Enhancing Soap Formulation from Waste Oil: An Analysis of Properties and User Satisfaction Using Taguchi Method

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Abstract. This research centers on modifying and optimizing waste oil soap formulation using Taguchi design of experiments (DOE). The aim of the study is to find optimal soap parameters with respect to the input variables such as water, NaOH, waste oil and agarwood dust. The output parameters to be investigated are pH, foaming rate, antimicrobial activity, and hedonic results which measure appearance, odor, textural properties, color, and general acceptability. Based on the hedonic results, Taguchi analysis reveals the rank order of parameters that influences the quality of the soap and it was noted that waste oil is the most important parameter followed by agarwood dust, water and NaOH. The optimal formulation determined consists of coconut oil, 70 ml of water, 2 g of agarwood dust, and 15 g of NaOH. Detailed properties analysis and the regression equation for this formulation are included to provide a comprehensive understanding of the soap's performance. This systematic approach not only enhances the soap's quality but also promotes the utilization of waste oil, contributing to environmental sustainability.

1 Introduction

In ancient cultures, a variety of ingredients like animal tallow, vegetable oils and ash were put in use to prepare cleaning products such as soap. It was stated that the oldest method of soap manufacture dates back to 2800 BC in Babylon, where a mixture of ash and oil was used [1]. Soap also kept changing in its composition and formulation with the advancement of new components and production techniques. Due to advancements in chemistry and the use of new feedstock resources such as palm and coconut oils, new varieties of soap emerged in the 19th century. Waste oil is one of the least residues when manufacturing and hence, if not disposed of carefully, the impact of waste oil's disposal can be considerable. One of them is land degradation. Soap also kept changing in its composition and formulation with the advancement of new components and production techniques. Due to advancements in chemistry and the use of new feedstock resources such as palm and coconut oils, new varieties of soap emerged in the 19th century. Waste oil is one of the least residues when

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manufacturing and hence, if not disposed of carefully, the impact of waste oil's disposal can be considerable. One of them is land degradation. The remaining oil that seeped into the ground can also harm the soil by degrading its quality and making it less suitable for planting. [2]. Next, waste oil that gets into rivers, lakes, or oceans can contaminate the water [3]. Oil builds up as a coating on the water's surface, obstructing sunlight and lowering oxygen exchange, both of which are bad for aquatic life. Lastly, air pollution. When waste oil is burned improperly, dangerous particles are released into the atmosphere, which adds to air pollution. Burning waste oil has been shown to release harmful chemicals that have been linked to respiratory issues, smog production, and climate change [4].

Today, soap is used for many different things, including cleaning the house, maintaining personal cleanliness, and even industrial uses. In order to attain desired features like lather, scent, and moisturizing benefits, different components and additions are employed in soap depending on the intended application. According to studies, using soap to wash your hands properly might greatly slow the spread of contagious diseases [5]. In this article, we created soap from waste cooking oil that can help support environmental sustainability, increase economic effectiveness, and produce social advantages in the community.

From time to time, soap manufacturers always search for sustainable soap formulas that balance effectiveness and pleasant aromas. Therefore in this paper, we used agarwood essential oil as the soap aromatic. Aromatics made from wood infected with resin and belonging to the genera Aquilaria and Gyrinops have a distinctive and priceless scent. In the trunk of the agarwood tree, resin is produced in reaction to internal injury and/or infection. Many cultures have long prized and employed agarwood-based incense and perfumes for its spiritual, opulent, and aphrodisiac properties. The first factor is the physical characteristics of the traded agarwood itself, which can be found in a variety of items ranging from raw chips, blocks, and flakes to finished oils, incense, perfume, accessories, and carvings [6]. The aim of this study is to utilize the Taguchi method to analyze the optimization of agarwood soap formulation. By systematically identifying and minimizing the impact of variations on the outcome, the study aims to improve the quality and performance of products and processes.

2 Soap Development and Analysis

Over the last few years, people have focused on the search for such products as eco-friendly and energy-saving products and services, which forced them to create innovations in many sectors, including the production of soaps. One of the approaches is to create soap with the help of waste oil, at the same time it is effective both in its way of reducing the amount of waste and in terms of getting a free raw material. This paper focus on the optimization of soap formulation parameters by using Taguchi design of experiment (DOE). The parters studied are waste oil, agarwood dust, water and sodium hydroxide (NaOH). The waste oils used in the development of the soaps were palm oil and coconut oil.

2.1 Taguchi DOE

To analyze the phenomena systematically, Taguchi DOE method that is famous for its effectiveness and stability in maximizing product quality and performance is used. Through an experimental design: mixed level design: (level ^ column: 2 ^ 1 and 3 ^ 3), 18 distinct formulations have been created. The distinct formulations aim to determine the optimal combination of components that yield the best soap characteristics. In the final stage, each formulation is enhanced with the addition of agarwood essential oil, known for its aromatic and beneficial properties. Table 1 shows the 18 formulations of Taguchi DOE.

Table 1. Taguchi DOE formulations

Sample	Agarwood Dust (g)	Waste Oil (mL)	Water (mL)	NaOH (g)
1	No	Palm	70	15
2	No	Palm	80	17
3	No	Palm	90	19
4	No	Coconut	70	15
5	No	Coconut	80	17
6	No	Coconut	90	19
7	No	Palm and Coconut	70	17
8	No	Palm and Coconut	80	19
9	No	Palm and Coconut	90	15
10	2	Palm	70	19
11	2	Palm	80	15
12	2	Palm	90	17
13	2	Coconut	70	17
14	2	Coconut	80	19
15	2	Coconut	90	15
16	2	Palm and Coconut	70	19
17	2	Palm and Coconut	80	15
18	2	Palm and Coconut	90	17

2.2 Soap preparation

In this experiment, 60 ml of waste cooking palm oil was measured. 19 g NaOH was weight and 70 ml of water was mixed using a hot plate. The temperature was measured and cooled down to 60 Celsius. NaOH was added to the oil and mixed with constant stirring. Next, 2 grams of agarwood dust was added, and the 2 ml of essential oil was put together. The soap solution was poured into the silicone mold. Left to dry for 24 to 48 hours. This is the step for the formulation no.10 in Table 1.

This step was repeated with waste palm oil, coconut oil with 15 grams and 17 grams NaOH, 80 ml and 90 ml water, with dust and no dust of agarwood according to the formulation in Table 1. If the waste oils were mixed (sample no.7, no.8, no.9, no.16, no17 and no. 18), we used 30 ml waste palm oil and 30 ml waste coconut oil. All the formulations were added 2 ml of agarwood essential oil.

2.3 Soap analysis

2.3.1 pH test

A 2 mg soap sample was combined with 10 ml of distilled water, but little lather resulted. For optimum soap dissolution, it was left undisturbed for 24 hours. The pH of each sample was then determined. The pH of the vast majority of soaps is between 9 and 10 [7]. This pH test was tested on the soap samples after 3 weeks.

2.3.2 Hedonic test

In an innovative approach to sustainable practices, we have developed a soap using waste oil, transforming a potential environmental pollutant into a valuable, eco-friendly product. To evaluate its acceptance, we conducted a Hedonic test, where participants assessed the soap based on specific sensory attributes such as color, aroma, texture, and appearance based on the [8] suggestion. The hedonic test is a procedure used to establish the extent of a person's liking of a given item or product mainly through tactile sensation. The different tests are done to measure the amount of product liking using an evaluation sheet that features a scale 1/9 where one is the lowest value and nine is the highest value [9]. Data was collected from 30 respondents/users and the hedonic scale criteria used in this research are:

1 = Dislike extremely
2 = Dislike very much
3 = Dislike moderately
4 = Dislike slightly
5 = Neither like nor dislike
6 = Like slightly
7 = Like moderately
8 = Like very much
9 = Like extremely

3 Results Analysis and Discussion

3.1 pH test analysis

An essential characteristic of soap is its pH, which determines the soap's performance and behavior when in contact with the human skin. This paper focuses on how the pH of soap influences its capacity to clean and its stability, as well as the possibility of skin ripping, leading to skin irritation. To confirm the acceptability and safety of soaps prepared from waste oil the pH was measured after 3 weeks. The intention of this analysis was consequently to check on the stability of the pH over the period and to confirm the acceptable pH range of the soaps so that they can be safely used. The results of the pH test, which is given above, are very informative and can be used to predict how this particular formulation will affect the skin's health and also help in the subsequent stages of improvement.

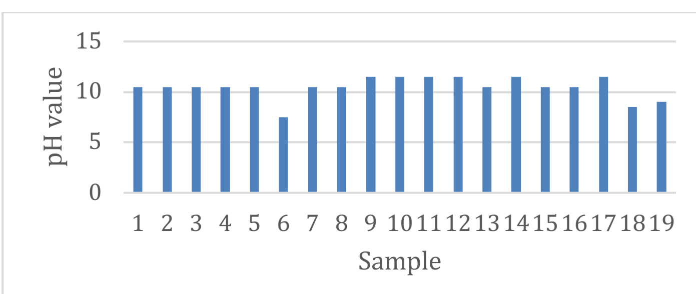

Fig. 1. pH value analysis chart for the soap formulations

According to Fig. 1, pH of the developed soap samples varies between 7. 5 to 11. 5, while the commercial control soap has pH of 9. Alkaline samples show most samples with a pH of 10. 5 or 11. at pH 5, the live bacteria-saturated clay was found to be significantly more alkaline than the control. Sample 6 is a sample that has a pH which ranges between 7. 5 while Sample 18 had a pH of 8. 5 are less acidic with values near to neutral level and could even be described as more friendly to the skin. At pH 9, the control soap falls within the typical range for commercial soaps and aligns better with the skin's natural pH. In contrast, the higher pH of many developed samples may lead to increased skin irritation and dryness [7]. These observations suggest a need for formulation adjustments to lower the pH of the more alkaline samples, enhancing their suitability for regular use and aligning them with consumer expectations for mild, skin-compatible products.

Samples 6 and 18 show promising results with lower pH values less likely to irritate the skin. These samples could serve as a basis for further refinement. Ensuring the soap is not overly alkaline will improve its marketability and user acceptance, aligning with the standards of commercial soaps.

3.2 Hedonic test analysis

This controlled study aims to provide insights into which attributes consumers prioritize and how different soap formulations compare in rassemblement these preferences. By systematically evaluating each sample against a commercial control, this test seeks to identify strengths and areas for improvement in the developed soap formulations, guiding future development efforts toward enhancing overall consumer acceptance and satisfaction. Figure 2 shows the Hedonic test score for 19 samples which is no.19 is the control (commercial soap).

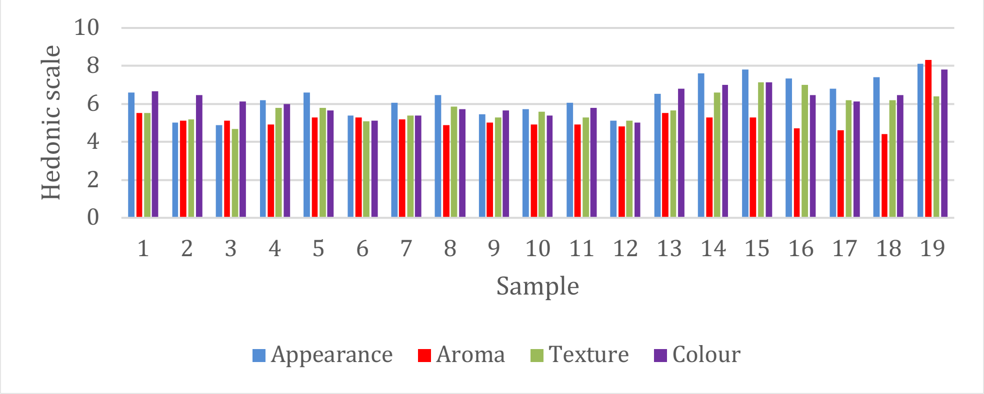

Fig. 2. Hedonic scale score for the soap samples

Fig. 2 shows that hedonic test data reveals significant variations in consumer preference across the 19 soap samples evaluated for appearance, aroma, texture, and color. Sample 19, the commercial control, consistently outperformed the developed soaps, receiving the highest scores in appearance (8.1), aroma (8.3), texture (6.4), and color (7.8). Developed samples like Sample 14 and Sample 15 showed moderate to high scores in specific attributes, such as appearance (7.6, 7.8) and color (7, 7.13), suggesting potential areas for improvement. Overall, [10] stated that enhancing the visual appeal, fragrance, texture, and color of the developed soaps could align them more closely with consumer expectations and preferences, and, currently dominated by the commercial soap's attributes.

3.3 Taguchi method analysis

In this paper, we study the results of the Taguchi method based on the signal-noise ratios. The formula selected for this analysis is larger-the-better which is formulated by:

$$\frac{S}{N} ratio = -10 \left(\frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2} \right)$$

where y_i is the measured value of the response and n is the number of observations. Table 2 shows the response table for signal-to-noise ratios (SNR) for hedonic properties (appearance, color, aroma, texture).

Table 2. Response table for Signal-to-Noise Ratios (SNR) for hedonic properties

Level	Dust	Waste Oil	Aqua	NaOH
1	13.01	12.74	13.48	13.49
2	13.59	13.83	13.45	13.15
3		13.33	12.98	13.26
Delta	0.59	1.09	0.50	0.33
Rank	2	1	3	4

Interpretation of SNR values was determined based on Table 2. SNR values provide insights into the signal (desired effect) to noise (undesired variation) ratio for each factor at different levels. The higher SNR values indicate a more favorable signal-to-noise ratio. The factor rankings are shown in Table 2.

The provided SNR ratio table shows the impact of four factors (dust, waste oil, aqua, and NaOH) at different levels on the process quality. The SNR for each factor at Levels 1 and 2 indicate the effect on the response variable, with waste oil having the highest impact (delta = 1.09) and ranked first in significance. Dust follows as the second most impactful factor (delta = 0.59), with aqua (delta = 0.50) and NaOH (delta = 0.33) having relatively smaller effects. These Deltas reflect the variation in SNR across the different levels of each factor, highlighting the factors' influence on the process.

In practice, optimization efforts should prioritize waste oil, as it has the most substantial effect on improving process quality. Adjusting the levels of dust can also significantly enhance the process, given its second-highest impact. While aqua and NaOH have smaller impacts, fine-tuning their levels can further optimize the process once the more influential factors are addressed. This structured approach ensures that the most critical factors are targeted first, leading to more efficient and effective process improvements. Figure 3 shows the SNR main effects plot for Hedonic properties.

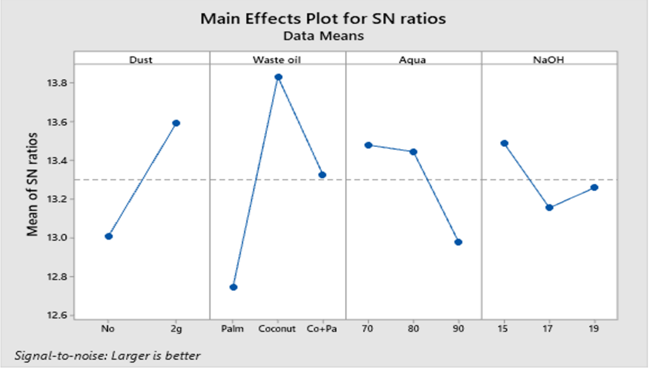

Fig. 3. SNR main effects plot for hedonic properties

The SNR main effects plot for hedonic properties in Fig. 3 illustrates the influence of four factors (dust, waste oil, aqua, and NaOH) at different levels on the process. For dust, the SNR significantly increases from "No" dust to "2g" dust, indicating that adding dust improves the response variable. Waste oil shows the highest SNR with coconut oil, followed by coconut+palm and palm oil, suggesting that coconut oil yields the best response. Aqua has its highest SNR at the 70 g level, with lower values at 80 and 90, making 70 g the optimal level. For NaOH, the SNR is highest at level 15 ml with lower values at 19 and 17 hence showing that level 15 is the most suitable.

From these results, it is evident that the process yields the best performing process when 2g dust, coconut waste oil, 70g aqua and 15ml NaOH are used. The figure is helpful to visualize the plot in order to determine the optimal value of settings regarding each factor. If process performance is directed towards these levels, it will inevitably lead to improvements in both quality and efficiency.

4 Conclusion

The Taguchi DOE enabled the analysis of input parameters, which pointed out the waste oil as the major determinant of soap properties, with a partial influence from agarwood dust, water and sodium hydroxide. The results of the signal-to-noise ratio (SNR) were very insightful in identifying the effects of each of the factors, which were waste oil, agarwood dust, water, and sodium hydroxide. This analysis guided the identification of an optimal soap formulation: 70 ml of coconut oil, 70 ml of water, 2 grams of agarwood dust and 15 grams of sodium hydroxide.

SNR plots further explained the effects of each factor on soap characteristics while showing the significance of waste oil in improving process characteristics. Through the identification of optimal waste oil and other proportions as revealed in the SNR results, not only was the soap performance enhanced but the viability of Taguchi DOE in product development was equally demonstrated. Further verification of the formulation effectiveness and consumers' preferences were given through the analytical outcomes of the pH tests and hedonic evaluations.

This study, therefore, affirms the possibility of using waste oil in the production of soap and presents practical and effective ways of solving some environmental issues. Future studies could extend to other fields of applying Taguchi methods to optimize a product and analyze the market to improve other strategies for making sustainable soap.

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