

Article

Formulation and Characterization of Eco-Enzyme and Soapberry (*Sapindus rarak* DC.) Based Shampoo Preparations as an Alternative Environmentally Friendly Hair Care Product

Article Info

Article history :

Received September 14, 2026

Revised October 24, 2026

Accepted October 28, 2026

Published October 30, 2026

Keywords :

Characterization,
eco-enzyme,
Sapindus rarak,
shampoo,
environmentally friendly

Najla Lubis^{1*}, Ruth Riah Ate Tarigan², Rusdianto³

¹Master of Agricultural Science, Universitas Pembangunan Panca Budi, Medan, Indonesia

²Master's in Regional and Urban Planning, Universitas Pembangunan Panca Budi, Medan, Indonesia

³Master's Student in Agricultural Science, Universitas Pembangunan Panca Budi, Medan, Indonesia

Abstract. Synthetic surfactants in hair care products can irritate skin and persist in the environment, which motivates milder bio-based alternatives. This study aimed to formulate and characterize a shampoo containing eco-enzyme and soapberry (*Sapindus rarak* DC.) extract (Sh.E) with methyl ester sulfonate (MES) as the surfactant. Lerak was fermented in eco-enzyme at 0, 5, 10, and 15% (w/v) in a completely randomized design. pH ($n = 3$) and Brookfield viscosity ($n = 3$) were analyzed by one-way ANOVA and Duncan's test, while foam ($n = 1$) and particle size (mean of three measurements) were described only. All formulas met the pH (5.43–6.00) and viscosity (680.67–3555.67 cP) ranges used as criteria. Sh.E changed pH ($F = 17.79$, $p < 0.001$) and viscosity ($F = 414,588.60$, $p < 0.001$) non-linearly, with minimum viscosity at 10%. Foam stability rose from 75.00% (control) to 84.21–88.10%. The 10% formula had the smallest Z-average (130.0 nm) but a high polydispersity index (PDI 0.697), indicating heterogeneous aggregates, whereas 15% had the lowest PDI (0.294). The 15% formula was most favorable against the criteria. Limitations are readings from one batch, single foam readings, no positive control, no raw-material characterization, and no stability, detergency, or safety tests.

This is an open access article under the [CC-BY](#) license.



This is an open access article distributed under the Creative Commons 4.0 Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. ©2026 by author.

Corresponding Author :

Najla Lubis

Master of Agricultural Science, Universitas Pembangunan Panca Budi, Medan, Indonesia

Email : najlalubis@dosen.pancabudi.ac.id**1. Introduction**

Anionic surfactants such as sodium lauryl sulfate (SLS) and sodium lauryl ether sulfate (SLES) dominate shampoos because they clean and foam efficiently [1]. Their drawbacks are skin irritation and environmental burden [2-3]. Washing can also strip hair lipids and alter the fibre [4-5]. Cleanser performance therefore depends on how surfactants interact with hair and skin surfaces [6-7]. These concerns push the industry toward milder, bio-based ingredients [8-10].

Eco-enzyme (EE) is a liquid obtained by fermenting fruit and vegetable waste with sugar and water [11-12]. It is made at village scale from household and farm waste [13-14]. It contains organic acids, minerals, and hydrolytic enzymes, and characterized EE shows protease, amylase, and lipase activity [12],[15]. Fruit-peel EE has also shown antimicrobial activity in vitro [16-17]. EE from fruit waste inhibited *Staphylococcus aureus* and *Escherichia coli* and was active against the yeast *Candida albicans* [18-19]. Fermentation is recognized as a route to sustainable cosmetic ingredients [20-21]. Fermented agricultural waste and EE have also been applied to shallot growth [22-23], and fermentation time changes the nutrient composition of fruit peel [24]. EE therefore offers a waste-derived source of organic acids and enzymes.

In a shampoo, EE could play three roles. Its organic acids may adjust pH, which matters because cleansers that shift skin pH can disturb the skin barrier [7]. Its hydrolytic enzymes may help remove lipid and protein soils, as reported for detergent enzyme cocktails and garbage enzyme [11],[25]. Its dissolved ions and organics may also change micellar packing and viscosity, as electrolytes do in surfactant systems [26]. Direct evidence of EE benefits or safety on scalp and hair is still missing. The closest data concern antimicrobial activity [16] and the lipase activity of *Malassezia* yeasts in dandruff [27-28], so scalp benefits remain a hypothesis. The yeast tested with EE was *Candida albicans*, not scalp *Malassezia* [19].

Soapberry (*Sapindus* spp.) fruit is rich in triterpenoid saponins used as natural detergents [29-30]. Saponins lower surface tension and form viscoelastic films at interfaces, which supports foaming and emulsification [30-31]. Extracts of *S. rarak* show moderate foaming and detergency compared with synthetic surfactants [32]. Foamability of soapnut saponin increases with its concentration [33]. *S. mukorossi* has also served as an emulsifying agent, as a biosurfactant for green material synthesis, and as a source of an anti-acne flower extract [34-36]. In this study, Sh.E denotes the combined EE and soapberry extract that supplies saponins together with EE.

Plant surfactants have already been tested in shampoos. Quinoa, soybean, and acerola extracts served as primary surfactants and removed sebum as well as a commercial shampoo [37]. Herbal shampoos from Ethiopian plants met pH and surface tension requirements [38], and vortex processing improved the stability of an organic shampoo [39]. *S. saponaria* extract improved foaming and foam stability of a liquid soap [40], and lerak extract has been used in liquid laundry soap [41]. These studies treat saponins as the main surfactant rather than as a co-ingredient in a synthetic base.

Methyl ester sulfonate (MES) is a palm-based anionic surfactant with good detergency, high biodegradability, and low ecotoxicity, but its viscosity and phase stability need control [42]. MES therefore suits a study of how natural additives change rheology. Mixed anionic and bio-based surfactant systems show composition-dependent behavior at interfaces and in aggregation [43-44]. Wormlike micelle length and flow depend on micellar composition and on surfactant polydispersity [45-47]. Hydrogen bonding between head groups can raise viscoelasticity [48]. These principles predict non-linear responses to a saponin-rich additive.

The closest precedent combined garbage enzyme with saponin-rich honeylocust fruit. That mixture had higher viscosity, foam stability, enzyme activity, and detergency than garbage enzyme alone [11]. It was developed as a produce-washing detergent, not as a shampoo in a synthetic base. No study located in our literature search combined EE and *S. rarak* saponins in an MES shampoo or linked pH, viscosity, foam, and aggregate size across concentrations. This is the research gap. It matters because non-linear responses make a single concentration hard to predict from single-surfactant data.

The aim of this study was to formulate MES shampoos containing Sh.E made with 0, 5, 10, and 15% (w/v) lerak in eco-enzyme and to characterize pH, viscosity, foam height and stability, and particle size. Formulas were judged against SNI 06-2692-1992 for liquid shampoo, which sets pH at 5.0–9.0 and foam height at 13–220 mm. Viscosity was judged against 400–4000 cP as a working range for this study. Foam stability and PDI served as ranking criteria (Section 2.6). The trends are interpreted with colloid theory, and the limits of the data are stated.

2. Experimental Section

2.1. Materials and Preparation of Sh.E

Eco-enzyme (EE) was prepared from orange, pineapple, and papaya waste (1 kg of each; peel only), brown sugar, and well water at a waste:sugar:water ratio of 3 kg:1 kg:10 L (3:1:10). The mixture was fermented for 100 days in a closed container at 25 °C. The liquid was then filtered. The pH, total acidity, and enzyme activity of the EE were not measured.

Sapindus rarak DC. (lerak) fruit was ordered from an online seller in Situbondo Regency, East Java, Indonesia. The fruit was supplier-identified, and no voucher specimen was kept. Only the peeled fruit flesh was used (seeds removed), and it was added to the EE without drying or powdering, at 0, 5, 10, or 15% (w/v; Section 2.2). The saponin content of the lerak was not tested.

The EE–lerak mixture was fermented further for 45 days in a wide-mouth container without stirring at 25 °C, then filtered to give Sh.E. The yield, pH, and saponin or enzyme content of Sh.E were not measured. Shampoos were made with technical-grade methyl ester sulfonate (MES) bought from a local chemical store. MES was the active surfactant and made up 2% of the formula. No thickener, preservative, fragrance, or other surfactant was added. The formulas relied on the natural scent of fermented lerak.

2.2. Formulation and Mixing

Four formulas were prepared with Sh.E made from 0, 5, 10, and 15% (w/v) lerak in EE (Table 1). For example, 5% means 250 g of lerak in 5 L of EE, and the 0% formula used EE alone. Each formula contained 2% MES, 80% Sh.E, and 18% water of the total solution. Lerak concentration was the only variable, and formulas are named by it (for example, “5%”). All components were mixed at 1200 rpm for about 5 min.

Table 1. Composition of the shampoo formulas.

Component	F0	F1	F2	F3
Lerak in EE for Sh.E (% w/v)	0	5	10	15
Sh.E (% of total solution)	80	80	80	80
MES (% of total solution)	2	2	2	2
Water (% of total solution)	18	18	18	18

2.3. Measurements

pH was measured with a digital pH meter (Gratech) calibrated with pH 4.01 and 10 buffers at 25 °C. Viscosity was measured by an external testing laboratory with a Brookfield viscometer at 6.0 rpm with spindle no. 62. This gives a single rotational speed, so the data describe viscosity at one point, not a

flow curve. Foam was assessed by the shake test. Initial foam height (H0) and foam height after a fixed standing time (Ht) were read in mm, with Ht taken 5 min after H0. Foam stability was calculated as $(H_t/H_0) \times 100\%$.

Particle size was measured by the same external testing laboratory using dynamic light scattering (DLS) with a Winner 901 particle size analyzer. Z-average, D10, D50, D90, and the polydispersity index (PDI) were recorded.

2.4. Experimental Design and Replication

A completely randomized design with four Sh.E levels was used. pH and viscosity were measured in triplicate ($n = 3$), particle size as the mean of three measurements by the laboratory, and foam once ($n = 1$). No positive control such as a commercial shampoo was included. All pH and viscosity replicates were repeated readings of one batch, so they are technical replicates. The ANOVA therefore tests differences within this batch, and batch-to-batch variation was not assessed. Organoleptic, specific gravity, detergency, and stability tests are addressed in Section 3.5.

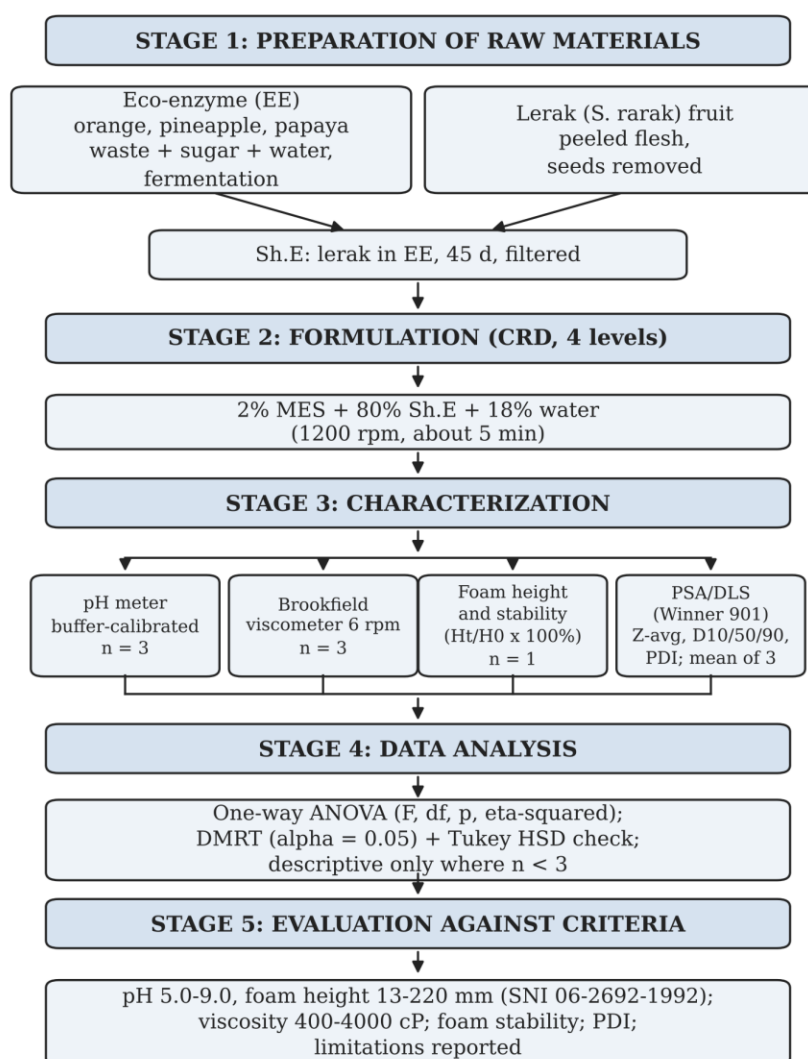


Figure 1. Research workflow from material preparation to evaluation.

2.5. Statistical Analysis

pH and viscosity were analyzed by one-way ANOVA, reporting F, degrees of freedom, p, and eta-squared (η^2). The coefficient of variation (CV) was calculated to express experimental precision. Residual normality (Shapiro–Wilk) and variance homogeneity (Levene) were checked. Means were separated by Duncan's multiple range test (DMRT, $\alpha = 0.05$), and Tukey's HSD was applied as a more conservative check. A Kruskal–Wallis test and, for viscosity, Welch's ANOVA checked robustness. Foam and particle size had $n < 3$ and are described without inference. Means, ANOVA, and DMRT were calculated in Microsoft Excel. The assumption checks, Tukey's HSD, Kruskal–Wallis, Welch's ANOVA, and η^2 were verified in Python 3.13 with SciPy 1.18.

2.6. Evaluation Criteria and Workflow

Formulas were evaluated against five criteria. pH had to fall within 5.0–9.0, foam height within 13–220 mm, and viscosity within 400–4000 cP. Among formulas meeting these limits, higher foam stability and lower PDI were preferred. A PDI above about 0.5 was treated as too broad for reliable size comparison. The 400–4000 cP range is a working range set by the authors for this study. It is not taken from SNI 06-2692-1992 or from a laboratory specification. The criteria were chosen after the data had been analyzed, so the selection of the best formula is exploratory.

3. Results and Discussion

3.1. pH

Mean pH ranged from 5.43 (5% Sh.E) to 6.00 (control) (Table 2). Sh.E concentration had a significant effect on pH (Table 3; $F(3, 8) = 17.79$, $p < 0.001$, $\eta^2 = 0.87$). The CV was 1.67%. Residuals were normal (Shapiro–Wilk $p = 0.23$) and variances were homogeneous (Levene $p = 0.72$). DMRT separated 5% (a), 10% and 15% (b), and 0% (c) (Figure 2). Under the more conservative Tukey test, 0% versus 15% was borderline ($p = 0.068$), so that pair should be read with caution.

Table 2. pH of the shampoo formulas ($n = 3$). Means followed by different letters differ (DMRT, $\alpha = 0.05$).

Lerak in EE (% w/v)	R1	R2	R3	Mean $\pm$ SD	DMRT
0	6.0	5.9	6.1	6.00 ± 0.10	c
5	5.3	5.5	5.5	5.43 ± 0.12	a
10	5.7	5.8	5.6	5.70 ± 0.10	b
15	5.8	5.8	5.7	5.77 ± 0.06	b

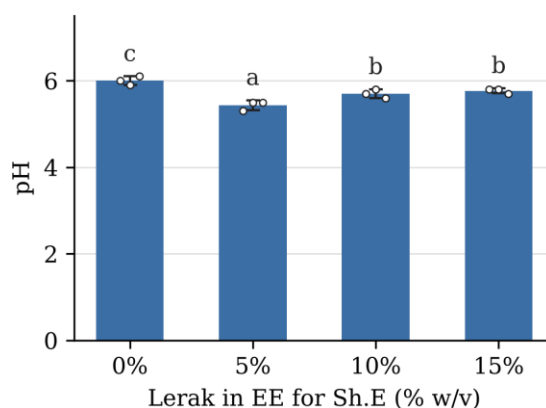


Figure 2. pH of the shampoo formulas (mean $\pm$ SD, $n = 3$; points are replicates; letters are DMRT groups).

All formulas lay within the SNI range of 5.0–9.0. Sh.E lowered pH by 0.23–0.57 units, consistent with the organic acids of EE [12]. Sh.E mixtures stayed in a mildly acidic range, similar to the pH of 5.90–7.45 reported for herbal shampoos [38]. A mildly acidic pH is desirable because cleansers that shift skin pH can disturb the barrier [7]. Irritation and scalp tolerance were not tested here, so no safety claim is made.

The pH did not fall steadily with Sh.E: 5% was lowest, and 10% and 15% were higher. A simple acid-addition model predicts a monotonic decline, so other factors must act. Possible causes are buffering by saponins and the MES base, and electrode response in viscous, high-ionic-strength media. The total spread is only 0.57 units, and independent batches are needed to confirm the pattern.

3.2. Viscosity

Viscosity was non-monotonic (Table 4, Figure 3). It was highest in the control (3555.67 cP), fell to a minimum at 10% (680.67 cP), and rose again at 15% (1203.33 cP). Sh.E strongly affected viscosity (Table 3; $F(3, 8) = 414,588.60$, $p < 0.001$). The CV was only 0.22%, which shows very high measurement precision. Residuals were normal (Shapiro–Wilk $p = 0.22$). Levene's test was borderline ($p = 0.044$), but the Brown–Forsythe test was not significant ($p = 0.81$), and Welch's ANOVA agreed ($F(3, 3.94) = 196,034.64$, $p < 0.001$). All six pairs differed in DMRT and in Tukey's test ($p < 0.001$). All values lay within the 400–4000 cP criterion, although the control approached the upper limit.

Table 3. Viscosity of the shampoo formulas ($n = 3$). Means followed by different letters differ (DMRT, $\alpha = 0.05$).

Lerak in EE (% w/v)	R1 (cP)	R2 (cP)	R3 (cP)	Mean $\pm$ SD (cP)	DMRT
0	3549	3559	3559	3555.67 ± 5.77	d
5	1065	1060	1063	1062.67 ± 2.52	b
10	680	680	682	680.67 ± 1.15	a
15	1205	1205	1200	1203.33 ± 2.89	c

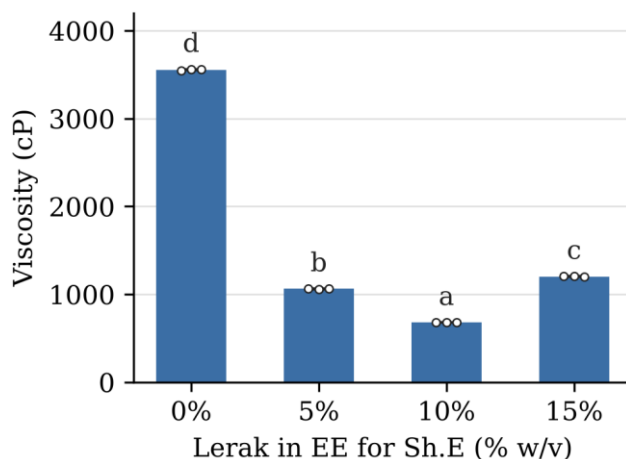


Figure 3. Viscosity of the shampoo formulas (mean $\pm$ SD, $n = 3$; points are replicates; letters are DMRT groups).

Table 4. One-way ANOVA for pH and viscosity (df = degrees of freedom; SS = sum of squares; MS = mean square; CV = coefficient of variation = $\sqrt{\text{MS within}} \div \text{grand mean} \times 100$).

Parameter	Source	df	SS	MS	F	p	CV (%)
pH	Between	3	0.4892	0.1631	17.79	< 0.001	1.67
	Within	8	0.0733	0.0092			
Viscosity	Between	3	15,339,778.25	5,113,259.42	414,588.60	< 0.001	0.22
	Within	8	98.67	12.33			

Why does viscosity fall so sharply? In the control, MES micelles in acidic, ionic EE may grow into entangled wormlike networks that give high viscosity. The length of such micelles depends on their composition through the scission free energy [45], and on the polydispersity of the surfactant itself [46-47]. Adding a different amphiphile therefore reshapes the network.

Saponins are bulky: a rigid triterpenoid tail and large hydrated sugar heads. Mixed with an anionic surfactant, they can raise the effective head-group area and favor more curved, shorter aggregates, as escin mixtures show a composition-driven shift from micelles to vesicles [43]. Shorter micelles entangle less and give lower viscosity. Ions and acids from EE may add a salt effect, and viscosity in anionic systems is known to rise and then fall with electrolyte or co-surfactant level [26]. Dilution cannot explain the five-fold drop, because MES and Sh.E amounts were the same in every formula. Only the lerak concentration changed.

The rebound at 15% suggests a different regime. More saponin may allow hydrogen bonding between glycoside head groups, which can raise viscoelasticity [48]. The larger aggregates measured at 15% (Section 3.4) support a stronger inter-aggregate network. Saponin interfacial moduli also pass through a minimum with concentration at the β -pinene/water interface [31], showing that non-monotonic saponin behavior is not unusual. These mechanisms are consistent with the data but untested: no flow curves, cryo-electron microscopy, or scattering were measured.

Earlier work agrees only partly. Garbage enzyme with saponin-rich fruit increased viscosity relative to garbage enzyme alone [11], whereas Sh.E lowered viscosity here, so the base matters. Lerak extract at 5–9% did not significantly change the viscosity of a laundry soap [41]. That window lacked a 0% control and was narrow, so a non-monotonic trend could be missed. Finally, the viscosity SDs (1.15–5.77 cP) are tiny, consistent with repeated readings from one batch; the very large F therefore reflects measurement precision, not batch-to-batch reproducibility.

3.3. Foam Height and Stability

Sh.E increased foam height and stability in the single measurements (Table 5). H0 rose from 20 mm in the control to 35–42 mm, and stability rose from 75.00% to 84.21–88.10%. All H0 values exceeded the SNI minimum of 13 mm and stayed below 220 mm. Because $n = 1$, no statistical test is possible. A 1 mm reading error changes stability by about 3 percentage points at these heights, so differences among the Sh.E formulas (84.21–88.10%) cannot be interpreted. Only the difference between the control and Sh.E formulas is large enough to be suggestive.

Table 5. Foam height and stability (single measurement, $n = 1$; stability = $\text{Ht}/\text{H0} \times 100\%$).

Lerak in EE (% w/v)	H0 (mm)	Ht (mm)	Stability (%)
0	20	15	75.00
5	35	30	85.71
10	38	32	84.21
15	42	37	88.10

The increase is consistent with saponin adsorption at the air–water interface, which lowers surface tension and forms viscoelastic films that slow drainage [30–31]. Saponin extracts alone give only moderate foaming [32], so a synthetic base plus saponin is a sensible combination. Anionic surfactant blends can also act synergistically on foam [49]. *S. saponaria* extract improved foaming and foam stability of a liquid soap [40], and saponin-rich garbage enzyme raised foam stability [11]. Foam was highest at 15% while viscosity was lowest at 10%, so foam was not governed by bulk viscosity alone. A triplicate re-test with a positive control is required.

3.4. Particle Size and Polydispersity

Particle size and polydispersity give a first indication of how uniform the dispersed system is, but they do not replace stability testing. Z-average followed a U-shaped trend: 536.9 nm (0%), 324.8 nm (5%), 130.0 nm (10%), and 387.3 nm (15%) (Table 6, Figure 4). D50 closely matched Z-average in every sample. PDI was 0.339 (0%), 0.650 (5%), 0.697 (10%), and 0.294 (15%). Each value is the mean of three measurements made by the laboratory, which reported only the mean without individual readings or SD, so no inferential test was applied.

Table 6. Particle size and PDI by dynamic light scattering (mean of three measurements, reported by the laboratory).

Lerak in EE (% w/v)	Z-average (nm)	D10 (nm)	D50 (nm)	D90 (nm)	PDI
0	536.9	430.8	536.6	669.1	0.339
5	324.8	213.9	324.6	492.7	0.650
10	130.0	85.3	129.9	204.3	0.697
15	387.3	320.3	387.1	468.1	0.294

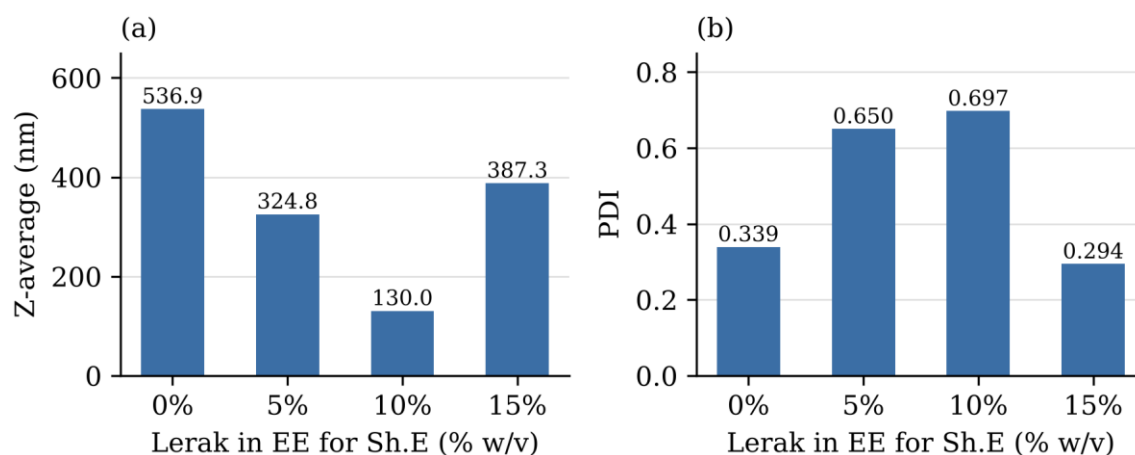


Figure 4. Particle size and polydispersity of the shampoo formulas: (a) Z-average; (b) PDI (mean of three measurements).

These sizes are far larger than single MES or saponin micelles, which are a few nanometers across. They therefore represent aggregates, vesicle-like structures, or elongated micelles, and DLS reports only an apparent hydrodynamic diameter for non-spherical objects [50]. EE particulates may also contribute. A smaller Z-average is not automatically better, and the smallest value (130.0 nm) occurred in the least homogeneous sample.

Why is the 10% formula so heterogeneous? It coincides with the viscosity minimum, where wormlike micelles have been shortened but saponin-rich aggregates may not yet dominate. Small mixed micelles and larger aggregates can then coexist, giving a broad distribution (PDI 0.697) [43],[46]. At 15%, more saponin may give more uniform mixed aggregates (PDI 0.294) that are larger (387.3 nm) and hydrogen-bonded, which matches the higher viscosity [48]. The 5% sample was also broad (PDI 0.650), so heterogeneity is not unique to 10%.

The PDI values of 0.65–0.70 are near the practical limit of cumulant analysis, and Z-average is intensity-weighted, so it is dominated by the largest species. Measurement of concentrated, viscous samples can also cause multiple scattering when dilution is inadequate. The 0% control (PDI 0.339) is itself polydisperse, as expected for commercial surfactant mixtures [46-47]. No penetration or deposition study was done, so no claim is made about follicle infiltration.

3.5. Tests Not Reported

Organoleptic properties, specific gravity, detergency, and accelerated stability (6 heating–cooling cycles) were not performed in this study. Without them, no claim is made about appearance, cleansing power, or storage stability. A commercial shampoo was also not included as a positive control. These gaps are limitations, and the formulas should be tested for them before any application.

3.6. Selection of the Most Favorable Formula

All four formulas met the pH, foam height, and viscosity criteria (Table 7), so these criteria did not discriminate among them. Foam stability and PDI did. The 15% formula had the highest foam stability (88.10%) and the lowest PDI among the Sh.E formulas (0.294). The 10% formula was not selected despite its smallest Z-average, because its PDI of 0.697 shows a heterogeneous system whose size is not reliable, and because it had the lowest viscosity.

Table 7. Evaluation of the formulas against the criteria (all listed values are within the criterion where one is given)

Parameter	Criterion	0%	5%	10%	15%
pH	5.0–9.0	6.00	5.43	5.70	5.77
Viscosity (cP)	400–4000	3555.67	1062.67	680.67	1203.33
Foam height (mm)	13–220	20	35	38	42
Foam stability (%)	Higher preferred	75.00	85.71	84.21	88.10
PDI	Lower preferred	0.339	0.650	0.697	0.294

The 15% formula is therefore the most favorable of the four tested, not a proven optimum. Foam stability rests on one reading, and PDI on laboratory means without individual readings. The stability, detergency, and safety data needed to call any formula optimal are absent. A confirmatory study with independent batches should test 12–18% Sh.E to resolve the region around the viscosity rebound.

3.7. Comparison with Previous Studies

Table 8 places the main findings beside earlier work. The novelty lies in the combination: EE with *S. rarak* saponins in an MES shampoo, with concentration-dependent viscosity and aggregate size. Earlier work used saponins as the primary surfactant or EE with another saponin source in a produce detergent. The non-monotonic viscosity and the high PDI at intermediate Sh.E levels have not been reported for such a system.

Table 8. Key findings compared with previous studies

Study	System	Reported effect	This study
Gu et al. [11]	Garbage enzyme + honeylocust fruit; detergent	Higher viscosity, foam stability, enzyme activity	EE + lerak in MES base: viscosity fell, then rose; foam stability higher
Cavaletti et al. [40]	<i>S. saponaria</i> extract in liquid soap	Better foaming and foam stability	Foam stability higher with Sh.E (n = 1)
Hawa et al. [41]	Lerak 5–9% in laundry soap	Viscosity and foam stability not significant	Viscosity strongly non-monotonic (0–15%)
Bezerra et al. [37]	Quinoa, soybean, acerola extracts in shampoo	Sebum removal like a commercial shampoo	Detergency not yet tested
Godeto et al. [38]	Herbal shampoos	pH 5.90–7.45	pH 5.43–6.00

4. Conclusion

Shampoos made with Sh.E from 0, 5, 10, and 15% (w/v) lerak in eco-enzyme and 2% MES had pH 5.43–6.00 and viscosity 680.67–3555.67 cP, both within the criteria used. Sh.E changed pH ($F(3, 8) = 17.79$, $p < 0.001$, $\eta^2 = 0.87$) and viscosity ($F(3, 8) = 414,588.60$, $p < 0.001$) non-linearly, with minimum viscosity at 10%. In single measurements, foam stability rose from 75.00% to 84.21–88.10%. The 10% formula had the smallest Z-average (130.0 nm) but a PDI of 0.697, whereas the 15% formula had the lowest PDI (0.294) and highest foam stability (88.10%).

The 15% formula was therefore the most favorable of the four against the stated criteria. This conclusion is provisional because foam was measured once, particle size twice, no positive control was used, and stability, detergency, and safety were not evaluated. Future work should use independent batches, triplicate foam tests, rheology, and accelerated stability tests.

5. Acknowledgement

LPPM UNPAB is providing financial assistance and facilitating the conduct of this research through the Internal Grant of Universitas Pembangunan Panca Budi, in accordance with Contract Number: 379/8/F/17/2026.

References

- [1] Thompson, C. J., Ainger, N., Starck, P., Mykhaylyk, O. O., & Ryan, A. J. (2023). Shampoo science: A review of the physiochemical processes behind the function of a shampoo. *Macromolecular Chemistry and Physics*, 224(3), 2200420.
- [2] Lu, M., Zhang, G., & Holmberg, K. (2024). Toxicity and environmental aspects of surfactants. *Tenside Surfactants Detergents*, 61(6), 505-518.
- [3] Lechuga, M., García, P. A., García-López, A. I., Tapia-Navarro, C., & Ríos, F. (2025). Development of a Predictive Classification Model for Surfactant-Induced Skin Irritation. *ACS omega*, 10(46), 55868.
- [4] Coderch Negra, M. L., Alonso, C., García Ramón, M. T., Pérez, L., & Martí, M. (2023). Hair Lipid Structure: Effect of Surfactants.
- [5] Dias, M. F. R. G., Loures, A. F., & Ekelem, C. (2021). Hair cosmetics for the hair loss patient. *Indian Journal of Plastic Surgery*, 54(04), 507-513.
- [6] Fernández-Peña, L., & Guzmán, E. (2020). Physicochemical aspects of the performance of hair-conditioning formulations. *Cosmetics*, 7(2), 26.
- [7] Mijaljica, D., Spada, F., & Harrison, I. P. (2022). Skin cleansing without or with compromise: soaps and syndets. *Molecules*, 27(6), 2010.

-
- [8] Moldes, A. B., Rodríguez-López, L., Rincón-Fontán, M., López-Prieto, A., Vecino, X., & Cruz, J. M. (2021). Synthetic and bio-derived surfactants versus microbial biosurfactants in the cosmetic industry: An overview. *International Journal of Molecular Sciences*, 22(5), 2371.
- [9] Romero Vega, G., & Gallo Stampino, P. (2025). Bio-based surfactants and biosurfactants: An overview and main characteristics. *Molecules*, 30(4), 863.
- [10] Sasounian, R., Martinez, R. M., Lopes, A. M., Giarolla, J., Rosado, C., Magalhães, W. V., ... & Baby, A. R. (2024). Innovative approaches to an eco-friendly cosmetic industry: a review of sustainable ingredients. *Clean Technologies*, 6(1), 176-198.
- [11] Gu, S., Xu, D., Zhou, F., Chen, C., Liu, C., Tian, M., & Jiang, A. (2021). The garbage enzyme with chinese hoenylocust fruits showed better properties and application than when using the garbage enzyme alone. *Foods*, 10(11), 2656.
- [12] Varshini, B., & Gayathrif, V. (2023). Role of eco-enzymes in sustainable development. *Nature Environment and Pollution Technology*, 22(3), 1299-1310.
- [13] Wasito, M., & Putri, R. E. (2023, August). Training on Making Eco Enzymes from Fruit Waste in Suka Damai Village, Kuala Sub-District, Langkat District. In *The International Conference on Education, Social Sciences and Technology (ICESST)* (Vol. 2, No. 2, pp. 232-241).
- [14] Warsito, K., Yamurni, L., Pradinata, R., Tamba, L. E. B., & Siregar, W. S. (2023). Budidaya Tanaman Tahunan dengan Ekoenzim. *Penerbit Tahta Media*.
- [15] Gumilar, G. G., Kadarohman, A., Fakhrurozi, M. F., Supriyanti, F. M. T., & Munawaroh, H. S. H. (2025). Characterization and Enzymatic Evaluation of Ecoenzyme Derived from Fruit and Vegetable Waste: An Effort to Achieve Zero Waste Concept. *Baghdad Science Journal*, 22(4), 1175-1184.
- [16] Mavani, H. A. K., Tew, I. M., Wong, L., Yew, H. Z., Mahyuddin, A., Ahmad Ghazali, R., & Pow, E. H. N. (2020). Antimicrobial efficacy of fruit peels eco-enzyme against *Enterococcus faecalis*: An in vitro study. *International Journal of Environmental Research and Public Health*, 17(14), 5107.
- [17] Lubis, N., Damayanti, R., & Wardani, S. (2025). Antimicrobial activity of eco-enzymes with various dilutions as a natural disinfectant. *Jurnal Penelitian Pendidikan IPA*, 11(5), 506-513.
- [18] Lubis, N., Damayanti, R., & Wardani, S. (2025). Chemical quality analysis and antibacterial properties of eco-enzyme derivative products as liquid organic fertilizers and natural disinfectants. *Jurnal Kimia Sains dan Aplikasi*, 28(10), 553-559.
- [19] Lubis, N., Tarigan, R. R. A., & Hayati, D. (2025). Uji Aktivitas Antifungal Ekoenzim terhadap Pertumbuhan *Candida albicans* pada Berbagai Konsentrasi secara In Vitro: In Vitro Assessment of Eco-enzyme Antifungal Effects on *Candida albicans* Growth Using Various Concentrations. *Biofarm: Jurnal Ilmiah Pertanian*, 21(1), 170-174.
- [20] Pérez-Rivero, C., & López-Gómez, J. P. (2023). Unlocking the potential of fermentation in cosmetics: a review. *Fermentation*, 9(5), 463.
- [21] Krzyżostan, M., Wawrzyńczak, A., & Nowak, I. (2024). Use of waste from the food industry and applications of the fermentation process to create sustainable cosmetic products: a review. *Sustainability*, 16(7), 2757.
- [22] Hakim, T., Sulardi, S., & Wasito, M. M. (2023). Analysis of the utilization of agricultural waste fermentation in increasing shallot production. *Jurnal Ilmiah Membangun Desa dan Pertanian*, 8(2), 61-67.
- [23] Luta, D. A., Siregar, M., Syam, F. H., Feruzi, Y., & Syafridawani, J. (2022). Efektivitas Pemberian Media Tanam dan Ekoenzim Pada Pertumbuhan Bawang Merah (*Allium ascalonicum* L.). In *Seminar Nasional UNIBA Surakarta* (pp. 275-277).
-

-
- [24] Ginting, R. B. (2023, November). Content of Crude Protein, Crude Fiber, and Crude Fat Kepok Banana Peel Fermented with SOC at Different Times. In *The International Conference on Education, Social Sciences and Technology (ICESST)* (Vol. 2, No. 2, pp. 257-265).
 - [25] Hmad, I. B., & Gargouri, A. (2024). Stable and effective eco-enzyme cocktails in powder and liquid form of *Stachybotrys microspora* used as detergent additives. *Heliyon*, 10(3).
 - [26] Uongpitakpan, P., & Kitsongsermthong, J. (2021). Investigation of sodium laurylglucosides hydroxypropyl sulfonate through response surface methodology—Effects of amphoteric surfactant and electrolyte. *Thai Journal of Pharmaceutical Sciences (TJPS)*, 45(2).
 - [27] Mayser, P., Genrich, F., Meunier, L., & Nordzieke, S. (2024). Scalp microbiome and dandruff—exploring novel biobased esters. *Cosmetics*, 11(5), 174.
 - [28] Cheng, Y., Cong, J., Xu, J., Tang, L., Zhou, Z., Yang, X., ... & Xiang, Q. (2025). Research progress on the exacerbation of lipid metabolism by *Malassezia* and its impact on the skin barrier function. *Cosmetics*, 12(2), 67.
 - [29] Sochacki, M., & Vogt, O. (2022). Triterpenoid saponins from washnut (*Sapindus mukorossi* Gaertn.)—A source of natural surfactants and other active components. *Plants*, 11(18), 2355.
 - [30] Rai, S., Acharya-Siwakoti, E., Kafle, A., Devkota, H. P., & Bhattarai, A. (2021). Plant-derived saponins: a review of their surfactant properties and applications. *Sci*, 3(4), 44.
 - [31] Lin, F. (2025). Adsorption and Dilational Viscoelasticity of Saponin at the β -Pinene/Water and Air/Water Interfaces. *Colloids and Interfaces*, 9(5), 68.
 - [32] Wisetkomolmat, J., Suksathan, R., Puangpradab, R., Kunasakdakul, K., Jantanasakulwong, K., Rachtanapun, P., & Sommano, S. R. (2020). Natural surfactant saponin from tissue of *Litsea glutinosa* and its alternative sustainable production. *Plants*, 9(11), 1521.
 - [33] Chae, C., Hong, J., Kim, H., Kim, D. H., Lee, S. O., & Kim, I. (2025). Extraction of saponins from soapnut and their application in controlling ammonia and particulate matter. *Rsc Advances*, 15(36), 29190-29200.
 - [34] Lunder, M., Tomšič, B., & Fink, R. (2023). Biobased Natural *Sapindus mukorossi*–Carvacrol Emulsion for Sustainable Laundry Washing. *Sustainability*, 15(14), 11029.
 - [35] Kumar, S. I., Kulkarni, R. M., & Ahalya, N. (2025). Congo red dye removal using green synthesized titanium oxide nanoparticles using saponin biosurfactant derived from *Sapindus mukorossi*. *International Journal of Sustainable Engineering*, 18(1), 2596410.
 - [36] Zhao, Z., Zhang, A., Song, L., He, C., & He, H. (2025). Evaluation of *Sapindus mukorossi* Gaertn flower water extract on in vitro anti-acne activity. *Current Issues in Molecular Biology*, 47(5), 316.
 - [37] Bezerra, K. G., Meira, H. M., Veras, B. O., Stamford, T. C., Fernandes, E. L., Converti, A., ... & Sarubbo, L. A. (2023). Application of plant surfactants as cleaning agents in shampoo formulations. *Processes*, 11(3), 879.
 - [38] Godeto, Y. G., Bachheti, R. K., Bachheti, A., Saini, S., Wabaidur, S. M., Mohammed, A. A., ... & Rai, N. (2023). Sustainable use of extracts of some plants growing in Ethiopia for the formulation of herbal shampoo and its antimicrobial evaluation. *Sustainability*, 15(4), 3189.
 - [39] Cao, X., He, S., Luo, X., Gao, J., Tang, Y., & Raston, C. L. (2024). Stability and cleansing function enhancement of organic shampoo by a vortex fluidic device. *ACS Sustainable Chemistry & Engineering*, 12(14), 5533-5543.
 - [40] Cavaletti, J. C. S., Prando, W. L. M., Ribeiro, E. B., & Valladão, D. D. S. (2023). Desenvolvimento e estabilidade de formulações de sabonete íntimo usando como tensoativo natural o extrato de *Sapindus saponaria* L. *Brazilian Journal of Biology*, 83, e276940.
 - [41] Hawa, L. C., Nada, U. Q., & Sumarlan, S. H. (2023). Karakteristik sifat fisikokimia sabun cuci cair menggunakan sari lerak sebagai surfaktan alami. *Agrointek: Jurnal Teknologi Industri Pertanian*, 17(1), 213-223.
-

- [42] Low, S. Y., Tan, J. Y., Ban, Z. H., & Siwayanan, P. (2021). Performance of green surfactants in the formulation of heavy-duty laundry liquid detergents (HDLD) with special emphasis on palm based alpha methyl ester sulfonates (α -MES). *Journal of Oleo Science*, 70(8), 1027-1037.
- [43] Tucker, I. M., Burley, A., Petkova, R. E., Hosking, S. L., Webster, J. R. P., Li, P. X., ... & Thomas, R. K. (2022). Self-assembly in escin-nonionic surfactant mixtures: From micelles to vesicles. *Journal of colloid and interface science*, 626, 305-313.
- [44] Thomas, R. K., & Penfold, J. (2025). Biosurfactant/surfactant mixing properties at the air–water interface: comparing rhamnolipids and sophorolipids mixed with the anionic surfactant sodium dodecyl benzene sulfonate. *Soft Matter*, 21(18), 3534-3546.
- [45] Wand, C. R., Panoukidou, M., Del Regno, A., Anderson, R. L., & Carbone, P. (2020). The relationship between wormlike micelle scission free energy and micellar composition: The case of sodium lauryl ether sulfate and cocamidopropyl betaine. *Langmuir*, 36(41), 12288-12298.
- [46] Ferraro, R., Salvatore, M. M., Esposito, R., Murgia, S., Caserta, S., D'Errico, G., & Guido, S. (2024). Impact of surfactant polydispersity on the phase and flow behavior in water: the case of Sodium Lauryl Ether Sulfate. *Journal of Molecular Liquids*, 405, 124990.
- [47] Flores, S. L., Mu, J., Cabry, C. P., Peterson, J., De Hert, S. C., Morrison, L., ... & Avendaño, C. (2023). Microstructural and thermodynamic characterization of wormlike micelles formed by polydisperse ionic surfactant solutions. *The Journal of chemical physics*, 159(5).
- [48] Lutz-Bueno, V., & Williams, A. P. (2025). Hydrogen bonding exacerbates viscoelasticity of amino acid–and betaine surfactant self-assemblies. *Journal of Colloid and Interface Science*, 139382.
- [49] Herrero, E., Calabuig, C., Ríos, F., & Lechuga, M. (2026). Synergistic Effects of Sodium Lauryl Sulfate and Lauryl Dimethylamine Oxide Blends on Foam Properties and Skin Irritation Reduction. *Cosmetics*, 13(1), 17.
- [50] Kadiri, A., Fergoug, T., Sebakhy, K. O., Bouhadda, Y., Aribi, R., Yssaad, F., ... & Van Steenberge, P. H. (2023). Insights into the characterization of the self-assembly of different types of amphiphilic molecules using dynamic light scattering. *ACS omega*, 8(50), 47714-47722.