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Taguchi-Based Optimization of Moringa oleifera Seed Powder Coagulation-Flocculation for TSS and TDS Removal from Industrial Rice Flour Wastewater

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ABSTRACT

Industrial rice flour generates significant volumes of cloudy, starchy wastewater, with high levels of total dissolved solids (TDS) and total suspended solids (TSS). The rich organic content of this effluent poses a substantial environmental threat. This study aimed to optimise the treatment of rice flour wastewater using natural Moringa oleifera seed powder (MSP) as a coagulant flocculant to reduce TDS and TSS levels by varying particle size and dosage, with the results analysed statistically using the Taguchi method. The treatment process consisted of gross filtration, pre-sedimentation, coagulation flocculation, and sedimentation. The MSP sizes varied among 60, 30, 18, 10, and 7 mesh, while the dosages were 1:1000, 1:660, 1:500, 1:330, and 1:250 of the mass dosage of MSP (g) to sample volume (mL). The results showed that the particle size and dosage had significant effects on the reduction of TSS and TDS. Treatment with 60-mesh MSP at a dosage of 1:330 resulted in a TSS reduction of 73.08 %. Meanwhile, treatment with 30-mesh MSP at a dosage of 1:1000 achieved a TDS reduction of 37.08%. Generally, the treatments of all variations tend to lower the pH. Taguchi analysis employing two factors and five levels indicated that the lowest average response was obtained at the 30-mesh size with a dosage of 1:660, where as the signal-to-noise (S/N) ratio analysis showed that the most stable and least noise-affected condition occurred at the 30-mesh size with a dosage of 1:1000.

Keywords: Rice Flour Wastewater; Moringa Oleifera Seeds Powder; Coagulant Flocculant; Taguchi

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INTRODUCTION

Environmental pollution remains a critical issue requiring serious attention, particularly in the management of industrial waste, to ensure negative environmental impacts are controlled and minimized. Every industrial activity generates waste that must be properly treated before being discharged into the environment, including liquid waste from various industrial processes. Industrial wastewater is defined as residual water produced from manufacturing activities, cleaning operations, production processes, or cooling systems that contains various types of contaminants at high concentrations (Kato & Kansha, 2024). One type of wastewater with the potential to pollute the environment is effluent generated from rice flour production activities. This wastewater generally contains suspended solids, organic matter, inorganic substances, and other pollutant compounds that can degrade the quality of aquatic environments. Therefore, wastewater from the food industry, including rice flour processing, represents an important source of environmental pollution that must be managed effectively and efficiently.

In the modern era, various wastewater treatment methods have been developed to reduce the negative impact of environmental pollution. One promising approach is the use of natural materials, such as Moringa oleifera seeds, as coagulant agents for wastewater treatment. Numerous studies have demonstrated that Moringa seeds are effective in treating wastewater, including domestic effluent and contaminated water, particularly in reducing turbidity and suspended solids (Puspita, Maryani, & Kosimaningrum, 2021)(Carlos, Herrera, Andrey, Agudelo-castañeda, & Paternina-arboleda, 2024). In the wastewater treatment of rice flour production, Moringa seeds have strong potential as a coagulant flocculant to bind suspended particles. Moringa seeds contain positively charged cationic polyelectrolyte proteins that can attract and neutralize negatively charged colloidal particles, thereby promoting aggregation and subsequent sedimentation at the bottom of the treatment medium (Hermida, Agustian, & Kurniasari, 2021).

The optimization of industrial wastewater treatment processes is a key factor in determining the most efficient and effective operating conditions. Each treatment stage is influenced by multiple interacting operational parameters; therefore, a systematic analysis is required to obtain optimal treatment performance. Consequently, the application of statistical analysis is an essential step in evaluating and optimizing wastewater treatment. This study aimed to identify the treatment conditions that yield the best performance using the Taguchi statistical method. The Taguchi method was selected because of its capability to optimize processes by considering the influence of multiple factors on output parameters while simultaneously minimizing process variability (Dwi et al., 2024). This approach enables the selection of the optimal parameter combination to achieve a stable and high-quality treatment performance. In the context of this study, variations in particle size (mesh) and dosage of Moringa seeds are important factors affecting the effectiveness of Moringa seeds as a coagulant flocculant in rice flour wastewater treatment. By applying the Taguchi method, the most optimal parameter combination is expected to be identified to improve the efficiency and performance of the treatment process.

This study aims to explore the effect of adding Moringa oleifera seed powder (MSP) on rice flour wastewater treatment and its process optimization by varying two main parameters: the particle size of MSP expressed in mesh units and the dosages, which are the mixing ratio between MSP (gram) and wastewater volume (mL). The reported application of Moringa seeds in wastewater treatment involves several pretreatment steps, such as solvent extraction (Series, 2021). Herein, MSP was used for rice flour wastewater treatment without pretreatment. The direct use of moringa seed powder is expected to be more practical, low-cost, sustainable, and effective in reducing turbidity, bacteria, and other contaminants. This study evaluated the effect of moringa seed powder particle size and dosage on the coagulation flocculation effectiveness of rice flour wastewater. The optimization process was determined using the Taguchi method. The Taguchi statistical method was implemented to efficiently identify the optimum parameter combination, thereby reducing the number of experiments without compromising the validity of the results. The findings of this study are expected to contribute to the development of simple, economical, and applicable natural-material-based wastewater treatment techniques, particularly in the food industry and environmental management.

METHODS

Material

The Moringa seeds used in this study were dehulled kernels of *Moringa oleifera* grown in East Nusa Tenggara, Indonesia. Rice flour wastewater was collected from a rice flour company located in Serang Regency, Banten, Indonesia. Wastewater samples were collected from the wastewater tank in the wet area during the rice soaking process. The filter paper used for TSS measurement in this study was Gelman Type A No. 42 (⌀ 11 cm) with a particle retention size of 1.0 μm.

Instruments

The TDS meter used in this study was a portable TDS & EC Meter with automatic calibration (Model B1900131A2) from Mediatech. The pH was measured using an automatic calibration pH meter (Model p2Z G011) with a measurement range of 0.0–14.0 pH, resolution of 0.1, and temperature range of 0–80 °C, also manufactured by Mediatech. The digital balance used in this study was an ACAS SF-400C with a maximum capacity of 600 g and an accuracy of 0.01 g, with selectable units of grams, ounces, pounds, and carats. The sieves used in this study were made of stainless steel 304, with a diameter of 30 cm and a height of 8 cm, and were available in various mesh sizes (60, 30, 18, 10, and 7 mesh).

Methods

The treatment process for rice flour wastewater in this study consisted of filtration, pre-sedimentation, coagulation flocculation, and sedimentation, as shown in **Figure 1**. The measured parameters in this study were Total Dissolved Solids (TDS), Total Suspended Solids (TSS), and pH.

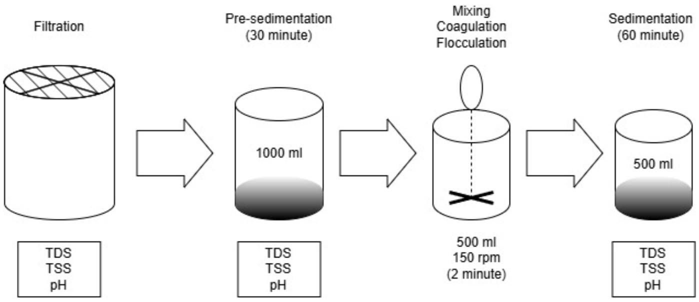

Figure 1. Process Flow of Rice Flour Wastewater Treatment

Moringa Seeds Powder (MSP) Preparation

The Moringa seeds were dehulled and stored in airtight plastic containers to ensure that the dehulled seeds remained dry and in good condition. The dehulled seeds were crushed using a chopper. After grinding, the Moringa oleifera seeds were sieved according to predetermined particle sizes. The sieving process used stainless steel 304 sieves with mesh sizes 60, 30, 18, 10, and 7. The ground seeds were sieved sequentially from the finest to the coarsest mesh to prevent coarse particles from mixing with finer particles, thereby ensuring homogeneous particle sizes. The sieved seed fractions, which are referred to as MSP, are shown in **Figure 2**. MSP of various sizes were then stored separately in airtight containers. Silica gel was added to each container to prevent moisture absorption and fungal growth.

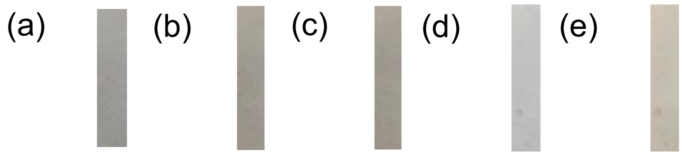

Figure 2. The moringa seeds powder at various particle sizes (a) 60 mesh (b) 30 mesh (c) 18 mesh (d) 10 mesh, and(e) 7 mesh

Rice Flour Wastewater Sample Preparation

Rice flour wastewater was collected from the rice flour industry during the production process. The wastewater was located in a ground tank at an elevation of −1 m which was positioned 1 m below ground level to facilitate gravity-driven flow within the industrial process. The wastewater samples were collected using a graduated cylinder and then transferred into jerrycans without prior filtration for use as the initial research samples.

Gross Filtration

The initial stage of the treatment process applied to the rice flour wastewater was gross filtration to remove coarse impurities from the stored rice flour wastewater. In this study, rice flour wastewater was filtered using a 30-mesh sieve. After filtration, 1000 mL of rice flour wastewater from each sample was transferred into smaller containers for further treatment. The filtrate from each sample was then analyzed for some key parameters, namely Total Dissolved Solids (TDS), Total Suspended Solids (TSS), and pH.

Pre-sedimentation

Pre-sedimentation was conducted to separate sludge and massive coarse materials from rice flour wastewater. This process employs a physical method to remove solid particles dissolved or dispersed in wastewater. It utilizes gravitational force to settle solid particles at the bottom of the settling tank or basin (Ibrahim, Ismail, Chua, & Adnan, 2021), thereby producing clearer supernatant water.

The filtered rice flour wastewater, which had been portioned into separate containers, was subjected to pre-sedimentation for 30 min. Subsequently, the Total Dissolved Solids (TDS), Total Suspended Solids (TSS), and pH were measured again to evaluate the effect of the pre-sedimentation process. After this stage, the clarified wastewater was carefully decanted from the top to separate it from the sediment and transferred into separate containers for subsequent treatment.

Coagulation flocculation

A total of 500 mL of supernatant obtained from the pre-sedimentation stage was mixed with MSP and stirred using a magnetic stirrer at 150 rpm for 2 minutes to ensure homogenization between the seeds, which varied based on particle size and dosage.

Coagulation occurs through the addition of chemical coagulants, such as salts, aluminum metals, sulfates, or coagulant flocculants, such as Moringa oleifera seeds, which promote the aggregation of small particles in water into larger flocs with greater mass (Wagh, Aher, & Mandalik, 2022).

Sedimentation

After the addition of the Moringa seed coagulant flocculant, the mixture was allowed to stand for 60 min to enable sedimentation. Larger and denser particles settled at the bottom of the containers. Sedimentation occurs because solid particles that are dissolved or suspended in the liquid settle or sink to the bottom under the influence of gravity.

The mechanism begins when particles with greater mass or density, previously dispersed throughout the liquid, begin to move downward under the influence of gravity. In this study, the sedimentation process of rice flour wastewater treated with Moringa oleifera seed powder was conducted by allowing the mixture to remain undisturbed for 60 minutes to provide sufficient time for particle settling at the bottom of the container.

Total Dissolved Solids Measurement

Total Dissolved Solids (TDS) were measured using a TDS meter that was calibrated with a standard solution to ensure measurement accuracy. The purpose of the TDS measurement was to determine the concentration of dissolved substances in the water. Dissolved solids in water may include salts, minerals, metals, and organic compounds with very small particle sizes that cannot be retained by filter papers.

Total Suspended Solids Measurement

Total Suspended Solids (TSS) were measured in accordance with the Indonesian National Standard (SNI) using the gravimetric method (Indonesia & Nasional, 2004). The procedure began by drying the filter paper in an oven at 103–105 °C for 60 minutes to ensure that the filter paper was clean and completely dry. The filter paper was then stored in a desiccator containing silica gel to maintain dryness. After confirming that no moisture remained, the filter paper was weighed to obtain its initial mass.

After the sedimentation process was completed, 300 mL of wastewater was transferred into a graduated cylinder and filtered using pre-dried filter paper. Once the wastewater had completely passed through and no liquid remained on the filter paper, the filter paper was dried in an oven at 103–105 °C for 60 min to remove residual moisture. The samples were then returned to a desiccator to maintain dryness. The dried filter paper was weighed again to determine the final mass after filtration and sedimentation were completed. The TSS value was calculated using **Equation (1)**.

$$TSS\left(\frac{mg}{L}\right) = \frac{\boldsymbol{(Final\,Weight\,(gram) - Initial\,Weight\,(gram))\;x\;1000}}{\boldsymbol{Water\,Volume\,(l)}} \quad (1)$$

pH measurement

Another measured parameter was pH, which indicates the acidity or alkalinity of a solution on a scale ranging from 0 to 14. A pH value of 7 represents a neutral solution, values below 7 indicate acidic conditions, and values above 7 indicate alkaline conditions.

The purpose of pH measurement is to understand the chemical characteristics of a liquid, such as wastewater, because pH can influence chemical reactions, solubility of substances, and biological processes occurring in environmental or treatment systems. In this study, the pH was measured using a calibrated pH meter.

Taguchi Method

The Taguchi method was employed to identify the optimal combination of process parameters that would yield minimum noise by considering the signal-to-noise (S/N) ratio. The Taguchi method guided the determination of the most stable combination of MSP particle size and dosage, thereby reducing process variability and producing more consistent and high-quality treatment performance.

The initial stage in applying the Taguchi statistical approach was the development of a Design of Experiment (DOE) based on the planned research data. The experimental design in this study used five levels and two influencing factors (**Table 1**), resulting in an orthogonal array **L25(5^2)** as shown in **Table 2.**

Table 1. Factors and Level

Factors	Level					Units
Size	60	30	18	10	7	mesh
Dosage	1:1000	1 :660	1 :500	1:330	1:250	gram: milliliter

Table 2. Design Of Experiment (DOE)

Size	Dosage	Size	Dosage	Size	Dosage	Size	Dosage	Size	Dosage
60	1:1000	30	1:1000	18	1:1000	10	1:1000	7	1:1000
60	1 :660	30	1 :660	18	1 :660	10	1 :660	7	1 :660
60	1 :500	30	1 :500	18	1 :500	10	1 :500	7	1 :500
60	1:330	30	1:330	18	1:330	10	1:330	7	1:330
60	1:250	30	1:250	18	1:250	10	1:250	7	1:250

After the measurement parameter data were obtained, the next step was to determine the mean value of the experimental results by substituting the data into **equation (2)**:

$$y_{avarage} = \frac{X1+X2}{Z} \qquad (2)$$

$y_{Average}$ = Average
X = Result of measurement (X1 = TDS, X2 = TSS)
Z = Amount of data

Equation $TSS(mg/L) = \frac{(Final\ Weight\ (gram) - Initial\ Weight\ (gram))\ x\ 1000}{Water\ Volume\ (l)}$ (1) was calculated for each level and factor. This study involved 25 experimental runs. The repetitions used to determine the value of y followed the number of experiments performed. Once the y values were obtained, the "means effect plot for means" was constructed by averaging the results for each variation and dosage ratio. This plot illustrates the influence of each level on the average response of the experiment, enabling the identification of the optimal level for reducing the measured parameters. After obtaining the mean plot, the signal-to-noise (S/N) ratio was calculated using the "smaller-is-better" criterion to evaluate the stability and consistency of the process at each factor level. The S/N ratio (smaller-is-better) is expressed by **Equation (3).**

$$\frac{S}{N} = -10 \log \left(\frac{1}{n} \times \sum_{k=1}^{n} y^2 k\right) \qquad (3)$$

S/N = Signal to Noise Ratio
n = Number of testing factors
y = Average value of measurement results

After the S/N ratio values were obtained from **Equation** $SN = -10 \log \left(\frac{1}{n} \times \sum_{k=1}^{n} y^2 k\right)$ (3), The main Effects Plot for S/N ratio was generated by averaging the values for each mesh size variation and dosage ratio to assess the level of disturbance affecting the influential factors in the experiment.

RESULT AND DISCUSSION

Table presents the measurement results of Total Suspended Solids (TSS), Total Dissolved Solids (TDS), and pH of rice flour wastewater before and after pre-sedimentation and sedimentation. The rice flour wastewater had severe turbidity, with an initial TSS of 6767 mg/L. Moreover, the wastewater still contained a large quantity of fine- to coarse-grained rice particles. Thus, the pre-sedimentation process was important before further wastewater treatment. In industrial sites, the pre-sedimentation process can also be recommended to avoid frequent suction pump clogging. The pre-sedimentation process significantly reduced the TSS to 1667 mg/L, corresponding to a reduction of 75.37%. This indicates that the suspended particles in the rice flour wastewater still possessed sufficient mass and density to be influenced by gravity and settle at the bottom of the container (Hostnik, Bajt, & Kova, 2023).

Table 1. TSS, TDS, and pH Measurement Results

Rice flour wastewater	TSS (mg/l)	TDS (ppm)	pH
Initial	6767	1698	3,91
AfterPre-Sedimentation	1667	1685	3,91

In contrast to TSS, the TDS value decreased insignificantly after the pre-sedimentation process. The initial TDS was 1698 ppm and decreased to 1685 ppm after pre-sedimentation, which only corresponds to a 0,77 % reduction. The pre-sedimentation process is ineffective in precipitating dissolved particles that are of low density and insufficiently massive to undergo natural sedimentation without the presence of a coagulant (Rasheed, Alkaradaghi, & Al-Ansari, 2023).

Effect of Moringa Seeds Powder Coagulation flocculation on TSS

The addition of MSP to pre-sedimented rice flour wastewater generally resulted in a reduction in the TSS value of the wastewater, as shown in **Figure 3**. MSP acts as a natural and powerful coagulant-floculant that binds suspended particles in wastewater, decreasing the TSS value. Herein, the effect of MSP on rice flour wastewater treatment was clear. The TSS of the wastewater after treatment without the moringa seed powder was recorded as 867 mg/L. However, treatment with MSP lowered the TSS by up to 233 mg/L or approximately73,08 % in reduction. This result was obtained by the treatment using 60 mesh MSP at a dosage 1 : 330 (powder mass in gram to wastewater volume in mL). This study also shows that the particle size and dosage of MSP influence the rice flour wastewater treatment process. The finest particles enable the optimum release of the coagullant-flocullant into the wastewater, ensuring an adequate supply for the coagulation-floculation process. In addition, the dosage or mixing ratio of powder mass to the wastewater volume is important. The suspended particles in wastewater require an adequate amount of coagulant to effectively facilitate the coagulation-flocculation process.

The excess wastewater volume leads to ineffective TSS removal due to insufficient coagullant-floculant. However, high doses of MSP leave excess fine particles that contribute to the TSS value.

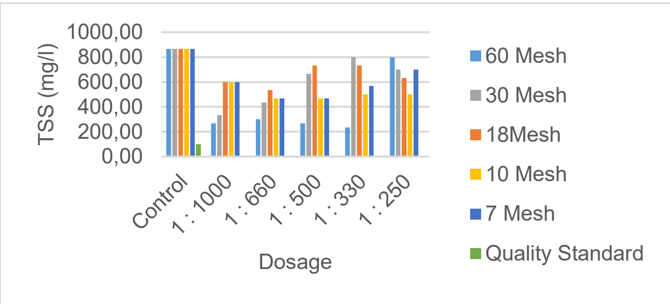

Figure 3. TSS values of treated rice flour wastewater using MSP at various particle sizes and dosages

The coagulation-floculation process of suspended solids in wastewater is illustrated in **Figure 4**. MSP releases positively charged ions from itsamine groups. These positively charged species interact with negatively charged particles present in rice flour wastewater (Aras, 2021). This process stimulates the formation of massive microflocs, which then become settleable solids to form sediment.

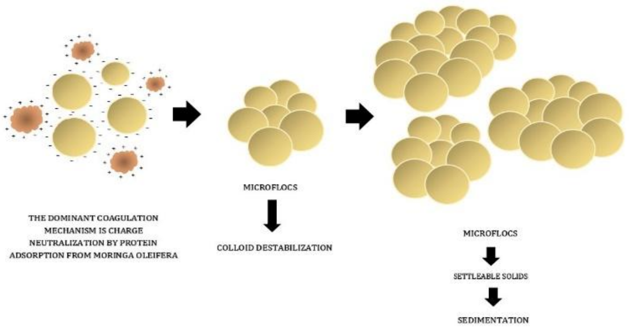

Figure 4. Coagulation-floculation process of suspended solids using moringa seed powder

The data also indicate that the effectiveness of MSP in reducing TSS decreases as finer powders (such as 60 and 30 mesh) are applied in excessive amounts. At a dosage of 1:250, the TSS values tended to be higher. This suggests that beyond a certain dosage of MSP, the TSS of rice flour wastewater may increase owing to overdosing of the coagulant. Consequently, excess Moringa seed material may contribute to dissolved or suspended matter in the wastewater. Moringa seeds can enhance TSS reduction by forming heavier flocs (Hizam, Noor, Faiz, & Mohd, 2022). However, the most significant performance occurs within specific limits of particle size and dosage ratio of the MSP.

Effect of Moringa Seeds Powder Coagulation flocculation on TDS

The total dissolved solids (TDS) level of the pre-sedimented rice flour wastewater was as high as 1685 mg/L. The effect of MSP addition on wastewater treatment is shown in **Figure 5**. Wastewater treatment without MSP resulted in an insignificant TDS reduction. In contrast, the TDS level generally decreased as MSP was applied in wastewater treatment.

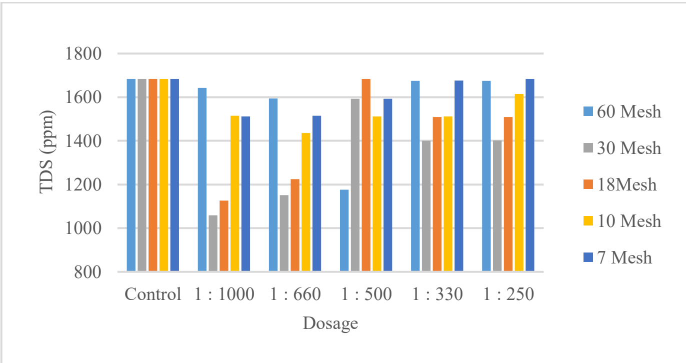

Figure 5. TDS values of treated rice flour wastewater using MSP at various particle sizes and dosages.

The particle size as well as the dosage of MSP affected the TDS reduction. As previously mentioned, fine particles enable the optimum release of coagulant-floculant and the dosage ensured an equivalent quantity of coagulant-fine particle to optimise floc formation, which then settled down and decreased the TSS and TDS levels. The experimental data also showed a tendency for TDS removal effectiveness to decline, as indicated by increasing TDS values at larger particle sizes and higher dosage ratios. Herein, 30-mesh MSP at a dosage of 1 : 1000 showed the best performance among others in this experiment to reduce TDS by approximately 37,08%. The particle size and dosage ratio of MSP as a coagulant flocculant affected the solution concentration and the available surface area for binding suspended and dissolved particles in rice flour wastewater. This interaction promoted floc formation and increased particle mass, consistent with findings reported by (Kitheka et al., 2022), thereby influencing the sedimentation rate in wastewater systems.

The lowest TDS value achieved in this study was 1059 ppm, which is still higher than the established benchmark for water quality. Dissolved solids can originate from the rice flour, which is predicted to contain neutral as well as positive particles that hardly react with the coagulant-floculant of moringa and remain as dissolved particles in the water contributing to a high TDS. The MSP also has the potential to release dissolved materials other than coagulant-floculant, which further increases the TDS level. This was also demonstrated by the TDS of the wastewater treated with a 60-mesh MSP, which significantly increased. Smaller powder particles enhance the dissolution of materials in moringa seeds, contributing to the increase in TDS. Larger powder particles (10 and 7 mesh) may result in insufficient dissolution of the coagulant-floculant, leading to ineffective wastewater treatment and maintaining a high TDS level.

Figure 5 also shows that the dosage influences the TDS of the treated rice flour wastewater. Excessive fine MSP particles are less effective in binding suspended matter in rice flour wastewater. This was observed under the 60-mesh condition (the finest size used in this study), where the reduction in TDS was not significant. However, at a dosage ratio of 1:660, the TDS decreased substantially to 1127 ppm, indicating that the coagulant flocculant dosage also plays an important role in floc formation and sedimentation. This finding is consistent with that of Eichhorn et al., 2002 (Eichhorn, Weckmüller, & Urban, 2022) regarding the effect of water concentration in mixtures containing Moringa seeds. Additionally, the data show that at dosages greater than 1:500, the reduction in TDS was not significant compared to other conditions. These results demonstrate that there is an optimal particle size for reducing TDS, and the finest particle size does not necessarily guarantee the highest removal efficiency in rice flour wastewater treatment. In other words, a specific Moringa seed particle size is most effective for binding dissolved particles in wastewater.

Effect of Moringa Seeds Powder Coagulation flocculation on pH

Figure 6 shows the effect of MSP on the treated wastewater pH. The control pH obtained from the measurements reflects the intrinsic pH of the rice flour wastewater. Naturally, rice flour water tends to have a near-neutral pH (6–7); however, fermentation or the presence of acidic additives can lower the pH (Winita, Geraldi, & Subahar, 2023). The addition of MSP to rice flour wastewater influenced the acidity level, which generally tended to lower the pH. The lowest pH was observed with treatment using 18-mesh MSP at ratios of 1:330 to 1:250. This increased acidity may be attributed to the high content of organic acids and phenolic compounds present in Moringa seeds, which affect the overall pH (Hafidz & Ariastuti, 2025). Increasing the concentration of MSP from a dosage of 1:1000 to 1:250 contributed to a higher total acid content in the system.

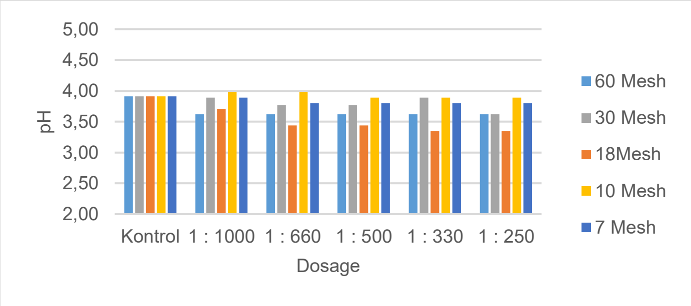

Figure 6. pH values of treated rice flour wastewater using MSP at various particle sizes and dosages

The data is shown in **Figure 6** indicate that the most significant factor affecting pH is particle size (mesh). The size of the MSP is directly related to its specific surface area and the dissolution kinetics of acidic compounds. Finer particles, such as those with 60- and 30-mesh sizes, produced lower pH values because their larger surface areas enabled faster and more efficient extraction and release of ions. In contrast, coarser particles, such as 10 mesh and 7 mesh, showed slightly higher pH values because the dissolution of acidic compounds from the particle core was hindered, thereby limiting the total amount of acid released into the mixture (Mughrbi, 2025).

Taguchi Method Analysis

The Taguchi method is widely used as a robust design approach to optimize process parameters while minimizing the influence of uncontrollable variables (noise), thereby improving process performance and consistency (Guadarrama-p, 2023). The experimental data analyzed using the Taguchi method were divided into two stages. In the first stage, the mean values of the experimental results at each factor level were calculated to identify the levels that produced either the smallest or the largest mean responses. In this study, achieving the smallest response was the primary objective, in accordance with the regulatory standards for rice flour wastewater established by the government (Lingkungan & Republik, 2014).

In the second stage of the Taguchi analysis, the robustness of the system against noise was evaluated by analyzing the results of Total Dissolved Solids (TDS) and Total Suspended Solids (TSS) using the Signal-to-Noise (S/N) ratio based on the "smaller is better" criterion. This criterion was applied in accordance with the wastewater quality standards, where lower values indicate better wastewater quality. The combination of S/N ratio analysis and mean response analysis provides a comprehensive evaluation, in which the S/N ratio ensures robustness against noise, while the mean analysis determines the optimal performance level. This approach enables the selection of process parameters that are not only optimal but also stable under varying experimental conditions (Hisam et al., 2024). The Main Effects Plot for Means is shown in **Figure 7** and **Figure 8** bellow :

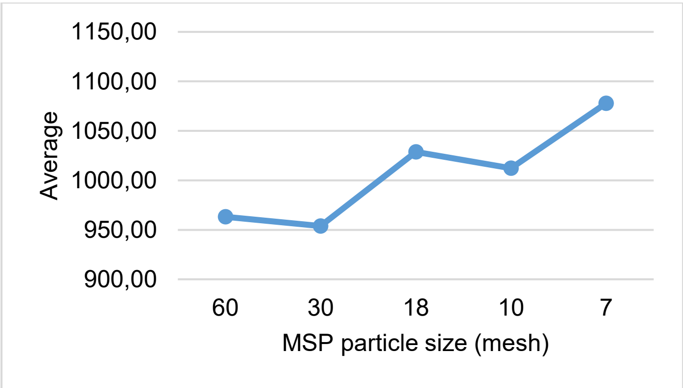

Figure 7. Main Effects Plot for Means MSP Particle Size

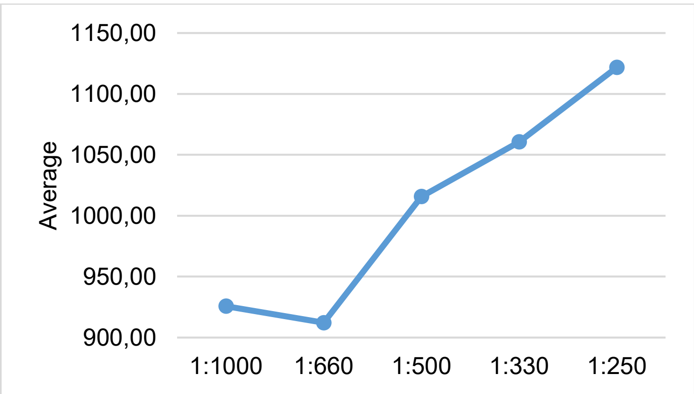

Figure 8. Main Effects Plot for Means MSP dosage

The initial stage of the Taguchi analysis, aimed at determining the mean response values is presented in **Figure 7**. It indicates that Moringa oleifera seeds, processed into natural powder have the ability to reduce TDS and TSS levels in rice flour wastewater. **Figure 7** shows that the lowest mean values of TDS and TSS were obtained at the 30-mesh particle size variation, with a mean value of 953.83 for the MSP particle size. Meanwhile, **Figure 8** presents the Taguchi mean response results for the MSP dosage variation, where the lowest mean value is observed at the dosage of 1:660, with an average value of 912.20.

These findings are consistent with previous studies demonstrating that Moringa oleifera seeds are effective in wastewater treatment for improving water quality (Hung, Han, Bang, & Ky, 2020). Furthermore, the results presented in **Figure 7** and **Figure 8** obtained from variations in MSP particle size and dosage at each level, indicate that each level has a distinct effect on the ability of Moringa oleifera to reduce TDS and TSS levels.

In the subsequent stage, following the determination of mean values, each variation was evaluated in terms of its stability and effectiveness in reducing the measured parameters. The Taguchi analysis using the Signal-to-Noise (S/N) ratio was performed to assess the level of disturbance or noise associated with each variation. The results of the S/N ratio for MSP particle size and dosage are presented in **Figure 9** and **Figure 10,** respectively.

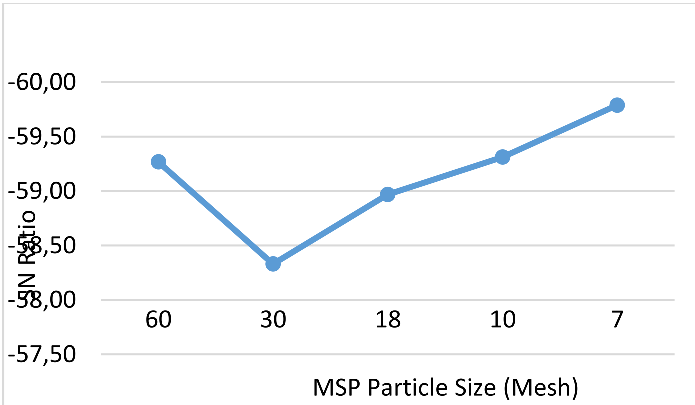

Figure 9. Main Effects Plot for SN ratios for MSP particle size

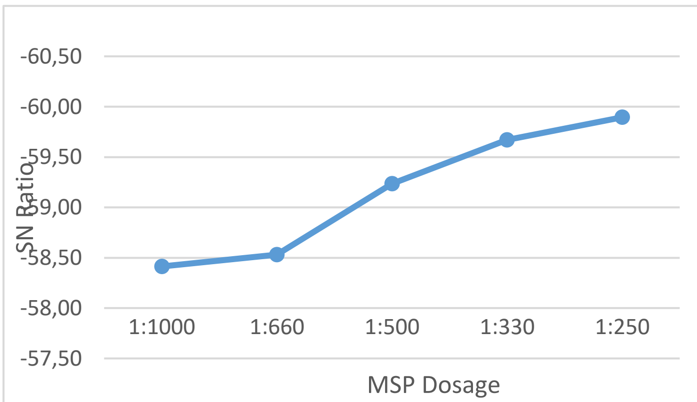

Figure 10. Main Effects Plot for SN ratios for dosage

Figure 9 presents the S/N ratio analysis results for the MSP particle size variation. Based on the Taguchi analysis, the 30-mesh particle size exhibits the lowest level of disturbance (noise), indicating better resistance to external disturbances. The S/N ratio value for the 30-mesh variation is −58.33, which is the highest (i.e., closest to zero) among all variations. Therefore, this variation is considered the most robust to noise. This result is also consistent with the mean response analysis shown in **Figure 7**, where the 30-mesh variation yields the lowest mean value.

Figure 10 presents the S/N ratio analysis results for the MSP dosage variation. Based on the Taguchi analysis, the 1:1000 dosage ratio exhibits the lowest noise level, with an S/N ratio value of −58.41. However, a discrepancy is observed between the optimal condition determined by the S/N ratio and that obtained from the mean response analysis, where the lowest mean value is found at the 1:660 dosage ratio, as shown in **Figure 8.**

This condition indicates that variations with lower noise levels exhibit higher stability in the experimental results. Lower noise reflects reduced variability, resulting in more consistent data that are closer to the target value. Under the smaller-is-better criterion, performance improves as the response approaches zero, indicating reduced sensitivity to noise factors (Rashid, 2023). In the Taguchi method, this condition implies that the parameter is more robust against the influence of uncontrolled factors.

The results of the Taguchi analysis are consistent with several previous studies that applied the same method in different cases. A study conducted by (Shi, Giasin, Barouni, & Zhang, 2024) analyzed hole quality by considering several influencing factors, such as kerf angle, cylindricity, and other parameters, to obtain optimal results by minimizing the response using the S/N ratio under the smaller-is-better criterion. Another study also demonstrated that the Taguchi method can be used to evaluate robustness against noise, as reported by (Gyliene, Brasas, Ciuplys, & Jablonskyte, 2024). which also explains that factors such as cutting velocity, feed rate, and cutting depth were analyzed to determine the optimal process conditions.

Figure 9 The 7-mesh MSP Particle size variation and the 1:250 ratio level exhibit high noise, meaning that at this point, the system is still highly susceptible to disturbances, which is reflected in the obtained S/N ratio. At the ratio level, **Figure 9** indicates that a higher coagulant dosage (smaller ratio) leads to increased disturbance. This condition affects the measurement outcomes of the key parameters TSS and TDS in this study.

CONCLUSION

Based on the research findings, the particle size and dosage of Moringa seeds added to rice flour wastewater influence the TSS, TDS, and pH values. The optimum condition, with the lowest level of variation (noise) according to the Taguchi method using the S/N ratio "smaller is better," was achieved at an MSP particle size of 30 mesh and an MSP dosage of 1:1000.

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