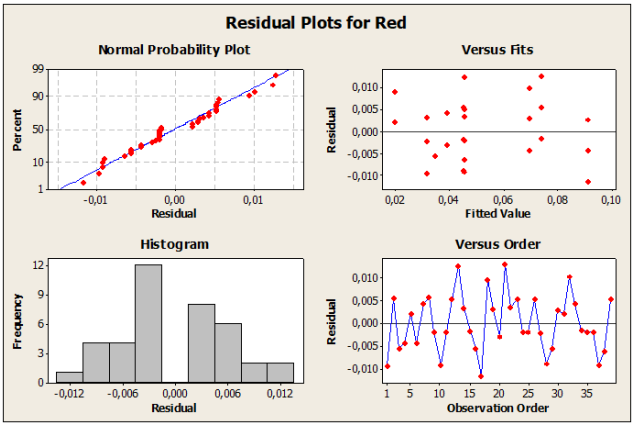


Figure 2. The Results of Residual Testing for Red

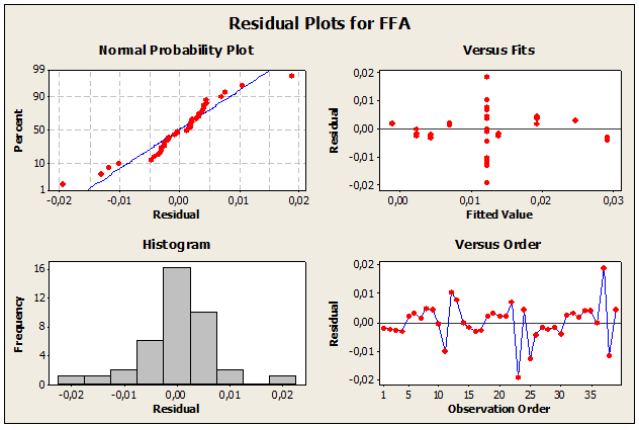


Figure 1. The Results of Residual Testing for FFA

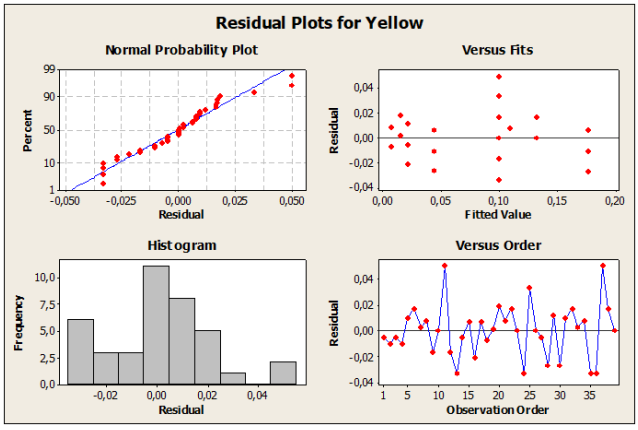


Figure 3. The Results of Residual Testing for Yellow

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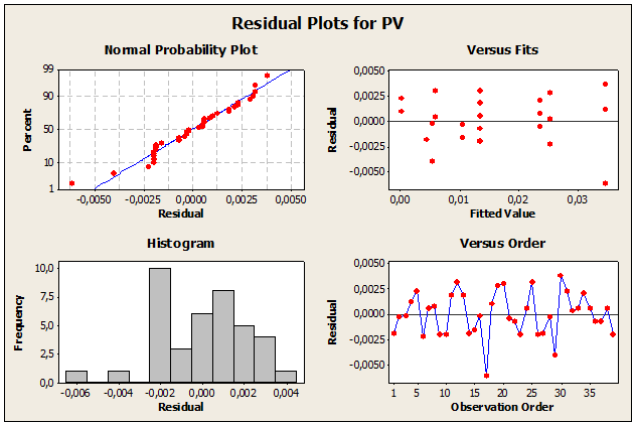


Figure 4. The Results of Residual Testing for PV

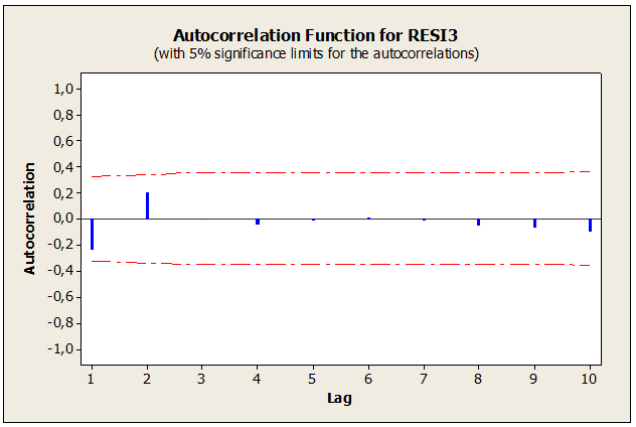


Figure 7. The ACF Plots of FFA's Residuals

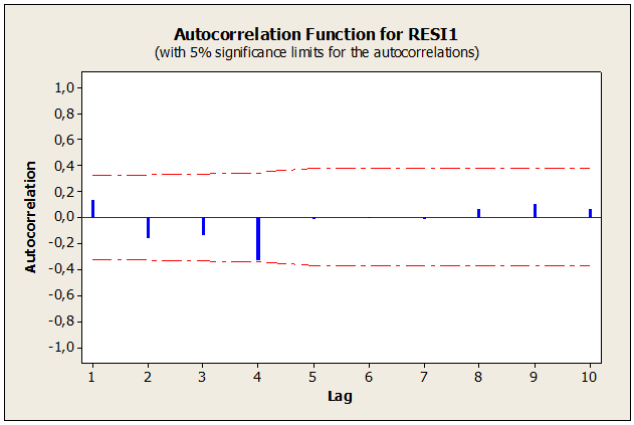


Figure 5. The ACF Plots of Red's Residuals

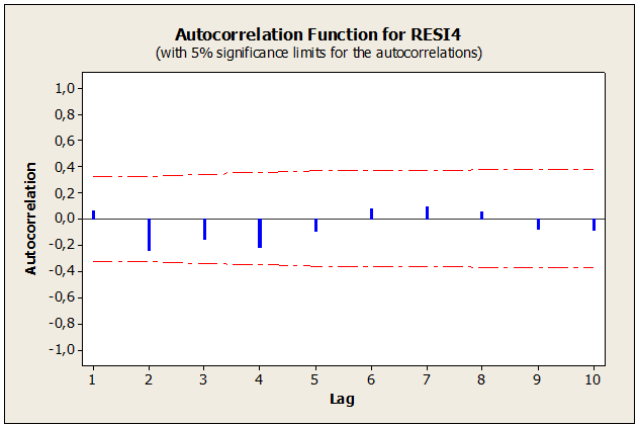


Figure 8. The ACF Plots of PV's Residuals

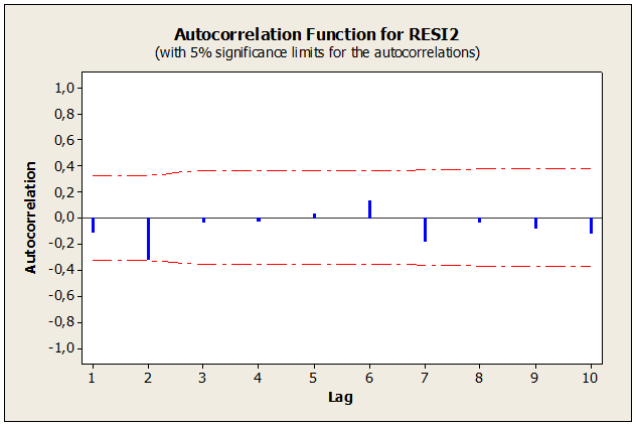


Figure 6. The ACF Plots of Yellow's Residuals

Surface Plot for All Responses

A surface plot is a three dimensional plot of the equation that has been obtained through the surface response analysis process. From the surface plot, it can be seen which areas will produce a maximum or minimum response, so it can be predicted at what level each factor will produce a maximum or minimum response. The surface plot for the entire response can be seen in Figure 9, Figure 11, Figure 13, Figure 15.

Figure 9-16 show the surface plots and the countour plots for the percentage response of the decreasing levels of red, yellow, FFA and PV. There is a quadratic effect due to the parabolic curve formed between the temperature and time. In addition, the percentage decrease in each response level will reach a maximum value when the temperature and time factors are at the highest level, namely temperature at 150 0C and heating time for three hours. According to Bezerra et al. [39], the surface plot shape as shown in Figure 9-16 indicates that the maximum achievable value by each response is outside the experimental area. Therefore, it is necessary to conduct further analysis through GP in order to find the optimal point of each factor that is within the limits of the experiment.

RSM has succeeded in producing equations (3-6), which have been tested and are statistically fit for modeling the relationship between factors and responses. The heating temperature and the heating time in the SBE regeneration procedure are proven to affect the quality parameters of the coconut oil i.e. colors (red and yellow), FFA and PV. The next stage of this research is to do an optimization to aggregate the two factors in order to achieve the expected coconut oil quality parameters.

Goal Programming Process

The initial coconut oil quality parameters and the reduction targets, as well as the quality level parameters to be achieved can be seen in Table 6. The initial coconut quality parametersare obtained from testing a sample of coconut oil be-

Table 6. The Quality Parameters of the Coconut Oil

No.	Parameters	Initial State	Target	Expected Decrease
1	FFA	15.4	< 15	> 2.5974%
2	Red	12.9	< 12	> 6.9767%
3	Yellow	75	< 70	> 6.6667%
4	PV	15.3	< 15	> 1.9608%

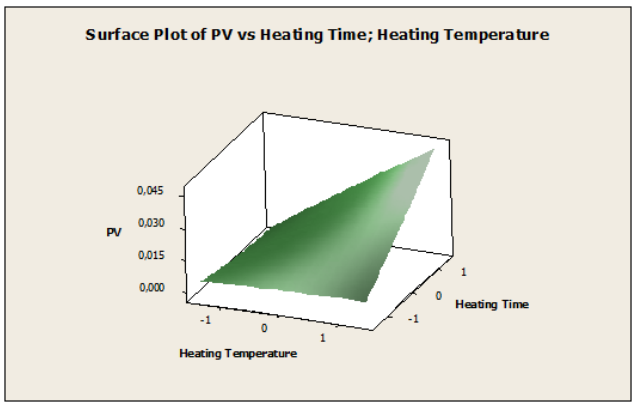


Figure 9. The Response Surface of the Effect of Heating Time and Heating Temperature on PV

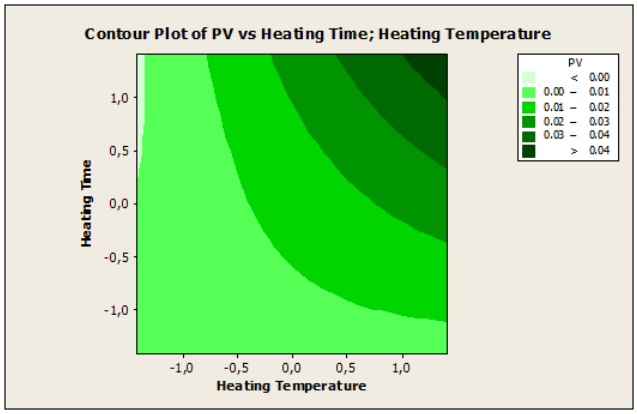


Figure 10. The Contour Plot of the Effect of Heating Time and Heating Temperature on PV

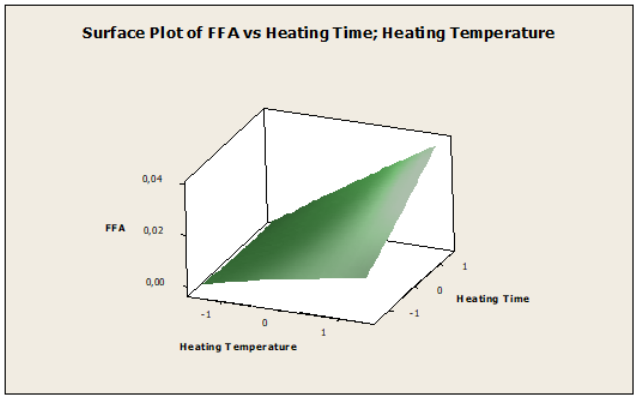


Figure 11. The Response Surface of the Effect of Heating Time and Heating Temperature on FFA

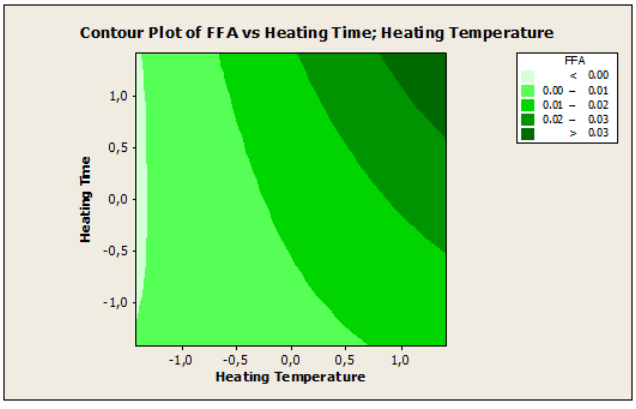


Figure 12. Figure 12. The Contour Plot of the Effect of Heating Time and Heating Temperature on FFA

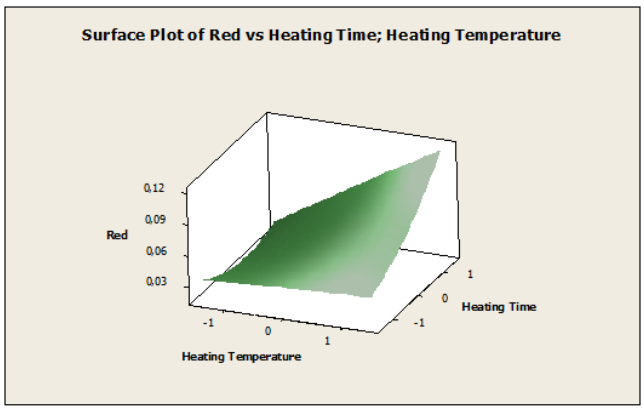


Figure 13. The Response Surface of the Effect of Heating Time and Heating Temperature on Red

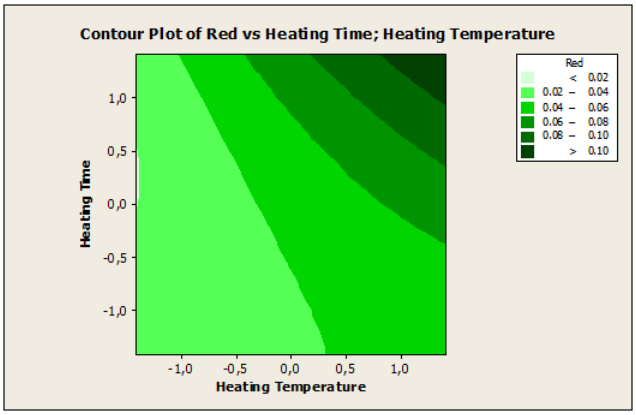


Figure 114. The Contour Plot of the Effect of Heating Time and Heating Temperature on Red

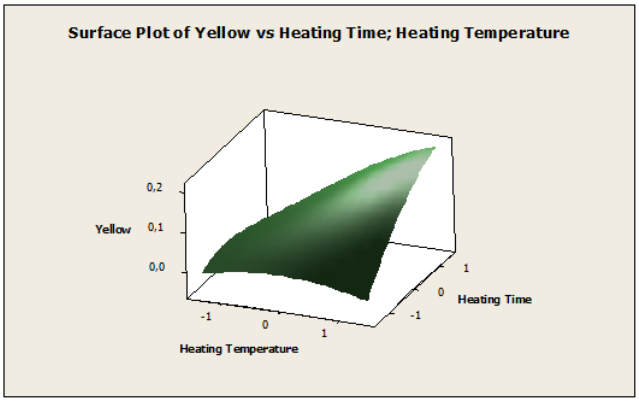


Figure 15. The Response Surface of the Effect of Heating Time and Heating Temperature on Yellow

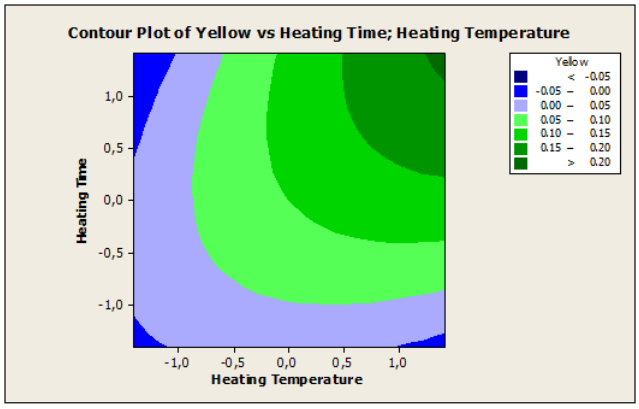


Figure 16. The Contour Plot of the Effect of Heating Time and Heating Temperature on Yellow

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fore being treated with HRSBE. The target of each quality parameter is the quality standard for coconut oil traded by the company. Then, the expected decrease column shows the percentage reduction in the initial quality parameter that HRSBE should achieve.

The initial step in the GP is to determine the range of level limits for each factor, which is derived from the level limits in the prior experiments. The aim is to find out whether there is an optimum value reached within the range of these limits. Therefore, the constraints are determined with a range of level values for each factor of -1,414 to 1,414. This range comes from the coded units used in the RSM experiment. The optimization process with GP is done iteratively starting from the most important quality parameter: FFA. In GP, the main objective function is to minimize the deviational variables that have been added to the objective constraints. The main objective function in the first iteration is shown in equation (7) and the objective constraints are shown in equation (8-11). The constraints from the coded are shown in equation (12-15).

$$\text{Minimize } Z = \delta_1^-$$

$$0{,}01226 + 0{,}00908\, x_1 + 0{,}00433\, x_2 + \delta_1^- + \delta_1^+ = 0{,}25974$$

$$0{,}4547 + 0{,}01767\, x_1 + 0{,}01234\, x_2 + 0{,}00561\, x_2^2 + 0{,}01073\, x_1 x_2 + \delta_2^- - \delta_2^+ = 0.06977$$

$$0{,}1 + 0{,}04440\, x_1 + 0{,}03336\, x_2 - 0{,}01493\, x_1^2 - 0{,}01910\, x_2^2 + 0{,}03333\, x_1 x_2 + \delta_3^- - \delta_3^+ = 0.06667$$

$$0{,}1348 + 0{,}00886\, x_1 + 0{,}00623\, x_2 + 0{,}00578\, x_1 x_2 + \delta_4^- - \delta_4^+ = 0.01961$$

$$x_1 \geq -1{,}414$$

$$x_1 \leq 1{,}414$$

$$x_2 \geq -1{,}414$$

$$x_2 \leq 1{,}414$$

The value of δ_1^- obtained in the first iteration is then used as an additional constraint in the second iteration. The values of δ_1^- and δ_2^- obtained in the second iteration are used as additional constraints in the third iteration and so on until the fourth iteration. The objective function from the second iteration to the fourth iteration are shown in equation (16-18).

$$\text{Minimize } Z = \delta_2^-$$

$$\text{Minimize } Z = \delta_3^-$$

$$\text{Minimize } Z = \delta_4^-$$

This iterative process is interpreted as follows:

1. Minimizing δ_1^- to reduce FFA concentration by 0.02597
2. Minimizing δ_2^- to reduce red level by 0.06977
3. Minimizing δ_3^- to reduce yellow level by 0.066667
4. Minimizing δ_4^- to reduce PV by 0.01961

The optimal values of x_1 and x_2 are are generated by the fourth iteration. The result of each iteration process can be seen in Table 6.

Table 7 shows the optimization results from the first to the fourth iteration. Based on the result of GP, to reduce FFA concentration by 2.5974%, red level by 6.9767%, yellow level by 6.6667%, and PV by 1.9608% then the SBE regeneration processed should be carried out by heating the SBE at a temperature of 151.64oC with a heating time of 3.414 hours.

Table 7. The Optimization Results

Steps	Factors	Coded	Uncoded	Unit
1	x_1	1.414	154.14	°C
	x_2	1.414	3.414	hours
2	x_1	1.164	151.64	°C
	x_2	1.414	3.414	hours
3	x_1	1.164	151.64	°C
	x_2	1.414	3.414	hours
4	x_1	1.164	151.64	°C
	x_2	1.414	3.414	hours

Table 8. The Prediction on Achieving the Target of Coconut Oil Quality Parameters

No.	Parameters	Expected Decrease	Optimization Result
1	FFA	> 2.5974%	2.896%
2	Red	> 6.9767%	11.235%
3	Yellow	> 6.6667%	19.529%
4	PV	> 1.9608%	4.2125%

Table 8 shows the prediction of the decrease that can be achieved if the SBE heating treatment is carried out at 151.64oC for 3.414 hours. FFA concentration can go down by 2.896%. Red level can go down to 11.23%, which is much better than the expectation at 6.9767%. Yellow level can also decrease by 19.529% and PV can decrease by 4.2125%. This result shows that the target of coconut oil quality can be achieved by regeneration SBE at a temperature of 151.64oC with a heating time of 3.414 hours. The heating temperature and the heating time are still within the experimental limits. These results conclude that the research objective has been achieved.

It is also important to note that, in the current study's research paradigm, there are several tools available to handle multi-response cases such as the integration of Taguchi Method (TM) and GP [40] or TOPSIS [41]. However, RSM is arguably a better approach than TM because the magnitude of interaction and optimal parameter settings predicted by RSM is clearer and the 3D response surface plot obtained by RSM can help visualize the effect of input factors on response variables across the specified ranges [42]. Meanwhile, TOPSIS cannot find an exact optimal point such as GP. TOPSIS uses the relative proximity approach of an alternative with an optimal solution. Therefore, the integration of RSM and GP to solve the multi-response problem as used in this study is arguably the most ideal approach with each tool playing its role effectively.

The results of this study indicate that the integration of RSM and goal programming has succeeded in showing an optimal point that satisfies all responses to reach the target. If we only apply RSM, we cannot find an optimal point within the experimental limits that satisfies all responses. The pattern produced by the surface plot still indicates that the maximum point for each response is outside the experimental area. . In fact, this study does not aim to find the optimal point for each response but aims to find the optimal point of the heat treatment factor level to produce HRSBE, which can be used to refine coconut

oil according to the target quality characteristics. Therefore, GP plays an important role to complement RSM in achieving the research objective.

CONCLUSION

AThe application of RSM and GP has successfully demonstrated the optimal combination of factors in regenerating SBE. Through RSM, it is revealed that heating temperature and heating time are proven to affect responses significantly: FFA, red, yellow and PV. Then, GP is able to determine the combination of factors that can meet the targets of the four quality parameters. GP is done iteratively to find out if there is a combination of factors within the limits of the experiment that can meet all quality targets. The results of GP has showed that SBE regeneration at a temperature of 151.64oC with a heating time of 3.414 hours optimally achieves the desired quality target of the coconut oil.

Recycling SBE will significantly reduce the solid waste generated by the coconut oil industry. The experiments carried out on a laboratory scale have proven to be feasible to be developed on a larger scale. HRSBE is able to influence the quality parameters of coconut oil. The integration of RSM and GP should become a proposed methodology to examine similar research objective. The RSM results show that higher temperatures make it possible to produce better HRSBE. However, the ability of the oven used in this study is not possible to increase the temperature. Therefore, future study will benefit from using a tool capable of producing higher temperature with the same estimated cost. Feasibility studies from the economic aspect also need to be carried out to support the idea of recycling SBE. In addition, studies to utilize SBE for other uses also need further research.

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NOMENCLATURE

Y_1	the decrease of FFA concentration
Y_2	the decrease of red level
Y_3	the decrease of yellow level
Y_4	the decrease of PV
x_1	heating temperature
x_2	heating time
δ_1^- and δ_1^+	deviational variables of FFA concentration
δ_2^- and δ_2^+	deviational variables of red level
δ_3^- and δ_3^+	deviational variables of red level
δ_4^- and δ_4^+	deviational variables of PV

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