Formulation and Characterization of a Biodegradable Effervescent Detergent Tablet Containing *Sapindus rarak* and *Citrus aurantifolia* Extracts

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Abstract

The increasing use of synthetic detergents containing surfactants such as Sodium Lauryl Sulfate (SLS) has raised environmental concerns due to their low biodegradability and potential aquatic toxicity. This study aimed to develop and characterize a biodegradable effervescent detergent tablet formulated from *Sapindus rarak* (lerak) and *Citrus aurantifolia* (lime) extracts as natural surfactant and antibacterial agents. The extracts were obtained by maceration using ethanol solvents and converted into dry granules using aerosil as a drying aid. The effervescent tablets were prepared by the wet granulation method with citric acid, tartaric acid, sodium bicarbonate, PEG 6000, and Avicel pH 101 as excipients. The results showed that the granules had good flow properties with a moisture content of 3.7%, an angle of repose of 27°, and compressibility of 8%. The resulting tablets exhibited good physical quality with hardness of 6 Kgf, friability of 0.17%, and disintegration time of 1.2 minutes, meeting the effervescent tablet standards. The stable foam formed up to 5 cm for 30 minutes indicated the strong natural surfactant activity of saponins from *Sapindus rarak*. Overall, the combination of *Sapindus rarak* and *Citrus aurantifolia* extracts produced an effervescent detergent tablet with excellent physical and sensory characteristics, demonstrating great potential as an eco-friendly detergent formulation that supports Sustainable Development Goal (SDG) 12 on responsible consumption and production.

***Keywords**: Sapindus rarak, Citrus aurantifolia, biodegradable detergent, effervescent tablet, sustainability*

Introduction

The increased use of synthetic detergents containing surfactants such as Sodium Lauryl Sulfate (SLS) and Linear Alkylbenzene Sulfonate (LAS) has become a major contributor to water and soil pollution in Indonesia. Environmental data from the Central Bureau of Statistics (BPS) show that Indonesia's environmental quality index has fluctuated at an average of 73.52 over the past five years, indicating persistent ecological pressure. Clean water availability is also projected to decline sharply, especially on Java Island, potentially worsening pollution problems caused by detergent waste. Surfactants and phosphates from household detergents further contribute to eutrophication, inhibited oxygen exchange, and aquatic ecosystem degradation (Nurdianti *et al*., 2024; Naufal *et al*., 2024).

Natural materials offer a promising alternative to synthetic detergents. *Sapindus rarak* (lerak), traditionally used since the Majapahit era as a natural cleanser, contains 28–35% saponins that act as biodegradable surfactants with strong foaming and cleaning abilities (Fajriaty et al., 2017) . Scientific studies report high foam stability and notable antimicrobial activity from 8% lerak extracts (Hapsari *et al.,* 2021). Meanwhile, 10% lime peel (*Citrus aurantifolia*) extract contains flavonoids, phenolic compounds, and essential oils that exhibit antibacterial, antifungal, and deodorizing properties. Its essential oil content also provides a natural fragrance, making it a valuable additive for eco-friendly cleaning formulations (Pratami et al., 2024; Sari & Asri, 2022).

Despite their potential, natural detergent formulations still face limitations. Powder detergents tend to leave residues and require more rinsing water, while liquid detergents are less practical due to their bulkiness, risk of spillage, and high plastic packaging needs. Effervescent detergent tablets have emerged as an innovative alternative due to their fast dissolution, portability, precise dosing, and reduced reliance on plastic containers. Market trends also show increasing consumer preference for biodegradable and eco-friendly cleaning products, aligning with global sustainability goals such as SDG 12 (Mestri *et al.,* 2021).

However, studies that combine *Sapindus rarak* and *Citrus aurantifolia* extracts into a single biodegradable effervescent detergent tablet remain limited. Most existing research focuses only on single-ingredient formulations or liquid products. Therefore, the aim of this research is to design, formulate, and evaluate a biodegradable effervescent detergent tablet incorporating lerak fruit extract as a natural surfactant and lime peel extract as a natural antibacterial and fragrance agent.

Methods

Extraction of lerak fruit and lime peel

The extracts of lerak fruit (*Sapindus rarak* DC.) and lime peel (*Citrus aurantifolia*) were obtained using the maceration method with ethanol (Merck, Tbk.) as the solvent. The extraction of lerak fruit was carried out by weighing 1 kg of dried powder and adding 70% ethanol at a ratio of 1:5 (w/v), then left to stand for 48 hours at room temperature. The filtrate obtained was concentrated using a rotary evaporator (Heidolph) to yield a thick extract, followed by oven drying (Memmert UN UF Series) at 70 °C for 24 hours. To obtain a dry extract granule, the concentrated extract was mixed with aerosol (Smartlab) at a ratio of 1:3, ground until homogeneous, sieved through mesh 16, dried at 60 °C for 1 hour, and sieved again using mesh 20 (Widowati et al., 2022).

The extraction of lime peel was conducted using a similar procedure. Two kilograms of lime peel were macerated with 96% ethanol at a ratio of 1:3 (w/v) for 24 hours at room temperature. The filtrate was concentrated using a rotary evaporator, oven-dried at 40 °C to obtain a thick extract, and then dried with aerosil at a ratio of 1:3 (concentrated extract:aerosil). The mixture was ground until homogeneous, sieved through mesh 16, dried at 60 °C for 1 hour, and sieved again through mesh 20 to obtain uniform dry extract granules (Sari&Asri, 2022).

Formulation of Effervescent Detergent Tablet

Table 1. Formula of Effervescent Detergent Tablet (3 g)

Material	Function	Amount (%w/w)
Dry Extracts of lerak fruit (*Sapindus rarak* DC.)	API	10%
Dry Extracts of lime peel (*Citrus aurantifolia*)	API	10%
Citric acid	Acid source	14%
Tartaric acid	Acid source	0.3%
Sodium bicarbonate	Base source	14.3%
PVP	Binder	1%
PEG 6000	Lubricant	2%
Avivel pH 101	Filler	ad 100%

The effervescent tablet was formulated with the following composition: 10% dry lerak extract, 10% dry lime peel extract, 14% citric acid (Merck, Tbk.), 0.3% tartaric acid (Merck, Tbk.), 14.3% sodium bicarbonate (Merck, Tbk.), 1% PVP (Merck, Tbk.), 2% PEG 6000(Merck, Tbk.), and Avicel pH 101(Merck, Tbk.) as filler up to 100%. The tablet was prepared using the wet granulation method. The active ingredients (lerak and lime peel extracts) were mixed with the filler (Avicel pH 101) until homogeneous, followed by the addition of part of the acid components (citric and tartaric acids). The mixture was moistened with a PVP solution in ethanol (Merck, Tbk.) to form a wet mass suitable for granulation. The moist mass was sieved through mesh 16 to form wet granules, dried in an oven at 60 °C to optimal moisture, and sieved again through mesh 20. The resulting granules that met the physical characteristics were then blended with sodium bicarbonate and PEG 6000 as a lubricant, followed by compression using a single punch tablet press (Swansoft) with 10 Kp pressure compression to obtain compact and uniform effervescent tablets (Purwanto et al., 2023).

Characterization of Granules

The granules were characterized by some test as following (USP, 2024):

1. Organoleptic testing
   Organoleptic testing involves observing the shape, odor, taste, and color of the granules.
2. Moisture content testing
   The moisture content is determined by placing 0.5 grams of granules into a moisture content analyzer (Mettler Toledo HC103) and recording the resulting moisture value.
3. Flow rate testing
   For the flow rate test, 100 grams of effervescent granules are placed into a funnel with a closed orifice. After all the material has been poured, the funnel's orifice is opened, and the time required for the entire mass to flow out is measured. A good flow rate is defined as a flow time of not more than 10 seconds.
4. Angle of repose testing
   The angle of repose test is performed after the flow rate test by measuring the height of the conical pile of material under the funnel and measuring the radius of the cone's base using calipers (Tricle brand). The acceptable requirement for the angle of repose is that it should be no greater than 40^{o}.

$$\alpha = [tan]^{-1}\frac{h}{r}$$

Explanation:
α = angle of repose
h = high of the cone (cm)
r = radius of the cone (cm)

5. Compressibility testing
   100 g of granules are poured into a 100 ml measuring cylinder and the initial volume is recorded. The cylinder containing the powder is then tapped 100 times using a tap density apparatus (Unilab MM-0101). The volume after tapping is recorded, and the compressibility value is calculated. Granules with good flow properties should have a Compressibility Index value of <20%.

$$\rho \text{ bulk} = \frac{Powder\ weight}{Volume\ before\ tapping}$$

$$\rho \text{ tap} = \frac{Powder\ weight}{Volume\ after\ tapping}$$

$$\%\ \text{Compressibility} = \frac{\rho\ tap - \rho\ bulk}{\rho\ tap} \times 100\%$$

Explanation:
ρ bulk = Bulk density of powder before tapping
ρ tap = Bulk density of powder after tapping

Characterization of Tablets

The tablets were characterized by some test as following (USP, 2024):

1. Organoleptic testing
   Organoleptic testing involves observing the shape, odor, taste, and color of the tablets produced from the formula using the tableting machine.
2. Weight uniformity testing
   Weight uniformity was assessed via a two-stage process (USP, 2024). The initial phase involved 10 tablets (L1 < 15). Should the sample fail this limit, an additional 20 tablets were evaluated, requiring a final acceptance value of L2 < 25.

$$L_1 = |M - \bar{X}| + k \cdot s$$

   Explanation:
   M = Reference value (determined based on the value of $\bar{X}$)
   $\bar{X}$ = Mean of individual contents (expressed as a percentage of the label claim)
   k = Acceptability constant (2.4 for n = 10; 2 for n = 30)
   s = Sample standard deviation
3. Size uniformity testing
   Size uniformity are tested by measuring the tablet's diameter and thickness. The automatic hardness tester is the instrument used to measure the thickness and diameter of each tablet. A good tablet should have a diameter that is no more than 3 times and no less than 1/3 times its thickness.
4. Hardness testing
   Ten randomly selected tablets are subjected to a hardness test individually using a hardness tester (Erweka TBH 125). The acceptable hardness range for a good tablet is typically between 4-8 kg (kilograms-force).
5. Friability testing

Friability testing involves weighing 10 tablets, placing them in a friability tester (TFT-2-D) rotating at 25 revolutions per minute (rpm) for 4 minutes, and then reweighing them. The acceptable limit for tablet friability is less than 1%.

$$\% \text{ Friability} = \frac{W_0 - W_1}{W_0} \times 100\%$$

Explanation:
W_0 = Initial tablet weight
W_1 = Final tablet weight

6. Dissolution time testing
   For the dissolution time test, the tablet is placed into a beaker glass (Iwaki) containing 200 ml of water, and the time taken for the tablet to completely dissolve is recorded. A good effervescent tablet should dissolve in less than 5 minutes.
7. Foam stability testing
   The foam stability test is performed by observing the foam remaining in the solution after the dissolution test. A tablet is considered to have good foam stability if a stable foam column of 3 cm in height persists for 30 minutes.

Results and Discussion

Table 2. Results of Testing the Characteristics of Granules

Granule evaluation	Requirements	Results ($\bar{X}$ ± SD)	Interpretation
Organoleptic	-	light brown color with a distinctive aroma of lerak and lime	Passed the requirement
Moisture content	2 – 5%	3.7 ± 0.11%	Passed the requirement
Flow properties	< 10 s	6 ± 0.05 seconds per 100 g	Passed the requirement
Angle of repose	25 - 40°	27 ± 0.18°	Passed the requirement
Compressibility	≤ 20%	8 ± 0.1%	Passed the requirement

The results of the granule evaluation indicated that the extract-based granules demonstrated excellent physical characteristics, which are essential for ensuring successful tablet compression and consistent tablet quality. The moisture content of 3.7% fell within the acceptable range for effervescent preparations, where controlling moisture is crucial to prevent premature acid–base reactions between citric acid, tartaric acid, and sodium bicarbonate. A low moisture value also contributes to better flow and reduces the risk of granule agglomeration during processing. The flowability assessment showed that 100 grams of granules flowed within 4 seconds, indicating a high flow rate that ensures uniform and uninterrupted filling of the tablet die cavity. The angle of repose value of 27° further confirmed the good flow properties, as values below 30° typically represent free-flowing granules with minimal interparticle friction. Additionally, the Carr's Compressibility Index of 8% classified the granules as having excellent compressibility and low cohesion, which are important attributes for achieving uniform packing during tableting (Purwanto et al., 2022).

Flowability plays a critical role in determining the physical quality of tablets. Granules with good flow characteristics ensure that each die cavity receives a consistent amount of material, leading to uniform tablet weight and preventing content variability. Inconsistent flow may result in underfilled or overfilled dies, producing tablets with variable hardness, friability, and disintegration time. Good flowability also contributes to smoother compression cycles, reducing mechanical stress on the tablet press and minimizing defects such as capping, lamination, or chipping. The combination of low moisture content, excellent flow rate, and good compressibility observed in this study indicates that the granules were highly suitable for effervescent tablet production (Rahmayanti, 2021). These properties supported the formation of tablets with consistent size, hardness, friability, and rapid dissolution, ultimately enhancing the overall performance and quality of the biodegradable effervescent detergent tablets formulated from *Sapindus rarak* and *Citrus aurantifolia* extracts.

Table 3. Results of Testing the Characteristic of Effervescent Tablet

Tablet evaluation	Requirements	Results ($\bar{X} \pm SD$)	Interpretation
Organoleptic	-	flat, cylindrical, light brown in color, and had a distinctive fragrance of lerak and lime extracts	Passed the requirement
Weight uniformity	No two tablets should deviate more than column A, and no single tablet should deviate more than what is specified by column B.	498±1,3 mg	Passed the requirement
Size uniformity	The tablet diameter should not be more than 3 times the tablet thickness and should not be less than 1 1/3 (one and one-third) times the tablet thickness.	- Diameter: 10,91±0,02 mm - Thickness: 4,64±0,01 mm	Passed the requirement
Hardness	4 – 8 KgF	6,00 ± 1,053 kgF	Passed the requirement
Friability	< 1%	0,17 ± 0,002 %	Passed the requirement
Dissolution time	1 – 2 minutes	01.20 ± 00.07 minute	Passed the requirement
Foam stability	The presence of stable foam 13 - 220 mm high for 30 minutes.	Stable foam 120±0,19 mm for 30 minutes	Passed the requirement

The evaluation of the effervescent detergent tablets demonstrated that the final formulation exhibited excellent physical quality, fulfilling the requirements for effervescent tablet standards. The tablets showed uniformity in both weight and size, indicating consistent die filling during compression, which is directly influenced by the granules' good flowability. Weight uniformity is essential for ensuring dose accuracy and reproducible performance because variations can lead to inconsistent effervescent reactions, different dissolution profiles, and unstable foam formation (USP, 2024).

The measured hardness value of 6 Kgf suggested that the tablets possessed sufficient mechanical strength to withstand handling, packaging, and transportation without fracturing. Hardness is a critical attribute in effervescent tablets, as overly hard tablets may prolong dissolution time, while overly soft tablets may be prone to breakage or crumbling. The friability value of 0.17% further confirmed the robustness of the tablets, remaining well below the acceptable limit of 1%, which demonstrates that the formulation and compression pressure successfully produced tablets resistant to abrasion and chipping (USP, 2024).

In addition to mechanical properties, the functional performance of the tablets was evaluated through dissolution and foam stability tests. The dissolution time of 1.2 minutes indicated rapid disintegration, which is a key characteristic of effervescent tablets. Fast tablet disintegration is primarily driven by the acid–base reaction between citric acid, tartaric acid, and sodium bicarbonate, producing carbon dioxide that breaks apart the tablet matrix. Efficient dissolution ensures that the active components, which saponins from *Sapindus rarak* and flavonoids and essential oils from *Citrus aurantifolia* are released promptly into solution, enhancing cleaning performance and user convenience. The foam stability test showed a consistent foam height of 5 cm maintained for 30 minutes, which reflects the strong surfactant activity of saponins. Stable foam formation is desirable in detergent formulations, as it correlates with good emulsification of oily dirt and consumer perception of cleaning effectiveness. The presence of lime peel extract also contributed positively by providing natural fragrance and potential antibacterial support, adding additional functional and sensory benefits to the final product (Rahmayanti, 2021).

These results collectively demonstrate that the formulation successfully achieved optimal physical and functional tablet characteristics. Appropriate hardness and friability ensured mechanical integrity, while rapid disintegration and foam stability confirmed effective effervescent behavior and surfactant performance. Each parameter from uniformity and flowability to dissolution and foam height plays a vital role in determining the tablet's overall quality, usability, and market feasibility. The successful outcomes of these evaluations support the potential of lerak and lime peel-based effervescent tablets as a promising biodegradable detergent alternative aligned with principles of sustainable product development.

Conclusion

This study successfully designed and formulated a biodegradable effervescent detergent tablet utilizing *Sapindus rarak* extract as a natural surfactant and *Citrus aurantifolia* peel extract as a functional antibacterial and fragrance agent. The resulting formulation achieved high-quality physical standards, including excellent granule flowability, precise weight uniformity, and rapid dissolution with stable foam formation. These results demonstrate that the combination of lerak and lime peel extracts can be effectively integrated into a solid effervescent dosage form that meets all required mechanical and physical parameters for an eco-friendly cleaning product.

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