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Effect of Lime (*Citrus aurantifolia*) Concentration and Stirring Time on the Quality of Palm Oil-Based Margarine

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Abstract. This study aims to analyze the effects of lime (*Citrus aurantifolia*) concentration and stirring time on the quality of palm oil-based margarine. The treatments included lime concentrations of 1%, 2%, and 3%, with stirring times of 5 minutes and 10 minutes. The observed parameters included moisture content, fat content, free fatty acid levels, emulsion stability, spread ability, color, texture, aroma, and taste. Analysis of variance (ANOVA) results indicated that lime concentration and stirring time significantly influenced most margarine quality parameters. Increasing lime concentration and stirring time resulted in a rise in moisture content, ranging from 1.7249% to 3.1094%, and an increase in free fatty acid levels from 0.2543% to 0.4195%. Conversely, fat content decreased, ranging from 88.4387% to 81.3954%. Emulsion stability was within 99.6927%–99.8795%, while spread ability varied from 2.6335 g/mm² to 3.6473 g/mm². In terms of organoleptic properties, margarine color showed significant differences, with the highest value of 3.0000 (yellow) observed in the 3% lime concentration with a 5-minute stirring time, and the lowest value of 1.9524 (very yellow) found in the 2% lime concentration with a 10-minute stirring time. Margarine texture varied from firm to slightly firm, with the highest score of 2.6667 recorded for the 1% lime concentration with both 5- and 10-minute stirring times. Aroma intensity increased with higher lime concentrations, with the strongest aroma recorded at 2.9524 in the 3% lime treatment with a 5-minute stirring time. Meanwhile, taste remained mostly neutral, with the highest score of 3.3333 observed in the 2% lime concentration with a 10-minute stirring time. This study highlights that the appropriate combination of lime concentration and stirring time can produce margarine with improved quality characteristics.

Keywords: Lime Concentration, Margarine, Palm Oil, Quality, Stirring Time

1 Introduction

Margarine is a water-in-oil (W/O) emulsion-based food product with a plastic texture. It is widely utilized in bakery products such as cakes, bread, biscuits, and others. Additionally, margarine is often used as a substitute for cooking oil in sautéing or frying foods that require minimal oil. Margarine typically consists of approximately 80% fat and 15–16% water, along with other added ingredients such as flavoring agents, emulsifiers, colorants, vitamins, and more [1]. The production of margarine is considered essential, as oils and fats play a crucial role in determining product quality. The type of oil used significantly influences the crystallization characteristics during margarine production [2]. Palm oil is one of the raw materials that can be utilized in margarine production. Its high melting point contributes to improved textural stability, making margarine more durable during use. In the manufacturing process, margarine is typically produced using either cooking oil or palm oil. The presence of palm oil enhances margarine's structural integrity, ensuring better consistency and stability [3].

Several common additives are used in margarine production, including egg yolk, lime (*Citrus aurantifolia*) extract, salt, and water. Egg yolk serves multiple functions, such as providing fat, acting as a natural emulsifier, and enhancing color. The fat content in egg yolk improves the texture and consistency of margarine, while lecithin functions as a natural emulsifier that facilitates the mixing of the water and oil phases. Additionally, egg yolk contributes to the desired yellow color of the final product [4][5]. Furthermore, lime extract enhances margarine by imparting a fresh taste and citrus aroma. The citric acid in lime acts as a pH regulator, maintaining the acid-base balance needed to achieve the desired product quality. Additionally, components such as citric acid and essential oils in lime possess antimicrobial properties, which help extend margarine's shelf life by inhibiting the growth of spoilage microorganisms [6]. Salt plays a crucial role in enhancing the taste of margarine, improving its flavor profile and overall palatability, while also helps improve taste and control microbial growth by regulating

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water activity, which affects texture, aroma, and organoleptic characteristics. Additionally, salt helps maintain margarine's stability and consistency by controlling water activity and inhibiting the growth of undesirable microorganisms. Water also plays a vital role in margarine production, particularly during emulsification, where it is mixed with vegetable oil to create a stable emulsion between oil and fat. This emulsion undergoes hydrogenation to transform vegetable oil into solid fat. Moreover, water assists in temperature regulation throughout the production process, ensuring the final product maintains its desired quality and consistency [7].

The study conducted by Hasibuan and Hardika [8] aimed to formulate and produce margarine using palm oil fractions, specifically RBDPO and red palm oil (RPO), and evaluate its application in roll cake production. This research consisted of three main stages: margarine formulation with various RBDPO and RPO ratios, production optimization using a texturing reactor, and stability and organoleptic evaluations in roll cakes. The results indicated that margarine with an optimal formulation and processing conditions at 95±5°C for 30 minutes achieved the best texture and stability. The application of this margarine in roll cakes enhanced texture and taste quality compared to commercial margarine, making it a promising alternative for small-scale production.

The study conducted by Hasibuan et al. [9] aimed to develop red palm oil (RPO)-based margarine and baking shortening while evaluating their application in bakery products. The RPO used was derived from neutralized crude palm oil (CPO) and fresh fruit bunches. The margarine formulation included two types: *grade* A (100% RPO) and *grade* B (a blend of RBDPO and RPO), while the baking shortening was formulated using RBDPS, RBDPKO, and RPO. The tested bakery products included sweet bread, donuts, and roll cakes. The findings indicated that the developed margarine and baking shortening had high carotene content and met the standards for peroxide value and free fatty acid (FFA) levels. The resulting bakery products exhibited color, aroma, and texture comparable to commercial products, with the MSM and RBDPO (50:50) blend yielding the best results. Thus, MSM and RBDPO can serve as alternative ingredients for enhancing the nutritional value of bakery products.

Previous research by Ramadhana and Kusnadi [10] focused on developing margarine using tuna oil (*Thunnus sp*) and palm stearin. The study employed a randomized block design with two key variables: the ratio of tuna oil to palm stearin (60%:40%, 50%:50%, and 40%:60%) and the concentration of BHA antioxidants (150 ppm, 175 ppm, and 200 ppm). The findings revealed that the optimal formulation consisted of a 40% tuna oil and 60% palm stearin blend, with 200 ppm of BHA antioxidants. This margarine exhibited the best characteristics based on peroxide, anisidine, totox, acid, and iodine values, along with high emulsion stability, an optimal melting point, and excellent spreadability. These results suggest that tuna oil can serve as a viable alternative ingredient in margarine production while providing additional nutritional benefits.

Despite extensive research on palm oil-based margarine formulation, studies investigating the effect of lime (*Citrus aurantifolia*) concentration and stirring time on margarine quality remain limited. Previous research has primarily focused on optimizing fat compositions, emulsifiers, and processing conditions to enhance margarine texture, stability, and nutritional properties. However, the interaction between lime concentration and stirring time in margarine production has yet to be systematically studied. Therefore, this research aims to fill the gap by examining how these factors impact the quality of palm oil-based margarine.

This research supports sustainable agriculture through the utilization of natural and locally available ingredients, such as lime (*Citrus aurantifolia*), in the development of palm oil-based margarine. Lime, as an additive, represents a form of biodiversity utilization that contributes to the diversification of ingredients in agroindustry. Its incorporation also offers opportunities for the valorization of citrus, thereby reducing agro-waste. Furthermore, this approach aligns with the principles of sustainable processing by minimizing reliance on synthetic additives and promoting the use of renewable, plant-based resources.

2 Method

2.1 Equipment and Materials

The equipment used for margarine processing includes a basin, spoon, mixer, knife, freezer, scale, tissue, napkin, gauze, thermometer, measuring glass, and stopwatch. Furthermore, the equipment utilized for analysis consist of an analytical balance, beaker glass, dropper pipette, graduated pipette, desiccator, hot plate, texture analyzer, porcelain dish, centrifuge, oven, Erlenmeyer flask, spatula, burette, Soxhlet flask, Soxhlet extraction apparatus, glassware, filter paper, and test tubes. The materials used for margarine production include 10 ml of SGTOPP brand palm oil, lime juice at concentrations of 1%, 2%, and 3%, 0.5 grams of salt, 20 grams of egg yolk, and 10 ml of water. Whereas, the materials used for analysis include n-hexane, 0.1 N NaOH, phenolphthalein indicator, distilled water (aquadest), 0.01 N $Na_2S_2O_3$, and 96% alcohol.

2.2 Lime Extract Production

Lime extract is produced through a juicing method with the following steps. First, the necessary tools and materials are prepared. Then, 500 grams of lime are weighed, thoroughly washed, and air-dried. The limes are

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then cut in half and squeezed using sterile gauze to extract the juice. The extracted liquid is filtered to separate the pulp, resulting in pure lime extract. From this process, lime extract is obtained, with specific samples of 1 ml, 2 ml, and 3 ml taken for further analysis.

2.3 Margarine Production

The margarine production process involves several key steps. First, the necessary ingredients are prepared, including 100 ml of palm oil, lime (*Citrus aurantifolia*) at concentrations of 1%, 2%, and 3%, 10 ml of water, 0.5 grams of salt, and 20 grams of egg yolk. It is essential to ensure that all equipment and ingredients are clean and sterile. In the mixing stage, palm oil and lime juice are blended first to form an emulsion. Then, egg yolk and salt are added, and the mixture is beaten at high speed for 5 or 10 minutes, depending on the stirring time. Once the emulsion is fully formed, the margarine is placed in the freezer for stabilization. Finally, it is stored in an airtight container to maintain its quality and stability. The margarine production process is presented in Figure 1.

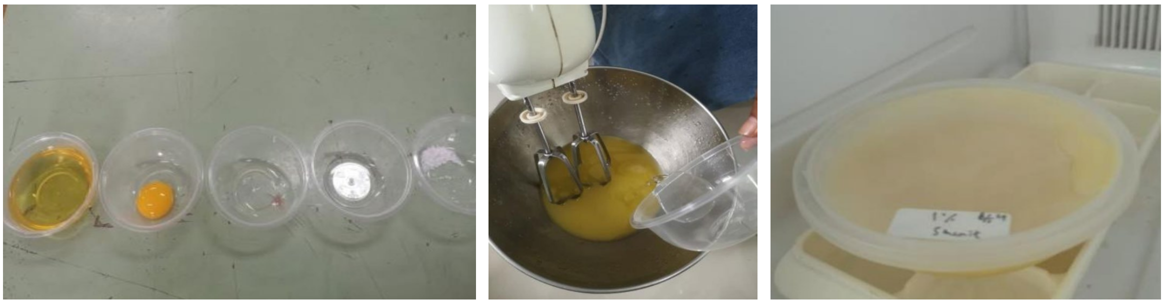

Figure 1. Production Process of Margarine

2.4 Research Analysis

2.4.1 Moisture Content

To determine the moisture content of margarine, all necessary equipment and materials must be prepared. First, preheat the oven to 93°C. Place an empty weighing bottle inside and dry it for 30 minutes. After drying, transfer the bottle to a desiccator for 15 minutes and record its weight. Next, weigh 5 grams of margarine in a porcelain dish and record the initial weight. Place the sample in the oven for 2 hours, then transfer it to the desiccator for 15 minutes before weighing it again. This drying process should be repeated until a constant weight is achieved. The moisture content is calculated using the following formula: [11]

$$Moisture\ Content\ (\%) = \frac{W_1 - W_2}{W}\ x\ 100\% \quad (1)$$

where W_1 represents the weight of the container and sample before drying, W_2 is the weight after drying, and W is the weight of the sample.

2.4.2 Free Fatty Acid

To conduct free fatty acid (FFA) analysis, first, prepare all necessary equipment and materials. Weigh 25 grams of the sample into a 250 ml Erlenmeyer flask, then add 50 ml of 96% alcohol and heat the mixture until it reaches a boiling point. Next, add three drops of 1% phenolphthalein (PP) indicator. Titrate the solution using 0.1 N NaOH until a light pink color appears and remains stable. Record the titration volume and calculate the free fatty acid content using the following formula: [12]

$$Free\ Fatty\ Acid\ (\%) = \frac{mL\ NaOH\ x\ Molecular\ Weight\ of\ Fatty\ Acid}{Sample\ Weight}\ x\ 100\% \quad (2)$$

2.4.3 Fat Content Analysis

Prepare the necessary equipment and materials for fat content analysis, including the margarine sample to be tested. First, dry the fat flask in an oven at 105°C for 30 minutes, then cool it in a desiccator for 15 minutes and weigh it (A). Weigh 5 grams of the sample (S) and wrap it in filter paper. Add an adequate amount of petroleum ether solvent into the fat flask, then place the wrapped sample into the Soxhlet extraction apparatus. Heat the fat flask and perform the extraction for 3–4 hours. After the extraction process is complete, distil the solvent back, remove the fat flask, and dry it in an oven at 105°C until no further weight reduction occurs (constant weight).

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Cool the flask in a desiccator for 20–30 minutes and weigh it again (B) until a stable weight is achieved. Finally, calculate the fat content using the following formula:

$$Fat\ Content\ (\%) = \frac{B-A}{S}\ x\ 100\% \quad (3)$$

2.4.4 Emulsion Stability

The necessary equipment and materials were prepared. A 10 ml sample of margarine, previously heated in a water bath at 80°C for 30 minutes, was collected. The sample was then centrifuged in a 10 ml graduated tube at a speed of 2700 rpm for 10 minutes. After centrifugation, the volume of the remaining emulsion was measured, and emulsion stability was calculated using the following formula:

$$Emulsion\ Stability\ (\%) = (100 - \frac{B}{A})\ x\ 100\% \quad (4)$$

where A is the total volume of emulsion and B is the volume of separated phase.

2.4.5 Spreadability Test

The product spreadability was tested by using a Texture Analyzer. The measurement results of the probe penetration depth into the margarine sample for 10 seconds directly correlate with the ease of spreading the margarine—the deeper the probe penetrates the sample, the easier the margarine is to spread.

2.4.6 Organoleptic Test

The Organoleptic test was conducted with 21 panelists to evaluate the physical characteristics of the margarine produced. This test assessed the color, aroma, texture and taste of the margarine using a five-point Likert scale [13]. The Likert scale for each category is presented in Table 1.

Table 1. The Likert Scale for Each Category

Scale	Color	Aroma	Texture	Taste
1	Very Yellow	Very Weak	Very Solid	Strongly Dislike
2	Yellow	Weak	Solid	Dislike
3	Slightly Yellow	Slightly Strong	Slightly Solid	Neutral
4	Pale Yellow	Strong	Liquid	Like
5	Very Pale Yellow	Very Strong	Very Liquid	Strongly Like

2.2 Data Analysis

The data analysis in this study was conducted using Analysis of Variance (ANOVA). If a significant effect was detected, further analysis was performed using a Least Significant Difference (LSD) test at a 5% significance level. This research employed a factorial Completely Randomized Design (CRD), with two treatment factors: lime concentration (J) and stirring time (W) in the production of margarine from palm oil. The lime concentration factor consisted of three levels: 1%, 2%, and 3%, while the stirring time factor had two levels: 5 minutes and 10 minutes. Each treatment combination was replicated three times, resulting in a total of 18 experimental units. The variations in treatment conditions are presented in Table 2. In the column of sample code, J refers to lime juice concentration, with numbers 1, 2, or 3 representing 1%, 2%, or 3%. Further, W represents stirring time, where W_5 indicates 5 minutes and W_{10} indicates 10 minutes. This coding system ensures a clear and structured identification of each experimental condition.

Table 2. Variation of Experimental Treatments

Sample Code	Palm Oil (ml)	Egg Yolk (g)	Water (ml)	Salt (g)	Lime Juice	Stirring Time
J_1W_5	100	20	10	0.5	1%	5 minutes
J_1W_{10}	100	20	10	0.5	1%	10 minutes
J_2W_5	100	20	10	0.5	2%	5 minutes
J_2W_{10}	100	20	10	0.5	2%	10 minutes
J_3W_5	100	20	10	0.5	3%	5 minutes
J_3W_{10}	100	20	10	0.5	3%	10 minutes

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3 Results and Discussion

3.1 Moisture Content, Free Fatty Acid, and Fat Content Analysis

The moisture content, free fatty acid, and fat content varied among treatment combinations, as presented in Table 3. The determination of moisture content is one of the quality testing standards for margarine. Margarine itself is a mixture consisting of 80% fat, 15–16% water, and other ingredients [14][15]. Based on the ANOVA variance analysis, the moisture content in this study showed a significant effect at the 5% level. The lime concentration treatment had an F-value greater than the F-table value (164.976 > 3.8852), indicating a significant difference. Similarly, the stirring time treatment also had an F-value higher than the F-table value (150.451 > 4.7472), confirming a significant effect with no interaction between the two factors. According to Tables 5 and 6, both the lime concentration and stirring time significantly influenced the moisture content of margarine. The analysis results showed that the moisture content increased with each treatment. The highest average moisture content was observed in the treatment with 3% lime concentration and 10 minutes of stirring, reaching 3.1094%. In contrast, the lowest average moisture content was recorded at 1% lime concentration with 5 minutes of stirring, at 1.7249%. These findings indicate that the applied treatments affected the margarine's moisture content, with values ranging between 1.7249% and 3.1094%.

Table 3. Moisture Content, Free Fatty Acid, and Fat Content of Margarine Based on Experimental Treatments

Experimental Treatments	Moisture Content (%)	Free Fatty Acid (%)	Fat Content (%)
J_1W_5	1.7249±0.0846	0.2543±0.0139	87.0781±1.7263
J_1W_{10}	2.1355±0.1526	0.3487±0.0510	88.4387±1.9826
J_2W_5	1.8955±0.0468	0.2898±0.0176	85.1932±0.3633
J_2W_{10}	2.3752±0.0813	0.3870±0.0162	86.9109±2.3327
J_3W_5	2.4932±0.0341	0.3391±0.0267	81.3954±0.6187
J_3W_{10}	3.1094±0.0696	0.4195±0.0136	84.2363±0.6344

An increase in the concentration of lime added and the longer the stirring time leads to the increase of moisture content of the margarine. This research is supported by the findings of Rifkowaty et al. [16], which showed an increase in margarine moisture content with the addition of lime. The addition of lime affects the stability of the emulsion between water and oil. Citric acid enhances the ability of water to disperse and become trapped in oil, leading to an increase in moisture content in margarine. Meanwhile, longer stirring time during margarine production can further increase moisture content, as intensive stirring over an extended period stabilizes the water-oil emulsion. Excessive stirring promotes emulsification, causing more water to be trapped and increasing the margarine's moisture content. However, higher moisture content in margarine leads to a decline in product quality. Excess moisture can accelerate triglyceride hydrolysis, forming free fatty acids that cause rancidity. This rancidity reduces the shelf life of margarine [17]. According to the Indonesian National Standard (SNI) of 2014 [18], the moisture content in margarine should not exceed 18% to be classified as safe for consumption.

Free fatty acids are one of the key indicators used to determine the quality of margarine. The free fatty acid value represents the amount of free fatty acids in margarine that has degraded due to oxidation and hydrolysis [19]. Therefore, the free fatty acid content can serve as a reference for assessing the quality or deterioration of oil. Based on the analysis of variance (ANOVA), the free fatty acid levels in this study showed a significant effect at the 5% level. The treatment using lime juice concentration had an F-value greater than the F-table (12.7650 > 3.8852), indicating a highly significant difference. Similarly, the stirring time treatment also showed a highly significant difference with an F-value greater than the F-table (51.9124 > 4.7472), with no interaction observed between the two factors. The data indicate that free fatty acid levels in margarine increased with each treatment. The lowest average free fatty acid content was observed at a 1% lime juice concentration and 5 minutes of stirring, reaching 0.2543%. In contrast, the highest average free fatty acid content was recorded at a 3% lime juice concentration and 10 minutes of stirring, at 0.4195%. The findings suggest that higher lime juice concentrations and longer stirring time result in higher free fatty acid percentages, while lower lime juice concentrations and shorter stirring time lead to lower free fatty acid levels. The applied treatments influenced the margarine's characteristics, with free fatty acid values ranging from 0.2543% to 0.4195%.

Free fatty acid levels increase with each treatment involving variations in lime juice concentration and stirring time. These factors influence the formation of free fatty acids. During hydrolysis, within a time range of 5 to 10 minutes, there is a rapid increase in free fatty acid levels. The longer the stirring process continues, the more free fatty acids are produced. Hydrolysis is a degradation process of chemical compounds caused by interaction with water. Since water is insoluble in the oil phase, this process results in the formation of free fatty acids and glycerol. More optimal stirring accelerates the production of free fatty acids. This research aligns with the findings of

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Andarwulan [2], which reported a free fatty acid content of 0.18%. This is related to the presence of unsaturated fatty acids in palm oil. According to the Indonesian National Standard (SNI) [18], the maximum permissible free fatty acid content is 4%. The formation of free fatty acids occurs due to the hydrolysis of triglycerides, which causes the breakdown of bonds and the release of free fatty acids. An increased hydrolysis rate in oil leads to the greater free fatty acid content produced [19]. This statement is supported by Nurhasnawati [20], who stated that the hydrolysis reaction is accelerated by factors such as heat, water presence, acidity levels, and catalysts (enzymes). The longer the hydrolysis process occurs, the greater the formation of free fatty acids.

Based on the analysis of variance (ANOVA), the fat content in this study showed a significance level of 5%. The treatment with varying lime juice concentrations had an F-value greater than the F-table (17.0977 > 3.8852), indicating a highly significant difference. Meanwhile, the stirring time treatment also showed a significant difference, with an F-value greater than the F-table (7.9211 > 4.7472). However, the interaction between lime juice concentration and stirring time had an F-value lower than the F-table (0.4047 < 3.8852), indicating no significant effect on the fat content in margarine. The treatments applied to margarine influenced each variable individually. The data obtained indicate that fat content in margarine decreased across all treatments. The highest average fat content was observed with a 3% lime juice concentration and 5 minutes of stirring, reaching 81.3954%. Meanwhile, the lowest fat content was recorded with a 1% lime juice concentration and 10 minutes of stirring, at 88.4387%. These findings suggest that higher lime juice concentrations and longer stirring times result in lower fat content, whereas lower lime juice concentrations and shorter stirring times lead to higher fat content. Overall, the fat content across the treatments ranged from 81.3954% to 88.4387%.

Lime juice concentration and stirring time influence fat content, as lime juice contains citric acid, an organic acid that plays a role in reducing fat levels. Citric acid also aids in the fat hydrolysis process, contributing to the reduction of fat content in margarine. Additionally, stirring time affects the effectiveness of fat reduction, as the longer lime juice interacts with fat, the greater the decrease in fat content. The findings of this fat content study are supported by Ulfa [21]. According to the Indonesian National Standard (SNI) [18], the maximum permissible fat content is 80%.

3.2 Emulsion Stability and Spreadability Test Results

The emulsion stability and spreadability performance varied among treatment combinations, as presented in Table 4. Based on the analysis of variance (ANOVA), the emulsion stability in this study showed a significance level of 5%. The treatment with varying lime juice concentrations had an F-value lower than the F-table (0.8558 < 3.8852), indicating no significant difference. However, the stirring time treatment showed a significant difference, with an F-value greater than the F-table (4.9609 > 4.7472). Meanwhile, the interaction between lime juice concentration and stirring time had an F-value greater than the F-table (3.9019 > 3.8852), indicating a significant effect on margarine emulsion stability. Based on the obtained data, the emulsion stability in margarine fluctuated across treatments. The highest average emulsion stability was observed with a 2% lime juice concentration and 5 minutes of stirring, reaching 99.8762%. Meanwhile, the lowest average emulsion stability was recorded with a 2% lime juice concentration and 10 minutes of stirring, at 99.6923%. These findings suggest that a 2% lime juice concentration with prolonged stirring reduces emulsion stability. However, when the lime juice concentration was increased to 3%, emulsion stability improved, indicating that the combination of concentration and stirring time must be carefully considered to achieve optimal results.

The stirring time can influence the chemical reactions between additives and other components in margarine. In margarine production that incorporates egg yolk as an additive, the stability of the resulting emulsion is affected by the presence of egg yolk. This is due to the lecithin content in egg yolk, which acts as an emulsifying agent. According to Fitriyaningtyas & Widyaningsih [22], emulsion instability is caused by an imbalance between the dispersed phase and the dispersing phase, as well as the addition of emulsifiers. Other factors influencing emulsion stability formation include temperature, stirring time, and stirring speed [23].

Table 4. Emulsion Stability and Spreadibility of Margarine Based on Experimental Treatments

Experimental Treatments	Emulsion Stability (%)	Spreadability (g/mm^2)
J_1W_5	99.8096±0.1142	2.9124±0.3367
J_1W_{10}	99.7983±0.0437	2.8331±0.2383
J_2W_5	99.8795±0.0209	2.9897±0.7770
J_2W_{10}	99.6927±0.0514	3.2353±1.3804
J_3W_5	99.8383±0.0507	2.6335±1.1918
J_3W_{10}	99.8296±0.0483	3.6473±1.2667

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Based on the analysis of variance (ANOVA), the spreadability of margarine in this study showed that at a 5% significance level, the treatment of lime concentration had an F-value lower than the F-table (0.1366 < 3.8852), indicating no significant difference. Similarly, the stirring time had an F-value lower than the F-table (0.7323 < 4.7472), as did the interaction between lime concentration and stirring time (0.4971 < 3.8852), meaning there was no significant effect on the spreadability of margarine. Within the range of treatments applied, the spreadability of margarine varied between 2.6335 g/mm² and 3.6473 g/mm². An increase in lime concentration at a stirring time of 5 minutes resulted in a decrease in spreadability, whereas at 10 minutes, the spreadability increased. This is because margarine undergoes a stabilization process during production. Since margarine consists primarily of fat, its physical and chemical properties remain relatively unchanged despite variations in lime concentration and stirring time. Additionally, lime, which is commonly used in food, does not significantly affect the physical properties of margarine, while longer stirring times also do not have a substantial impact on its spreadability. This study aligns with the findings of Dian et al. [24].

3.3 Organoleptic Test Results

The organoleptic test results were obtained from various treatments of lime concentration and stirring time. Table 5 presents the organoleptic data for color, aroma, texture and taste based on the average results of each treatment. The color of margarine influenced by the addition of lime and different stirring time exhibits a significant variation. According to the findings, the interaction between lime concentration and stirring time has a notable impact on the margarine's color. ANOVA analysis reveals that the organoleptic evaluation of color by panelists shows a 5% significance level, with an F-value higher than the table F-value (2.7014 > 1.6764), indicating a significant difference. Likewise, in the sample treatments, the F-value is also greater than the table F-value (5.2977 > 2.3053), confirming a significant effect. The applied treatment influences each examined parameter. The highest average color rating by panelists was recorded for the sample with 3% lime concentration and 5 minutes of stirring, scoring 3.0000. Conversely, the lowest average color rating was observed in the sample with 2% lime concentration and 10 minutes of stirring, scoring 1.9524. An increase in lime concentration and a shorter stirring time in margarine result in a more pronounced yellow color, indicating a normal state. Conversely, as the stirring time extends, the obtained value decreases, producing a slightly yellow hue that remains within the normal range. This phenomenon occurs because margarine's primary ingredients, palm oil and egg yolk, contain carotenoids (beta-carotene), which impart a natural yellow shade. When prolonged stirring is combined with a higher lime concentration, the environment becomes less stable for beta-carotene. Consequently, extended stirring times may cause a decline in beta-carotene activity and purity within margarine.

Table 5. The Average of Organoleptic Score for Each Category in Each Experimental Treatment

Experimental Treatments	Color	Aroma	Texture	Taste
J_1W_5	2.7619	2.0952	2.6667	2.9524
J_1W_{10}	2.1905	2.2857	2.6667	3.1905
J_2W_5	2.5714	2.0476	2.1429	3.2381
J_2W_{10}	1.9524	2.1905	2.3810	3.3333
J_3W_5	3.0000	2.9524	2.3810	3.1429
J_3W_{10}	2.4286	2.5714	2.3333	3.0000

The aroma of margarine produced with the addition of lime juice and different stirring times exhibited a significant interaction between these factors. The ANOVA analysis showed that the organoleptic aroma test had a 5% significance level. In the panelist assessment, the F calculated value was higher than the F table value (6.64366 > 1.6764), indicating a significant effect. Similarly, in the sample treatment, the F calculated value exceeded the F table value (6.6123 > 3.2058), confirming a significant impact. Each treatment affected the aroma intensity of margarine. The highest mean aroma rating, as evaluated by panelists, was observed in the sample with 3% lime juice and a stirring time of 5 minutes, scoring 2.9524, which corresponds to a strong aroma. Conversely, the lowest mean value was found in the sample with 2% lime juice and a 5-minute stirring time, scoring 2.0476, indicating a normal (moderately strong) aroma. Samples containing 1% and 2% lime juice with stirring times of 5 and 10 minutes resulted in a moderately strong aroma. In contrast, samples with 3% lime juice for the same stirring times produced a strong aroma. This is attributed to the presence of lipase enzymes in lime juice, which break down fats into fatty acids and glycerol. This reaction enhances the formation of a more pronounced and distinctive aroma in margarine. A higher concentration of lime juice activates more enzymes, leading to an increased intensity of the margarine’s aroma.

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The texture of margarine produced with the addition of lime juice and varying stirring times was found to be solid. The study results demonstrated a significant interaction between lime juice concentration and stirring time in affecting the margarine's texture. According to ANOVA analysis, the organoleptic texture test at a 5% significance level showed that the F calculated value exceeded the F table value in both panelist assessment (4.9831 > 1.6764) and sample evaluation (3.0976 > 2.3053), indicating a significant impact. Each treatment contributed to the texture variations observed in margarine. The highest mean texture score, as rated by panelists, was recorded in samples containing 1% lime juice with stirring times of 5 and 10 minutes, scoring 2.6667, which corresponded to a solid texture. In contrast, the lowest average score was found in samples with 2% lime juice and a stirring time of 5 minutes, with a value of 2.1429, indicating a slightly solid texture. The findings suggest that the concentration of lime juice and stirring time significantly influence margarine texture. Samples containing 1% lime juice with stirring times of 5 and 10 minutes, as well as those with 2% lime juice for the same durations, resulted in a consistently solid texture. Meanwhile, samples with 2% and 3% lime juice stirred for 5 and 10 minutes exhibited a slightly solid consistency. These results are consistent with previous spreadability assessments.

The taste of margarine produced with the addition of lime juice and different stirring times exhibited a significant interaction between these factors. The ANOVA analysis showed that the organoleptic taste test had a 5% significance level. In the panelist evaluation, the F calculated value was greater than the F table value (5.3019 > 1.6764), confirming a significant effect. However, in the sample treatment, the F calculated value was lower than the F table value (1.6341 < 3.2053), indicating no significant difference. Each treatment influenced the taste profile of the margarine. The highest mean taste rating, as evaluated by panelists, was observed in the sample with 2% lime juice and a stirring time of 10 minutes, scoring 3.3333, which corresponds to a neutral taste. Conversely, the lowest mean value was found in the sample with 1% lime juice and a stirring time of 5 minutes, scoring 2.9524, also indicating a neutral taste. Increasing the lime juice concentration from 1% to 2% resulted in a stronger taste perception, but at 3% concentration, a decrease was noted. Sample analysis indicated no significant taste difference, whereas panelist evaluation showed a noticeable distinction. This suggests that the lime juice concentration had already reached an optimal level for the desired effect. Once the appropriate concentration is achieved, further increases do not lead to a significant taste change.

4 Conclusion

The findings indicate that lime concentration and stirring time significantly affect various aspects of palm oil-based margarine quality. Moisture content increases with higher lime concentrations and longer stirring durations, while fat content decreases. Free fatty acid levels rise with increasing stirring time and lime concentration. Emulsion stability remains relatively unchanged, but spreadability varies between 2.6335 g/mm^2 and 3.6473 g/mm^2. Regarding organoleptic properties, margarine color changes based on the applied treatments, with the highest recorded value of 3.0000 (yellow) and the lowest at 1.9524 (very yellow). The texture remains firm to slightly firm, while aroma intensity increases with higher lime concentrations. In terms of taste, a 2% lime concentration yields the highest neutral score of 3.3333, but at 3%, a slight decline is observed. Overall, the optimal margarine formulation can be achieved by carefully selecting the appropriate combination of lime concentration and stirring duration. Thus, a 2% lime concentration with a 10-minute stirring duration is recommended to achieve optimal margarine characteristics.

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