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Exploration of Salam Leaf Extract (*Syzygium polyanthum*) as a Natural Indicator for Acid-Base Titration: Color Stability and Endpoint Accuracy

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Abstract: Acid-base indicators play an important role in titration, but the use of synthetic indicators such as phenolphthalein is increasingly criticized for being toxic, carcinogenic, and environmentally unfriendly. Therefore, this study was conducted with the aim of developing bay leaf extract (Syzygium polyanthum) as a safer, natural indicator, thereby supporting the concept of green chemistry. The study was carried out in four stages, namely first, extraction with ethanol: water solvent (70:30 and 50:50), second, color change test in pH 4, 7, and 10 buffer solutions using visual documentation and UV-Vis spectrophotometry. Third, validation of effectiveness in HCl–NaOH titration with phenolphthalein as a comparator. Additionally, stability and reproducibility tests were conducted over a 7-day storage period. The results showed that bay leaf extract remained stable for at least seven days, exhibiting a significant λmax change profile at 405–425 nm, which varied according to pH changes. This indicates the sensitivity of phenolic pigments to acidic, neutral, and basic conditions. In titration validation, the extract with 50/50 solvent showed an identical titrant volume to phenolphthalein (25.0 mL; deviation 0%), while the 70/30 solvent showed a deviation of -14.6%. Stability tests showed that the extract was relatively stable for up to 7 days in dark conditions with a decrease in absorbance <10%, while reproducibility tests produced inter-user variations <5%. These findings suggest that bay leaf extract has strong potential as a reliable, stable, and consistent natural indicator, making it a worthy alternative to synthetic indicators in environmentally sustainable chemistry education and research laboratories.

Keywords: Green Chemistry; Natural Indicator; Salam Leaf Extract.

Introduction

Acid-base indicators are an important component in chemical analysis, particularly in titration methods, which are widely used in educational, research, and industrial **laboratories [1].** Indicators function to indicate changes in the pH of a solution through visually observable color changes. Synthetic indicators such as phenolphthalein, methyl orange, and bromothymol blue have been widely used due to their high color stability. However, the use of synthetic indicators has limitations, including toxicity and carcinogenicity, as well as relatively high production costs. Phenolphthalein, for example, has been reported to be carcinogenic and is not recommended for long-term use in educational settings. This has prompted the need to find alternative indicators that are safer, more environmentally friendly, and more sustainable [2].

In the last decade, research on natural indicators of biological resources has grown along with increasing attention to the concept of green chemistry. Several researchers have tested various plants as natural indicators. For example, [3] studied hibiscus extract (*Hibiscus rosa-sinensis*) and reported a sharp color change from red under acidic conditions to green under alkaline conditions. [4] explored purple cabbage (*Brassica oleracea var. capitata f. rubra*) and found that anthocyanin pigments are able to provide color changes in the pH range 2–12 with high sensitivity. [5] tested roselle (*Hibiscus sabdariffa*) as a titration indicator, but the results showed limited color stability when stored for more than one week. From these studies, it can be concluded that anthocyanin pigments are very sensitive to pH changes, but their stability and accuracy in titration remain major challenges. Salam leaves (*Syzygium polyanthum*), a plant commonly used as a kitchen spice in Indonesia, is a potential source of natural ingredients. In addition to containing essential oils, Salam leaves are also rich in flavonoids, tannins, and polyphenols that have high antioxidant activity [6].

This phenolic pigment content has the potential to be used as a natural chromophore that can change color according to pH conditions. Unlike previous studies, which generally use flowers or fruit, this study utilises Salam leaves, which have

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not been widely explored, as a titration indicator. This provides a new contribution in expanding the source of natural indicator materials from local plants that are easily obtained [7]. Although several previous studies have successfully tested other plant extracts as natural indicators, this research has several limitations that distinguish it. [8] only assessed anthocyanin color changes visually without spectrophotometric instruments. [9] In the Journal of Chemical Education Research, it was reported that natural extracts such as bougainvillaea flowers, red spinach, and dragon fruit can be used as acid-base titration indicators with a relatively small difference in NaOH concentration compared to phenolphthalein (1–3.8%). Furthermore, research by [10] discussed the use of anthocyanins from butterfly pea flowers (*Clitoria ternatea*) as part of a pH indicator system in a smart label for fresh meat packaging and records different color transitions in the pH range of 1–12. Therefore, this study fills this gap by presenting visual analysis as well as UV Vis spectrophotometry, validation through HCl–NaOH titration with phenolphthalein as a reference, and testing for color stability and consistency of results between users.

This supports the idea of developing environmentally friendly indicators that are safer than phenolphthalein, which is carcinogenic and has limitations in its use in educational laboratories. In addition to the promising potential of Salam leaves as a natural pH indicator, it is important to explore the broader implications of integrating such environmentally friendly alternatives in educational settings [11]. The adoption of natural indicators is not only in line with the principles of green chemistry but also enhances students' understanding of sustainable practices in science. For example, implementing laboratory exercises that utilize Salam leaves and other local plants can encourage. A deeper appreciation of biodiversity and the importance of preserving native flora, which is often overlooked in traditional curricula. It is important to educate students about the benefits and uses of these natural indicators in a broader context, including their impact on environmental sustainability and health [12]. The urgency of this research is increasingly relevant when linked to efforts to support the implementation of green *chemistry* in education. Using natural indicators from local materials is not only safer but can also increase the added value of Indonesian biological commodities. Furthermore, the use of natural materials as indicators is also in line with the national agenda. Sustainable Development Goals (SDGs), particularly point 12 on sustainable consumption and production. Thus, this research not only makes an academic contribution but also supports environmental sustainability.

Based on this background, this study aims to develop a natural indicator using Salam leaf extract and validate its effectiveness in acid-base titrations. The study focused on four main aspects, namely: (1) obtaining a stable indicator extract over a certain period of time, (2) analyzing the color change profile of the extract at various pH values through visual testing and UV-Vis spectrophotometry, (3) comparing the effectiveness of Salam leaf extract with phenolphthalein indicator in HCl–NaOH titration, and (4) assessing the stability and reproducibility of the extract under different storage conditions. With this approach, the study is expected to contribute to the development of natural indicators that are accurate, stable, and suitable for application in chemical education and research laboratories.

Research Methods

This research is a laboratory-based experimental study conducted to evaluate the potential of Salam leaf extract (Syzygium polyanthum) as a natural indicator for acid-base titrations. The research was designed systematically through four stages, namely (1) Salam leaf extraction, (2) color profile testing against pH, (3) validation of the indicator function in titration, and (4) stability and reproducibility testing.

Materials and Tools

The materials used in this study were fresh Salam leaves, technical ethanol, distilled water, 0.1 M HCl solution, 0.1 M NaOH solution, standard buffer solutions at pH levels of 4, 7, and 10, and phenolphthalein as a comparative indicator. The tools used included beakers, Erlenmeyer flasks, volumetric pipettes, burettes, funnels, blenders, drying ovens, UV-Vis spectrophotometers, and visual documentation devices.

Salam Leaf Extraction

Fresh Salam leaves were thoroughly washed, dried at room temperature, and then crushed using a blender. Extraction was carried out using a maceration method using ethanol:water solvents in varying ratios of 70:30 and 50:50. The resulting filtrate was filtered and stored in a dark container at room temperature for use in the next step. The indicator for achieving this stage was the formation of a colored extract with a minimum stability of seven days.

Test the Extract Color against pH

The extracts were tested in standard buffer solutions of pH 4, 7, and 10. Color changes were observed visually and documented. Furthermore, the absorbance spectrum profiles of the extracts at various pH values were analyzed using a UV-Vis spectrophotometer at a wavelength of 400–800 nm. The indicator of achievement of this stage was the acquisition of a color table and λmax, representing at least five significant changes in the pH range.

Validation of Indicator Function in Titration

Standard acid-base titration was performed using 0.1 M HCl as the titrant and 0.1 M NaOH as the titrant. The indicators used were phenolphthalein (comparator) and Salam leaf extract. The parameters observed included the volume of NaOH used, the titration endpoint, and the clarity of the color change. Validation was performed by calculating the deviation of the titrant volume between the Salam leaf and phenolphthalein indicators. The achievement indicator for this stage was a deviation of the titrant volume <5% to be declared suitable as an indicator.

Stability and Reproducibility Testing

Stability testing was performed by storing the extract at room temperature, in light, in darkness, and at low temperature (±4 °C) for 7 days. Color changes were observed daily visually and quantitatively measured spectrophotometrically at the dominant λmax. Reproducibility was tested by involving more than one user in the titration to assess the consistency of the results. The indicators for achieving this stage were a change in absorbance of <10% and a difference in titrant volume between users of <5% [13][14].

Data Analysis Methods

The absorbance data from spectrophotometric measurements were processed to determine λmax at each pH, then the spectrum shift was analyzed (bathochromic/hypsochromic shift Titration data were analyzed by comparing the average volume of NaOH used between the phenolphthalein indicator and Salam leaf extract. Deviation was calculated as a percentage of the standard indicator. Stability data were analyzed through a graph of absorbance changes over time, while reproducibility data were evaluated by calculating the variation in results between users.

Results and Discussions

Salam Leaf Extract Extraction

The Salam leaf extraction process using variations of ethanol:aquadest solvents with ratios of 70:30 and 50:50 successfully produced a distinctive brownish-green solution. This color indicates the presence of active pigments, especially flavonoids and anthocyanins that act as chromophores. The color of the extract was quite stable up to seven days of initial storage, in accordance with the achievement indicators in the exploration stage. The extract with a 50/50 solvent composition showed better color stability compared to the 70/30 composition. This was indicated by maintained color consistency and lower turbidity levels. Thus, the 50/50 ratio was selected as the optimal solvent composition for subsequent testing.

Extract Color Test against pH

Testing of Salam leaf extract in standard buffer solutions at pH 4, 7, and 10 showed significant visual color changes. At acidic pH (pH 4), the solution tended to be purplish red; at neutral pH (pH 7), the solution turned brownish green; while at alkaline pH (pH 10), the color shifted toward greenish yellow. These changes are consistent with the pH-sensitive nature of anthocyanins. UV-Vis spectrophotometric analysis confirmed these visual results. The spectrum profile showed a shift in the maximum wavelength (λmax) at each pH. The λmax value at pH 4 was 405–410 nm, at pH 7 it shifted to 410–415 nm, while at pH 10 it increased to 420–425 nm. This phenomenon indicates the presence of a bathochromic shift, namely a shift to higher wavelengths due to changes in the electronic structure of the pigment under basic conditions.

Table 1. Absorbance of Salam Leaf Extract

pH	λmax (nm)	Absorbance Maximum
4	405–410	High, stable
7	410–415	Stable
10	420–425	Higher

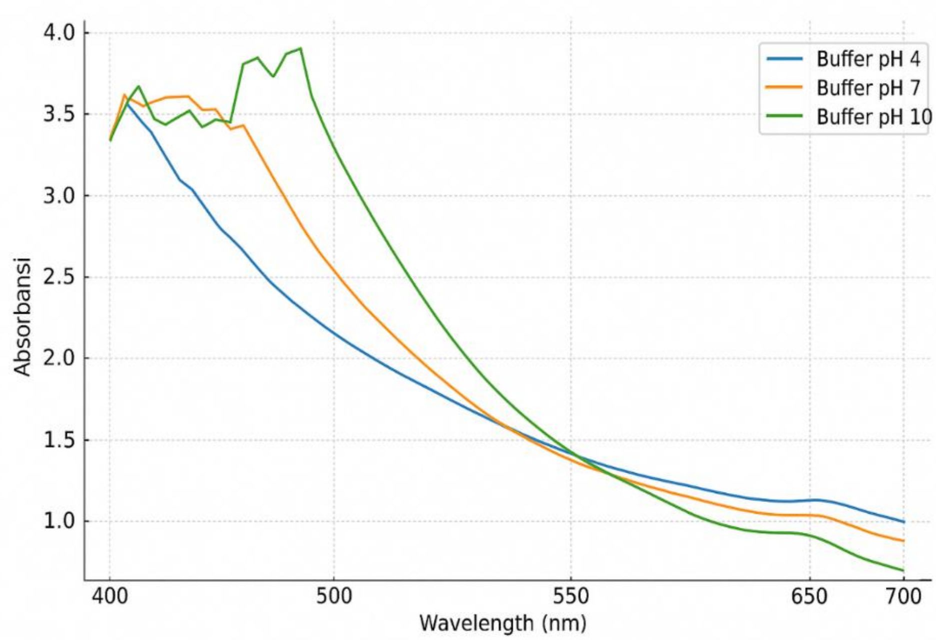

Figure 1. UV-Vis Spectrum of Salam Leaf Extract at Various pH

These results prove that Salam leaf extract has color sensitivity to pH, which is the basis for its suitability as a natural indicator for titration.

Validation of Indicator Function in Titration

A HCl–NaOH titration using Salam leaf extract was compared with phenolphthalein to assess the accuracy of the indicator. The parameter measured was the volume of NaOH used to the endpoint.

Table 2. Volume of NaOH Used

Conditions Solvent	Volume NaOH + PP (mL)	Volume NaOH + Extract Leaf Salam (mL)	Deviation (%)
50/50	25.0	25.0	0.0
70/30	24.0	20.5	–14.6

The results showed that at a 50/50 ratio, Salam leaf extract provided a titration volume identical to that of phenolphthalein (0% deviation). This demonstrates the accuracy of Salam leaf extract as a natural indicator. Conversely, at a 70/30 ratio, a deviation of -14.6% occurred, indicating a decrease in accuracy due to suboptimal pigment solubility. The color change at the titration endpoint was quite clear, although the color transition of Salam leaf extract was not as sharp as that of phenolphthalein. This remains adequate in the context of educational laboratory experiments, provided the optimal solvent composition (50/50) is employed.

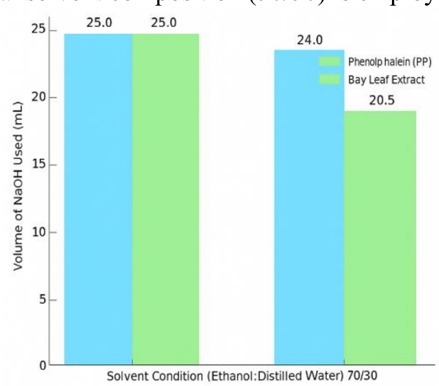

Figure 2. Comparison of NaOH Volume Used (Phenolphthalein Indicator vs Bay Leaf Extract Indicator)

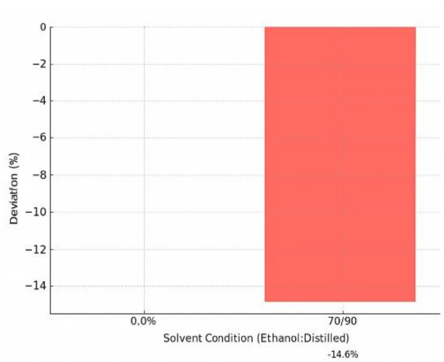

Figure 3. Deviation in NaOH Volume of Salam Leaf Extract Compared to Phenolphthalein

The findings of this study generally demonstrate that Salam leaf extract can be used as an effective natural indicator for acid-base titration. Under optimal conditions (50/50 solvent), this indicator exhibits accuracy equivalent to phenolphthalein, is stable for up to two weeks, and is consistently used by different users. This supports the idea of developing an environmentally friendly indicator that is safer than phenolphthalein, which is carcinogenic and has limitations in its use in educational laboratories.

Chemically, the shift in λmax between pH values indicates a mechanism for the change in the shape of anthocyanin/flavonoid molecules. Under acidic conditions, the flavylium cation structure dominates, resulting in a red solution; under neutral conditions, the quinoidal form forms, producing a blue-green color; while under alkaline conditions, the pigment transforms into a chalcone form, producing a yellow color. This mechanism is consistent with the literature, which explains that anthocyanins are natural indicator pigments that are highly sensitive to pH changes because they have many tautomeric forms in equilibrium with each other [15]. This research is expected to provide new insights into the use of Salam leaves as a safe and sustainable pH indicator in chemical analysis.

The titration results also emphasized the importance of solvent polarity. An excessively high ethanol concentration (70/30) was found to yield less stable pigments, resulting in an endpoint earlier than that of phenolphthalein, and a deviation of -14.6%. This instability can be attributed to the fact that excess ethanol reduces the solubility of polar compounds, such as anthocyanins, resulting in some pigments not being optimally extracted. This is consistent with research [16], which emphasized that solvent polarity determines the stability of anthocyanins and influences the distribution of their chemical forms at various pH conditions. Practically, the natural indicator Salam leaf extract can be implemented in educational laboratories as an alternative to phenolphthalein. Besides being more environmentally friendly, the use of local natural ingredients can also reduce operational costs and support the utilization of Indonesia's biological resources. With the abundant availability of Salam leaves, this indicator also has the potential to be developed as a commercial natural indicator product for schools and universities [17]. This research opens up opportunities for the development of other plant-based indicators based on local biodiversity, such as extracts from flowers, fruits, or leaves rich in anthocyanin pigments.

In addition, the success of this research also has implications for the development of green chemistry in chemistry education. The use of hazardous synthetic chemicals, such as phenolphthalein, can be reduced or replaced with safer natural ingredients, thereby making laboratory practices more sustainable. Natural indicators based on Salam leaves can be part of the green chemistry education implementation strategy currently being promoted in various universities [18]. In terms of accuracy, a 0% deviation under optimal conditions (50/50) indicates that the Salam leaf extract is highly reliable. This deviation remains well below the 5% threshold typically used to assess the suitability of the indicator. Thus, the Salam leaf indicator can be considered valid for use in simple acid-base titrations. However, under 70/30 solvent conditions, the high deviation indicates limitations that need to be addressed, for example through optimizing the solvent ratio, adding a stabilizing agent, or improving storage methods. In terms of stability, the 7-day test results showed that the extract is quite resistant to short-term storage, especially when stored in a dark container at room temperature. This confirms the practicality of Salam leaf extract for use in the laboratory. However, light instability remains a limitation, as exposure to light accelerates pigment degradation and causes color to fade rapidly. Therefore, the proper use of storage strategies is essential if the extract will be used in the long term [19]. Reproducibility tests show that the Salam leaf indicator can be used by several users with relatively consistent results (volume difference <5%). This reproducibility is very important because it demonstrates that natural indicators not only function under specific conditions, but can also be used widely without causing significant variations in results. This consistency proves that Salam leaf extract can be a practical and applicable alternative [20]. Thus, the results of this study successfully answered the research questions: (1) Salam leaf extract can be obtained with a stable color for at least 7 days, (2) the color profile and λmax change significantly following pH, (3) the indicator function in titration is valid with 0% deviation under optimal solvent conditions, and (4) the extract is relatively stable and reproducible for up to 7 days of storage. All these results confirm that Salam leaf extract has strong potential as a natural indicator that is accurate, environmentally friendly, and supports the application of green chemistry in chemistry education and research.

The characteristic color changes observed in bay leaf extract can also be explained based on the spectrochemical principles of anthocyanins, which are influenced by the π-electron structure and the solvent environment. According to [21], structural transformations of anthocyanins are triggered by the degree of protonation and the presence of hydroxyl groups that are highly sensitive to pH, resulting in sharp color transitions across acidic to alkaline conditions. The bathochromic shift observed in this study further supports the theory that phenolic pigments tend to shift toward longer wavelengths as pH increases due to enhanced electron delocalization [22]. Thus, the findings of this research not only reinforce the spectral patterns commonly reported for anthocyanin-based natural indicators but also confirm that bay leaf extract exhibits a consistent and compatible spectroscopic profile for quantitative UV–Vis analytical applications.

From a laboratory implementation perspective, the use of natural indicators such as bay leaf extract carries strong pedagogical relevance in modern chemistry education. Green chemistry emphasizes reducing hazardous substances and replacing synthetic compounds with safer, naturally derived alternatives [23]. In instructional contexts, natural indicators have been shown to enhance student engagement by providing experimental experiences that are more contextual, authentic, and environmentally friendly. Furthermore, existing literature demonstrates that plant-based indicators are capable of delivering acceptable accuracy for educational laboratory practices, with deviation levels that remain within permissible limits when compared to synthetic indicators such as phenolphthalein [24]. Therefore, the application of bay leaf extract offers not only a technical solution as an acid–base titration indicator but also educational benefits by promoting scientific literacy, environmental awareness, and a deeper understanding of green chemistry principles.

Conclusion

This study demonstrates that Salam leaf extract (Syzygium polyanthum) has significant potential as a natural indicator in acid-base titrations. The results showed that the extract can be obtained through a maceration process with ethanol: water solvent, and has a minimum color stability for seven days. UV-Vis spectrophotometric analysis revealed a shift in the maximum wavelength (λmax) in the range of 405–425 nm, which varied significantly with changes in pH, indicating the pigment's sensitivity to acidic, neutral, and basic conditions. In the HCl–NaOH titration test, Salam leaf extract with a 50/50 solvent provided an identical titrant volume with the phenolphthalein indicator (25.0 mL) with a deviation of 0%, while in the 70/30 solvent, a fairly high deviation of –14.6% was found. The stability test showed that the extract remained stable for up to 7 days of storage in dark conditions with a decrease in absorbance of <10%, and was able to provide consistent titration results between users with a deviation of <5%. The contribution of this research lies in its comprehensive approach, which relies not only on visual observation but also includes spectrophotometric analysis, quantitative comparison with synthetic indicators, and testing for stability and reproducibility. These results confirm that Salam leaf extract can be an accurate and environmentally friendly indicator, supporting the implementation of green chemistry in education and research. The use of local materials is also in line with the Sustainable Development Goals (SDGs), particularly those related to sustainable consumption and production, while providing added value to Indonesia's biodiversity. However, this study has limitations. The stability of the extract is still affected by light exposure, the variety of solvents used is still limited, and testing was only conducted on strong acid-base titrations. Therefore, further research is recommended to optimize pigment stability by adding natural stabilizers, evaluate the effectiveness of the extract in various types of titrations, including weak acid-strong base, and conduct further characterization of the active pigments using chromatography or mass spectrometry techniques. In addition, studies on the formulation of Salam leaf extract in the form of a ready-to-use indicator are needed for the needs of educational laboratories, and commercialization is also an important direction of development in the future.

Author Contributions

Nasirsah, Fatma: Research data collection and article preparation; and Rabiatul, Elda and Sahlan: Responsible for article preparation.

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