Optimization of chlorophyll extraction from pineapple plantation waste

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1. Introduction

Renewable energy technologies have been popular recently among researchers and developers. The availability of fossil fuel will eventually run out with an escalating population rate in the near future, which has triggered researchers and developers to invent technologies from renewable sources [1]. Biomass is the best green energy option for meeting the growing demand for renewable energy due to the availability of biowastes. With rising global demand for pineapple, the abundance of waste generated in Malaysia poses a threat to environmental issues [2]. To overcome this problem, the application of dye-sensitized solar cell (DSSC) was introduced to be an alternative to a conventional solar cell [3].

The dye sensitizer in the DSSC plays an important role as it absorbs light and transforms solar energy into electrical energy. Most studies on chlorophyll DSSC have been conducted using an extraction process from natural pigments. Wormwood as a chlorophyll dye for DSSC produced an open circuit voltage of 0.585V, a current short circuit of approximately 1.96 mA, a conversion efficiency of 0.538%, and a fill factor (FF) of approximately 44.69% [6]. Another study used shisoin mixed with chlorophyll extracted from shiso leaves as a dye for a solid state DSSC. The open circuit voltage (mV), current density (mA/cm2), FF, and efficiency (%) were discovered to be 432 Mv, 3.52, 0.39, and 0.59, respectively, with the highest efficiency being 1.31%. According to Kushwaha et al. [7], the leaves of teak (Tectona grandis) showed the best photosensitization effect with a broad range absorption of the visible region spectrum between 470 nm and 662 nm. These studies show that the natural dye chlorophyll has a high potential, particularly in the application of DSSC. As a result, extensive studies have been conducted on the extraction of chlorophyll pigment from waste using various extraction methods.

The extraction of chlorophyll can be done using three methods, which are aqueous extraction, chemical extraction, enzymatic extraction, and supercritical or subcritical extraction [8]. Most studies performed by various researchers have used chemical extraction. This

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method is less time-consuming and high efficiency, but not preferable due to the toxicity of the chemical to the environment, especially when a large amount of solvent is required [9]. Meanwhile, enzymatic extraction was not feasible to be used at the industrial level due to the sensitivity of the behavior of enzymes [10]. Mechanical extraction is the best option for the extraction of chlorophyll as it is easier to handle, does not involve chemicals in the process, and takes the least amount of time to extract. Thus, in this study, chlorophyll was extracted mechanically using a sugarcane press machine. A recent study found that the best conditions to get the highest chlorophyll content using the mechanical method were storage time and extraction cycle. However, no further study was conducted to identify the optimum condition. Hence, this study would focus on optimization to get a higher yield of TC from pineapple leaves.

The optimization process refers to improving the system’s performance in order to identify the conditions under which a procedure can produce the best possible response. Conventional optimization carried out only one factor at a time can be time-consuming and costly, especially when there are many independent variables [11]. Furthermore, conventional optimization may overlook the interaction of factors, making the true optimum point impossible to achieve [12]. Response surface methodology (RSM) was the most relevant technique for the optimization process because it provides analysis of the independent variable effects and their interactions on dependent variable. RSM is a statistical modelling approach that is ideal for optimization processes that combines design of experiment with interpolation using a first or second polynomial equation. The experimental design used in this study was central composite design (CCD). Many research conducted using CCD as an experimental design for instance to optimize biogas production from poultry manure wastewater [13], ferulic acid extraction from banana stem [14], and ultrasonic extraction for marine Spirulina maxima [15]. Hence, this study was performed to identify the optimum conditions to produce the highest yield of TC from pineapple leaves using mechanical method through the application of RSM with CCD.

2. Material and methods

2.1. Collection of samples

Pineapple leaf samples for this research were acquired from Pekan Pina Sdn. Bhd. in Pahang, Malaysia (pineapple plantation industry). The samples weighed about 10 kg per experiment. Figure 1 depicts a sample of pineapple leaves. In this study, the matured leaves were chosen for further investigation to ensure consistency throughout all experimental runs and to prevent bias. The leaves were also cut to an identical length of 10 cm before being used.

![Figure 1. Sample of pineapple leaves.](Image)

2.2. Preparation of the sample

The pineapple leaves were first cleaned with tap water to remove any contaminants and soil that could interfere with the extraction later on. The cleaned samples were dried with a paper towel before being stored in the chiller overnight.

2.3. Extraction of chlorophyll from pineapple leaves using a sugarcane press machine

The prepared samples of pineapple leaves were extracted by using a sugarcane press machine in the Faculty of Chemical & Natural Resources Engineering (FKKSA) laboratory. The sample leaves were extracted multiple times using the machine at different extraction cycles. The juice extracted from the extracted samples was filtered and collected from the pipe. The chlorophyll juice was then collected and placed in a centrifuge tube before being measured with an Ultraviolet-visible (UV-VIS) spectrophotometer for chlorophyll concentration. Then, the samples were stored in a freezer at -20 °C to investigate the effect of storage time on chlorophyll concentration. Lastly, samples from different storage times were removed from the freezer, thawed, and measured to determine their final chlorophyll concentration.

2.4. Determination of chlorophyll contents

The chlorophyll concentrations in pineapple leaves was identified using a UV-VIS spectrophotometer (Genesys 50, Thermo Scientific). Chlorophyll a and b are the two forms of chlorophyll present in pineapple juice samples. To identify the peak of chlorophyll a and b, a wavelength range of 350–800 nm was used for scanning (Suppl. Figure 1). According to the calibration graph of standard chlorophyll, the wavelengths specified for chlorophyll a and b were 662 nm and 646 nm, respectively. After setting the wavelength, the samples were tested in the UV-VIS spectrophotometer. The wavelength values of both chlorophylls were then read and recorded. The quantity of chlorophyll a and b is calculated using Eqs. (1), (2), and (3) [16]:

\[
\text{Chl a (mg/L)} = \frac{A_{662} - 0.0014}{0.0922}
\]

\[
\text{Chl b (mg/L)} = \frac{A_{646} - 0.0011}{0.043}
\]

\[
\text{Total chlorophyll (TC) (mg/L)} = \text{Chl a} + \text{Chl b}
\]

2.5. Preliminary experiment setup

In this preliminary experiment study, the experiment was conducted based on their best condition from the previous study [16]. Table 1 shows the four factors with their best conditions that affected the chlorophyll extracted.

2.6. Experimental setup for optimization of chlorophyll extraction

Based on the preliminary research, the two most important factors in obtaining the optimum TC concentration (mg/L) were further optimized [16]. The factors investigated were the extraction cycle and storage time.

| Table 1. Experimental table for a preliminary experiment. |
|----------------------------------------------------------|
| Factor | Condition |
| Type of waste | Leaves only |
| Pre-heat treatment | No |
| Extraction cycle | 3 cycles |
| Storage time | 8 h |

![Table 1. Experimental table for a preliminary experiment.](Image)
(hours). In this study, the design of the experiment (DOE) for optimization was determined using response surface methodology (RSM), which was generated by CCD in Design Expert (DE) software (Ver 7.1.6). A total of 13 experimental runs, including center points were accomplished. Table 2 shows the ranges of selected factors. In the experimental design, low and high factors were coded as -1 and +1, respectively, while the midpoint was coded as 0 and α value was set as 2. ANOVA evaluated the statistical validity of the model at a 95% confidence level using the p-value. A second-order model was then fitted to it in order to link the response variable to the independent variables. Experiments were performed in triplicate to ensure data accuracy.

2.7. Validation of experiment

After obtaining the optimum conditions suggested by CCD for extraction of pineapple leaves that achieves a maximum yield of TC, validation of the model was tested. The optimum conditions were determined to be 3 times of extraction cycle and 8 h of storage time, with a predicted value was 693.292 mg/L. To validate the model, the percentage error between actual and predicted values was calculated using Eq. (4) [16].

\[
\text{Error} \, (\%) = \frac{\text{predicted value} - \text{actual value}}{\text{predicted value}} \times 100\%
\]

(4)

3. Results and discussions

3.1. Preliminary result

Table 3 illustrates the chlorophyll extraction results based on the best conditions. As the result shows, the highest TC concentration was 242.68 mg/L under this condition. Thus, it was proven that the best conditions for chlorophyll extraction to achieve the highest TC yield were using the leaves only with extraction cycle of 3 without pre-heating treatment with a storage time of 8 h.

3.2. Overall result

Table 4 reports the TC content of 13 sets of experiments with varying point of factors: 1–5 of extraction cycle and 7–9 h of storage time. According to the results, the TC concentration of the samples vary from 259.534 mg/L to 693.292 mg/L. The greatest TC yield (693.292 mg/L) was gained with an extraction cycle of 3 and an 8-hours of storage time, whereas the lowest yield was 259.534 mg/L with an extraction cycle of one and an 8-hours of storage time. The results demonstrated that the higher extraction cycle is useful for chlorophyll extraction from leaves. However, exceeding the optimal extraction point could reduce the amount of chlorophyll extracted due to a decrease in juice extraction from the leaves.

3.3. Analysis of variance (ANOVA)

The analysis of variance (ANOVA) as shown in Table 5 was performed to calculate the model coefficients (p-value), determine the significance of each parameter of a regression equation (F-value), and indicate the strength of each parameter’s interaction. A “Prob > F” < 0.05 implies that the model terms are significant. Model significance was confirmed by an F-value of 9.15 found in this research. A ‘Prob > F’ value of 0.056 indicates that there was only a 0.56% probability that a model F-value this large could occur due to noise. The model with the p < 0.05 indicates this model is statistically significant, indicating that it was a good fit for this study. In this study, the p-values for storage time and extraction cycle were 0.1106 and 0.4696, respectively. According to McLeod [17] the smaller the p-values, the stronger the evidence to favor the alternative hypothesis, which means the variable studied does influence the response variable. Since storage time has a smaller p-value compared to extraction cycle, this factor was a crucial factor affecting the TC yield. For the interaction of storage time and extraction cycle (AB), the p-value was 0.1314. The result interprets that the interaction has simultaneous changes in the levels of both factors to the output response [18].

| Table 2. Selected factors and corresponding range in CCD. |
|----------------------------------|------------------|------------------|------------------|
| Independent variable             | Range and level   |                  |                  |
| Extraction cycle                 | 2.00 (+α)        | -1               | 0                | 1.00 (+α)        |
| Storage time (hour)              | 7                | 7.5              | 8.0              | 8.5              | 9                  |

| Table 3. Result for a preliminary experiment to the best condition from the previous study. |
|----------------------------------|------------------|------------------|
| Sample                          | Chl a (mg/L)     | Chl b (mg/L)     | TC (mg/L)        |
| Sample 1                         | 78.0109          | 163.0907         | 241.10           |
| Sample 2                         | 70.7223          | 146.6256         | 217.35           |
| Sample 3                         | 79.3124          | 163.3698         | 242.68           |

| Table 4. Experimental data and response value for optimization. |
|----------------------------------|------------------|------------------|
| Std Factor 1                     | Factor 2         | Response 1 Chl a (mg/L) | Response 2 Chl b (mg/L) | Response 3 TC (mg/L) |
|                                  | A                | B                |                          |                         |
| 1                                | 7.5              | 2                | 180.039                 | 385.858                 | 565.897              |
| 2                                | 8.5              | 2                | 124.193                 | 243.416                 | 367.609              |
| 3                                | 7.5              | 4                | 180.657                 | 228.509                 | 409.167              |
| 4                                | 8.5              | 4                | 183.965                 | 274.347                 | 458.312              |
| 5                                | 7.0              | 3                | 148.293                 | 278.812                 | 427.104              |
| 6                                | 9.0              | 3                | 88.9436                 | 183.695                 | 272.639              |
| 7                                | 8.0              | 1                | 86.2104                 | 173.323                 | 259.534              |
| 8                                | 8.0              | 5                | 157.306                 | 231.137                 | 388.443              |
| 9                                | 8.0              | 3                | 178.423                 | 321.323                 | 499.746              |
| 10                               | 8.0              | 3                | 325.364                 | 367.928                 | 693.292              |
| 11                               | 8.0              | 3                | 325.364                 | 348.114                 | 673.478              |
| 12                               | 8.0              | 3                | 276.384                 | 345.786                 | 622.172              |
| 13                               | 8.0              | 3                | 325.364                 | 367.928                 | 693.292              |

A: Storage time (hours), B: Extraction cycle.

| Table 5. ANOVA for optimization of TC contents from pineapple leaves, response total chlorophyll yield (mg/L). |
|----------------------------------|------------------|------------------|------------------|
| Source                           | Sum of Squares   | Mean Square      | F-value          | p-value          | Prob > F |
| Model                            | 240000           | 47990.43         | 9.15            | 0.0056           | significant |
| A                                | 17485.96         | 17485.96         | 3.33            | 0.1106           |          |
| B                                | 3065.30          | 3065.30          | 0.58            | 0.4696           |          |
| AB                               | 15305.78         | 15305.78         | 2.92            | 0.1314           |          |
| A^2                              | 119600           | 119600           | 22.81           | 0.0020           |          |
| B^2                              | 142000           | 142000           | 27.07           | 0.0012           |          |
| Residual                         | 36721.59         | 5245.94          |                 |                  |          |
| Lack of fit                      | 9996.63          | 3332.21          | 0.50            | 0.7029           | not significant |
| Pure Error                       | 26724.96         | 6681.24          |                 |                  |          |
| Cor Total                        | 276700           |                 |                 |                  |          |
| R-squared                        | 0.8673           |                 |                 |                  |          |
| Adj. R^2                         | 0.7725           |                 |                 |                  |          |
| Pred. R^2                        | 0.5356           |                 |                 |                  |          |
| Adeq Precision                   | 7.426            |                 |                 |                  |          |
means that the amount of TC yield cannot be estimated solely on the basis of the individual effects of the various changes in this model due to the interaction effect.

The regression coefficient ($R^2$) from the ANOVA was 0.8673. According to previous research, an $R^2$ value greater than 0.75 indicates a highly accurate and satisfactory regression model [19]. The $R^2$ for these response variables was higher than 0.7, indicating that the regression model was a good fit. Meanwhile, the values of adj-$R^2$ and pred-$R^2$ were 0.7725 and 0.5356, respectively. However, the pred-$R^2$ was not as close to the Adj-$R^2$ with $R^2$ as one might normally expect. But since both values were acceptable close to value $R^2$, this proved that the regression model obtained in this study can determine the optimum parameter precisely [14]. Pred-$R^2$ was used to determine how well a regression model predicts to provide a good fit, while adj-$R^2$ was used to compare the goodness of fit for the regression model, and “Adeq Precision” measures the signal-to-noise ratio, with a ratio >4.0 is preferable [20, 21]. For this study, a signal to the noise ratio of 7.426 indicates an adequate signal. As a result, this confirmed that each model in this study can be used to navigate the design space.

The ANOVA also revealed a not significant lack of fit (p-value > 0.050). The lack of fit is the inverse of the whole-model test, which determines if all the model terms are significant with respect to the output response. Lack of fit tests also specify if the regression model was a good or poor model of data based on the experimental factors chosen. In this study, the lack of fit p-value was 0.7029, which implies that the lack of fit was not significant relative to the pure error. According to Sivamani [22] if $p > 0.050$ (not significant) means that the model fits well. Hence, the model for this study was well fitted with a good choice of variables to determine the optimum condition for achieving the highest TC yield.

Eq. (5) is the quadratic equation in coded terms that explains the relationship between the yield of TC content and variables:

$$Total\ Chlorophyll\ (mg/L) = -15048.51647 + 4177.08280A - 501.37057B + 123.71654AB - 289.03613A^2 - 78.72987B^2 \quad (5)$$

In Eq. (5), $A$ is storage time (hours) and $B$ is extraction cycle. Factors $A$ and $B$ are referred as the main effects, while $AB$, $A^2$, and $B^2$ are the interaction effects in the process.

Figure 2a presents the correlation of actual conversions and values predicted by the model. The predicted values of TC concentration computed from Eq. (5). The presence of a linear distribution implies that the model fits well. The predicted values estimated from Eq. (5) were close to the actual TC concentration values. The normal probability plot presented in Figure 2b suggests that the residuals (difference between predicted and actual values) are normally distributed and develop a nearly straight line.

### 3.4. Main and interaction effects

Figure 3 displays the influence of two independent factors on TC concentration. The storage time plays an important role in chlorophyll extraction from pineapple leaves. The TC content seems to be affected by storage time more profoundly than extraction cycle. Based on the graph in Figure 3a, the concentration of TC increased with increasing storage time from 7 h to 8 h with 427.10 mg/L and 693.29 mg/L, respectively. However, upon increasing the storage time from 8 h to 8.5 h, TC content seemed to level off. This was due to the sample oxidizing in the environment with a longer storage time [16]. Wasmund [23] reported in their studies that chlorophyll content of vegetables changes or loses color during storage due to chlorophyll degradation. Thus, this result indicates that the longer storage time of chlorophyll extracted did not appear to have a good effect on TC.

On the other hand, for factor $B$ the yield of TC showed an upward trend when the extraction cycle increased from one cycle to three cycles as shown in Figure 3b. However, the tailing of a growing trend started to decrease after the extraction cycles from four to five cycles. This result indicates that excessive extraction applied to the sample using the mechanical method did not influence the TC content. This indicates that three cycles of the extraction cycle were sufficient to produce the highest concentration of TC. It was confirmed by Cano et al. [24] and Bahçeci et al. [25] who stated that samples need to be extracted between one and three cycles in order to achieve total extraction. The chlorophyll concentration of the juice could also not be increased beyond one to three extraction cycles. This was due to the samples were being completely crushed under high compression of sugarcane press machine after three cycles. Olaoye [26] also highlighted that the amount of extracted juice would decrease if the size of the sample decreased. Thus, it was proven that after maximum condition, the machine would totally collapse the cell wall of plant fiber and consequently, the amount of juice extracted from pineapple leaves decreases.

The effects of process parameters and response may also be observed through 3D-response surface and contour plots in Figures 3c and 3d, respectively. The curvature in Figure 3c reveals that the parameters of extraction cycle and storage time factors had a quadratic influence on chlorophyll concentration, indicating an optimum response near the center point. Meanwhile, the elliptical contour plot shown in Figure 3d demonstrates a significant interaction between the parameters, with the peak falling within the parameter ranges indicated by the red area near the center point. Both figures show that chlorophyll concentration improved as extraction cycle and storage time increased and started to decrease as the extraction cycle and storage time became higher. The effect of storage time was more significant at 8 h while the extraction cycle was at three cycles. At this point, the concentration of TC from pineapple leaves was at its maximum yield. As a result, the optimum extraction chlorophyll condition could be achieved using this design.

### 3.5. Validation of experiment

This extraction procedure is carried out using the numerical optimization approach through the DE software. To maximize the desirability, the extraction cycle and storage time factors were both adjusted within the range, while the yield of TC was adjusted to the highest.

![Figure 2](image-url)
As depicted in Figure 4, the software only recommended one solution: three extraction cycles and 7.87 h of storage time. However, a rounded condition value to 8 h was done in the actual experiment to make it precise. This design has a desirability value of 0.857, indicating that it is appropriate for use. However, the selected conditions can only achieve 631.392 mg/L, although the maximum TC concentration measured was 693.292 mg/L. Therefore, 693.292 mg/L was selected as the predicted value. In validation studies, the discrepancy between predicted and actual values is measured as a percentage error (Table 6). It is shown that the error was within an appropriate range, with a satisfactory error percentage of less than 30% as a rule of thumb. The actual concentration of TC gained under the recommended optimum conditions was 663.500 mg/L, which was the highest of the three validation studies. Therefore, the proposed condition at three cycles of extraction cycle with 8 h storage time was an acceptable optimum condition for chlorophyll extraction to achieve maximum TC concentration.

In contrast to other past investigations, Wu et al. [27] obtained 4.80 mg TC per gram of chlorophyll from moso bamboo culm using an ultrasonic-assisted extraction. This method is simple, less time-consuming, and reliable for chlorophyll extraction, but this method is not preferable compared to other methods. The proper optimization in ultrasound frequency, propagation of cycle, input power, and nominal power of the device must be determined to ensure that the structure of the value molecules is not damaged during the extraction process [9]. The lack of bath temperature and adequate power control would affect the efficiency of the extraction. In addition, the solvent was also included in this method even in minimal amounts, this was still considered costly and toxic for the environment.

Figure 3. Effect of two individual parameters (a) storage time and (b) extraction cycle on TC concentration. Graphs of (c) 3D-response surface curve and (d) contour plot showing TC concentration as a function of storage time and extraction cycle.

![Figure 3](image.png)

Figure 4. Solution of optimum parameters for maximum TC yield suggested by CCD.

![Figure 4](image.png)
Table 6. The error between the predicted and actual value of all experiments.

| Factor 1: Storage time | Factor 2: Extraction cycle | TC yield (mg/L) | Error (%) |
|------------------------|---------------------------|-----------------|-----------|
|                        | Predicted                 | Actual          |           |
| 8 h                    | 3 cycles                  | 693.292         | 663.500   | 4.30      |
| 8 h                    | 3 cycles                  | 693.292         | 566.134   | 18.34     |
| 8 h                    | 3 cycles                  | 693.292         | 500.848   | 27.76     |

Table 7. Comparison of TC contents using different methods from the previous study.

| Sample             | Method              | TC yield (mg/g) | Author         |
|--------------------|---------------------|-----------------|----------------|
| Pineapple Leaves   | Mechanical extraction| 663.5 mg/L      | This research  |
| A. sessilis        | Solvent extraction  | 920.5 mg/L      | [8]            |
| Moso bamboo culm   | Ultrasonification   | 4.8 mg/g        | [27]           |
| Mature white pine  | Solvent extraction  | 2.6 mg/g        | [28]           |
| Conocarpus lancifolius | Solvent extraction | 59.64 mg/g      | [29]           |

Solvent extraction or leaching method is a very common method used by researchers due to easy operation, low energy consumption, and could extract a higher yield of TC. Jinasena et al. [8] investigated the recovery of TC from A. sessilis and gained 920.5 mg/L of TC content using solvent extraction. Another study by Hiscox and Israelstam [28] showed a 2.6 mg/g of TC content also by solvent extraction. Similarly, the research of Jasim [29] did the extraction of chlorophyll from Conocarpus lancifolius using solvent extraction and obtained 59.64 mg/g TC. However, this method is costly, particularly when a large amount of chemical is required in the extraction process, and results in increased chemical waste generation, which may be harmful to the environment. These comparisons are listed in Table 7. Therefore, a low-cost and environmentally friendly single step of extraction of chlorophyll, as conducted in this study using mechanical extraction, was a more efficient and feasible method of extracting chlorophyll from pineapple leaves.

4. Conclusion

A CCD was used to determine the optimum conditions for the extraction of TC content from pineapple leaves. Based on F-value, it was discovered that the two process variables studied had a significant effect on the TC yield. The p-value from the ANOVA test shows that the model terms of storage time and extraction cycle were not statistically significant. But as compared to the p-value, storage time was smaller than the extraction cycle, thus this factor was the strongest factor that influenced the TC contents. Meanwhile, the interaction among the process variables studied shows an interaction effect where there is a simultaneous change in the levels of both factors to the output response. The lack of fit value in this study showed a non-significant lack of fit, indicating that this model was geared toward perfect fitness. Besides that, the quadratic model proposed in this work demonstrates a strong connection between the experimental and predicted concentration of TC. Response surface analysis was discovered to be an effective method for estimating the optimum condition for achieving maximum concentration of TC. The optimal conditions determined were 8 h of storage time and three cycles of extraction cycle. Under this condition, 663.500 mg/L of TC yield was obtained. This accounted for a 4.30% error from predicted models. Therefore, it was suggested the model obtained was favorable for optimizing the extraction of chlorophyll from pineapple leaves using a mechanical method. It is recommended to further research under this condition by using a difference type of mechanical method that may give a higher yield of TC concentration.

Declarations

Author contribution statement

Siti Hajar Abd Rahim: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Norazwina Zainol: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Kamaliah Abdul Samad: Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest’s statement

The authors declare no conflict of interest.

Additional information

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References

[1] A.D. Chintagunta, S. Ray, R. Banerjee, An integrated bioprocess for bioethanol and biomasse production from pineapple leaf waste, J. Clean. Prod. 165 (2017) 1508–1516.

[2] A.F.A. Hamzah, M.H. Hamzah, H.C. Man, N.S. Jamalji, S.I. Siajam, M.H. Imail, Recent updates on the conversion of pineapple waste (Ananas comosus) to value-added products, future perspectives and challenges, Agronomy 11 (2021) 2221.

[3] B. Romero, What is the Difference between Dyensensitized Solar Cell and Organic Photovoltaics?, 2015. https://www.researchgate.net/post/What_is_the_difference_between_dyesensitized_solar_cell_and_organic_photovoltaics accessed March 11, 2022.

[4] H. Chang, M.J. Kao, T.L. Chen, C.H. Chen, K.C. Cho, X.R. Lai, Characterization of natural dye extracted from wormwood and purple cabbage for dye-sensitized solar cells, Int. J. Photoenergy 2013 (2013).

[5] E.M. Jin, K.-H. Park, B. Jin, J.-J. Yun, H.-B. Gu, Photocatalysis of nanosized TiO2 films with natural dye, Phys. Scripta 2010 (2010), 014006.

[6] L.G. Oktariza, B. Yuliarto, Suyatman, Performance of dye sensitized solar cells (DSSC) using Syngonium Podophyllum Schott as natural dye and counter electrode, AIP Conf. Proc. 1958 (2018) 1–5.

[7] R. Kushwaha, P. Srivastava, L. Bahadur, Natural pigments from plants used as sensitizers for TiO2 based dye-sensitized solar cells, J. Energy 2013 (2013) 1–8.

[8] M.A.M. Jinasena, A.D.U.S. Amarasinghe, B.M.W.P.K. Marasinghe, M.A.B. Prashantha, Extraction and degradation of chlorophyll a and b from Alternanthera sessilis, J. Natl. Sci. Found. Sri Lanka 44 (2016) 11–21.

[9] N.A. Sagar, S. Pareek, S. Sharma, E.M. Yahia, M.G. Lobo, Fruit and vegetable waste: bioactive compounds, their extraction, and possible utilization, Comp. Rev. Food Sci. Food Saf. 17 (2018) 512–531.

[10] W.A.J.P. Wijesinghe, Y.J. Jeon, Enzymatic extraction of bioactives from algae, Funct. Ingredients From Algae Foods Nutracucci. (2013) 517–533.

[11] M.A. Bezerra, R.E. Sanselli, E.F. Oliveira, L.S. Villar, L.A. Ecaleira, Response surface methodology (RSM) as a tool for optimization in analytical chemistry, Talanta 76 (2008) 965–977.

[12] G.E.P. Box, K.B. Wilson, On the experimental attainment of optimum conditions, J. Roy. Stat. Soc. 13 (1951) 1–45.

[13] C.W. Chun, N.F.M. Jamaludin, N. Zainol, Optimization of biogas production from poultry manure wastewater in 250 ML tanks, J. Teknol. 75 (2015) 275–285.

[14] S.S. Mohd Shafii, E.S. Thor, N. Zainol, M.F. Jamaluddin, Optimization of ferulic acid production from banana stem waste using central composite design, Environ. Prot. Sustain. Energy 36 (2017) 1217–1223.

[15] W.Y. Choi, H.Y. Lee, Enhancement of chlorophyll a production from marine Spirulina maxima by an optimized ultrasonic extraction process, Appl. Sci. 8 (2017) 26.

[16] N.P. Melrookan, N. Zainol, K.A. Samad, Chlorophyll extraction from pineapple plantation waste through mechanical extraction, Biocatal. Agric. Biotechnol. 39 (2022), 102264.

[17] S.A. McLeod, What a P-Value Tells You about Statistical Significance, Simply Psychol, 2019. https://www.simplypsychology.org/p-value.html. (Accessed 20 May 2019).
[18] D. Kiernan, Main Effects and Interaction Effect, 2022. https://stats.libretexts.org/@go/page/2904. (Accessed 2 May 2021).

[19] S. Ferreira, A.P. Duarte, M.H.L. Ribeiro, J.A. Queiroz, F.C. Domingues, Response surface optimization of enzymatic hydrolysis of Cistus ladanifer and Cytisus striatus for bioethanol production, Biochem. Eng. J. 45 (2009) 192–200.

[20] J. Frost, How to Interpret Adjusted R-Squared and Predicted R-Squared in Regression Analysis, Stat. By Jim, 2017. https://statisticsbyjim.com/regression/interpret-adjusted-r-squared-predicted-r-squared-regression/. (Accessed 4 August 2022).

[21] G. Singh, N. Ahuja, P. Sharma, N. Capalash, Response surface methodology for the optimized production of an alkalophilic laccase from γ-proteobacterium JB, Bioresources 4 (2009) 544–553.

[22] S. Sivamani, What is the Meaning of P-Value of Lack of Fit on Response Surface Methodology (RSM)?, 2014. https://www.researchgate.net/post/What_is_the_meaning_of_p_value_of_lack_of_fit_on_response_surface_methodology_RSM (accessed March 11, 2022).

[23] N. Wasmund, L. Topp, D. Schories, Optimising the storage and extraction of chlorophyll samples, Oceanologica 48 (2006) 125–144.

[24] M.P. Cano, M. Monreal, R. De Ancos, R. Alique, Effects of oxygen levels on pigment concentrations in cold-stored green beans (Phaseolus vulgaris L. cv. Perona), J. Agric. Food Chem. 46 (1998) 4164–4170.

[25] K.S. Bahçeçi, A. Serpen, V. Gokmen, J. Acar, Study of lipooxygenase and peroxidase as indicator enzymes in green beans: change of enzyme activity, ascorbic acid and chlorophylls during frozen storage, J. Food Eng. 66 (2005) 187–192.

[26] J.O. Olaoye, Development of a sugarcane juice extractor for small scale industries, J. Agric. Technol. 7 (2011) 931–944. http://www.ijat-aatsea.com.

[27] J.H. Wu, S.Y. Wang, S.T. Chang, Extraction and determination of chlorophylls from moso bamboo (Phyllostachys pubescens) culm, J. Bamboo Rattan 1 (2002) 171–180.

[28] J.D. Hiscox, G.F. Israelstam, A method for the extraction of chlorophyll from leaf tissue without maceration, Can. J. Bot. 57 (2011) 1332–1334.

[29] N.J. Jassim, Solvent extraction optimization of chlorophyll dye from Conocarpus lancifolius leaves, J. Eng. Technol. Sci. 52 (2020) 14–27.