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INNOVATIVE SOAP FORMULATION ENRICHED WITH GREEN AND RED SORREL (*RUMEX* SPP.) EXTRACTS: PHYSICOCHEMICAL PROPERTIES AND ANTIMICROBIAL POTENTIAL

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Abstract

The paper aimed to present the innovative formulation of a natural soap enriched with plant extracts from green sorrel (Rumex acetosa) and red sorrel (Rumex sanguineus). The extracts were obtained using ethanol, methanol, and water as solvents, targeting a broad spectrum of bioactive compounds with known antioxidant and antimicrobial properties. The soap formulation process involved the cold saponification method, followed by the incorporation of these extracts. The resulting soap samples were evaluated for key physicochemical parameters, including pH value, moisture content, total fat content, and free alkali levels (NaOH, KOH). Additional analyses included foaming capacity and antimicrobial activity testing. The antimicrobial effect was assessed against Staphylococcus aureus ATCC 43300, Escherichia coli ATCC 8739, Pseudomonas aeruginosa ATCC 1544, Salmonella enterica subsp. enterica serovar Typhimurium ATCC 14028, and Staphylococcus epidermidis ATCC 51625, using standard disc diffusion and broth dilution methods. The results revealed a skin-compatible pH, low residual alkali content, and promising antimicrobial efficiency, particularly against Gram-positive bacteria. These findings highlight the potential of Rumex-derived extracts as multifunctional ingredients in sustainable, bioactive soap formulations.

Key words*: antimicrobial activit, natural soap, physicochemical properties, plant extracts.*

INTRODUCTION

In recent years, the cosmetics industry has increasingly turned toward plant-derived extracts due to their rich bioactive profiles and beneficial effects on the skin. This shift is largely driven by the presence of phenolic compounds - potent antioxidants with anti-inflammatory and anti-aging properties. These molecules help neutralize oxidative damage caused by UV radiation and environmental stressors, thereby supporting skin vitality and resilience (Korpelainen & Pietiläinen, 2020; Vasas et al., 2015).

Scientific research has reinforced the role of natural ingredients in personal care products as both safe and effective. Extracts obtained from fruits, seeds, and medicinal plants are known for their high content of vitamins, essential fatty acids, and antioxidants, which contribute to skin hydration, regeneration, and protection (Mathew et al., 2025).

Among the genus *Rumex*, both green sorrel (*Rumex acetosa* L.) and red sorrel (*Rumex sanguineus* L.) exhibit a particularly promising phytochemical profile. Recent metabolomic analyses of *R. sanguineus* identified over 300 metabolites - predominantly polyphenols and anthraquinones - highlighting its potential for sophisticated cosmetic applications (Ramundi et al., 2025). Comparative research across *Rumex* species grown under similar conditions revealed high phenolic contents in *R. sanguineus*, while *R. acetosa* displayed notable levels of hydroxycinnamic acids and flavonoids - compounds closely linked to antioxidant and antimicrobial activities (Feduraev et al., 2022).

Based on existing evidence of the significant antioxidant and antimicrobial activity of *R. acetosa* and *R. sanguineus* extracts, this study investigates their incorporation into a natural soap matrix obtained through cold saponification. This method, executed at low

temperatures, preserves thermolabile phytochemicals and maintains functional activity (Vasas et al., 2015; Mathew et al., 2025). As a result, the soap is expected to offer emollient, antioxidant, and antimicrobial benefits.

Integrating extracts of green and red sorrel into a cold-processed soap reflects a strategic move toward sustainable and skin-compatible formulations. The unique combination of bioactive compounds like flavonoids, anthraquinones, tannins, and phenolic acids - supports a gentle yet effective ingredient profile that aligns with consumer demand for safe, natural personal care products (Vasas et al., 2015; Ramundi et al., 2025).

The principal goal of this research is to formulate and optimize an artisanal solid soap that combines cleansing efficacy with the functional benefits of *R. acetosa* and *R. sanguineus* extracts. Emphasis is placed on developing a cosmetic product that aligns with contemporary consumer expectations for natural, safe, and multifunctional skin care, while also ensuring sustainability through the use of plant-derived raw materials, an energy-efficient cold saponification process, and the absence of synthetic additives that may impact human health or the environment. The sustainability of the proposed soap formulation derives from several factors: (i) the use of renewable, plant-based extracts as active ingredients, (ii) the cold saponification process, which minimizes energy consumption compared to conventional hot methods, and (iii) the biodegradability of both the soap base and the incorporated phytoconstituents, which reduces environmental impact after use.

MATERIALS AND METHODS

1. Formulation and Processing Stages of Sorrel-Enriched Soaps

The formulation of the soap was developed through iterative trials based on practical observations and comparative online sources, ultimately resulting in an optimized and original composition (Table 1).

The cold saponification method was selected for its ability to preserve the functional integrity of the plant-based ingredients.

The preparation of the soap followed the cold saponification technique, chosen for its ability to preserve the bioactivity of thermolabile plant compounds. The process was carried out in several carefully controlled stages to ensure both safety and consistency in product quality.

Table 1. Ingredients and quantities used for soap base preparation

Ingredient	*Quantity*	*Unit*
Sodium hydroxide (NaOH)	192	g
Distilled water	350	ml
Fresh animal fat (pork)	420	g
Cold-pressed extra virgin olive oil	980	ml
Sorrel extract (green/red)	1	g

Initially, the sodium hydroxide (NaOH) solution was prepared by slowly dissolving a precise quantity of NaOH (192 g) in distilled water. As the dissolution is highly exothermic, the resulting solution was allowed to cool naturally until it reached approximately 40°C. This temperature was considered optimal to prevent degradation of both the oils and the added botanical extracts during subsequent stages.

In the same time, the lipid phase was prepared by gently melting fresh pork fat at low temperature (35°C) until it was fully liquefied. This rendered fat was then combined with cold-pressed extra virgin olive oil. The blend was left to cool until it reached the same temperature as the sodium hydroxide solution (~40°C), in order to facilitate homogeneous saponification and minimize thermal shock.

Once both aqueous and lipid phases were temperature-balanced, the sodium hydroxide solution was gradually poured into the oil mixture. The blend was mixed continuously using a hand-held immersion blender operating at low speed. The mixing continued until the soap mixture reached the so-called "trace" stage - an emulsified state in which the composition thickens, indicating that the saponification process has effectively begun.

To enhance the final product with bioactive properties, sorrel (*Rumex* spp.) extracts were incorporated into the soap base. Specifically, 1 g of extract was added to 98 mL of the cooled soap base. Extracts were obtained using different solvents (water, ethanol, or methanol) from both fresh and dried leaves *of Rumex acetosa* L. (green sorrel) and *Rumex sanguineus* L. (red sorrel), allowing for a broad

range of phytochemical profiles. Each soap variant was created by integrating a specific type of extract into the base formulation.

After thorough mixing, the resulting soap mixtures were poured into silicone molds and placed in a stable environment at a constant temperature of approximately 19°C. The curing process was allowed to proceed undisturbed for 4 to 5 weeks, permitting full saponification and gradual moisture loss. This slow maturation step was essential to obtain firm, stable soap bars while preserving the antioxidant and antimicrobial properties imparted by the sorrel extracts.

2. Physicochemical and Antimicrobial Characterization of the Soap

2.1. *pH Value Determination*

Following the curing period, the pH level of the soap samples was measured to assess product safety and skin compatibility. Maintaining an appropriate pH is essential, as values below 8 may suggest incomplete saponification, potentially affecting both product stability and shelf life. Conversely, pH values exceeding 11 can indicate the presence of residual free alkali, which may lead to skin irritation or excessive dryness upon use. Therefore, accurate pH monitoring is a critical control step in the evaluation of soap quality. In this study, pH values were determined using a calibrated GroLine digital pH meter, and all measurements were conducted in the Fermentative Biotechnology Laboratory of the Faculty of Biotechnologies.

2.2. *Moisture Content Analysis*

The moisture content of the soap samples was determined in accordance with the protocol adapted from Mwanza and Zombe (2020), with slight procedural adjustments to suit local equipment conditions. Approximately 2 grams of each soap sample were weighed and placed in a PRECISA XM 60 thermobalance (located in the Fermentative Biotechnology Laboratory, Faculty of Biotechnologies). The samples were dried at a constant temperature of 105 °C until a stable final weight was recorded. The percentage of moisture was calculated based on the weight loss during drying, reflecting the water content retained in the soap matrix post-curing.

2.3. *Total Fatty Mater Content Determination*

The quantification of total fat content was performed using a modified version of the protocol developed by Popescu et al. (2011). This method involves the extraction of residual lipid fractions present in the final soap product, which were not fully saponified. The procedure provides insight into the efficiency of the saponification process and the potential emollient properties retained in the formulation. Lipid extraction was carried out using an organic solvent system, followed by gravimetric analysis to determine the total fat percentage.

2.4. *Free Alkali Content (NaOH, KOH)*

The determination of free alkali residues, specifically sodium hydroxide (NaOH) and potassium hydroxide (KOH), was carried out to evaluate the chemical safety of the soap samples. The analysis followed the methodology proposed by Mahesar et al. (2019), adapted to suit the experimental conditions. This analysis is crucial in order to confirm that all added alkalis were adequately consumed during the saponification process. Residual alkali levels were quantified through acid-base titration techniques, ensuring that the final products fall within safe pH and irritancy thresholds suitable for cosmetic use.

2.5. *Foaming Capacity Evaluation*

Foaming capacity was assessed in order to determine the soap's cleansing efficiency and consumer acceptability. The procedure applied was based on the method described by Mahesar et al. (2019), with minor adaptations. For the preparation of the test solution, 1 g of the soap sample was accurately weighed and introduced into a 100 mL graduated cylinder, to which distilled water was added up to the 10 mL mark. The mixture was agitated under standardized conditions, and the height of the resulting foam layer was measured immediately after agitation as well as after a defined resting period. This procedure enabled the evaluation of both foamability and foam stability, thereby providing relevant information on the surfactant performance of each experimental variant.

2.6. *Antimicrobial Activity*

To assess the antimicrobial activity of the soap formulated with plant extracts, the solid medium diffusion method was employed using the well diffusion technique, following a protocol adapted from Fatchiyah et al. (2023). The tested cosmetic product (soap) was dissolved in sterile water at a ratio of 5 g per 10 mL, resulting in a homogeneous solution with a concentration of 0.5 g/mL. Prior to testing, the solution was sterilized through a 0.22 µm membrane filter to prevent contamination. The bacterial strains selected for the assay, chosen based on their clinical relevance, included *Staphylococcus aureus* ATCC 43300, *Escherichia coli* ATCC 8739, *Pseudomonas aeruginosa* ATCC 1544, *Salmonella enterica subsp. enterica serovar* Typhimurium ATCC 14028, and *Staphylococcus epidermidis* ATCC 51625, obtained from international collections and cultivated in the Microbiology Laboratory of the Faculty of Biotechnology. Standardized bacterial inocula (~1.5 × 10^8 CFU/mL) were prepared for each strain. Using the diffusion method, 100 µL of the soap solution was introduced into each well on agar plates inoculated with the respective bacteria. Plates were then incubated at 37°C for 24 hours. After incubation, the inhibition zones formed around the wells were measured in millimetres using a digital caliper. All tests were performed in triplicate, and the average inhibition zone diameters were used to interpret the antimicrobial efficacy.

The antimicrobial activity was assessed using a symbolic rating scale of "+" or "–," based on the diameter of the inhibition zone (Table 2).

Table 2. Antimicrobial activity intensity scale (− / +)

Symbol	*Interpretation*
-	Diameter < 5 mm/No activity
+	Diameter = 6-10 mm/Weak activity
++	Diameter = 11-20 mm/Moderate activity
+++	Diameter = 21-30 mm/Good activity
++++	Diameter = 31-40 mm/Strong activity

The following table presents the different experimental formulations of soap tested in this study, each incorporating various types of sorrel extracts prepared with different solvents (Table 3).

Tabel 3. Experimental soap variants

Sample Code	Experimental Variant Description
M - Control	Soap base without plant extract
FPRAAP	Base soap + fresh green sorrel extract (aqueous)
FPRAET	Base soap + fresh green sorrel extract (ethanolic)
FPRAMEOH	Base soap + fresh green sorrel extract (methanolic)
FURAAP	Base soap + dried green sorrel extract (aqueous)
FURAET	Base soap + dried green sorrel extract (ethanolic)
FURAMEOH	Base soap + dried green sorrel extract (methanolic)
FPRSAP	Base soap + fresh red sorrel extract (aqueous)
FPRSET	Base soap + fresh red sorrel extract (ethanolic)
FPRSMEOH	Base soap + fresh red sorrel extract (methanolic)
FURSAP	Base soap + dried red sorrel extract (aqueous)
FURSET	Base soap + dried red sorrel extract (ethanolic)
FURSMEOH	Base soap + dried red sorrel extract (methanolic)

RESULTS AND DISCUSSIONS

The production of soap using the cold saponification method allowed for the preservation of a substantial proportion of unsaponified fatty acids and natural phenolic compounds, which are known contributors to the antioxidant potential of the final product. These findings are consistent with those reported by Prieto Vidal et al. (2018), who noted that 60-100% of the unsaturated fatty acids present in vegetable oils are retained during cold saponification. Additionally, phenolic compounds from plant extracts remain bioactive in the final product (Prieto Vidal et al., 2018).

Maintaining a controlled temperature of approximately 40 °C and avoiding excessive heating during the process were key to protecting the structural integrity of both polyphenols and unsaponified lipids. This aligns with previous observations showing that cold saponification is more effective than hot processing in preserving thermosensitive ingredients, which are otherwise prone to oxidation and degradation. Following the pouring into silicone molds, the soap samples underwent a curing period of 4-5 weeks at ambient room temperature (around 19 °C), resulting in increased hardness and a stable pH value ranging between 8 and 10, which is suitable for topical application.

The incorporation of extracts from *Rumex acetosa* (green sorrel) and *Rumex sanguineus* (red sorrel) into the cold-processed soap matrix was successful, enhancing the functional profile of the product. These additions are supported by literature highlighting the dual

antioxidant and antimicrobial activities of polyphenol-rich plant extracts. For instance, Zillich et al. (2015) emphasized the capacity of polyphenols to act against both Gram-positive and Gram-negative bacteria. Therefore, including sorrel extracts in the soap base supports the hypothesis that such formulations may help protect the skin through a synergistic effect of antioxidant and antimicrobial mechanisms (de Lima Cherubim et al., 2020).

The experimental results demonstrated that the extracts played a significant role by effectively inhibiting bacterial growth - evidenced through clear inhibition zones in well diffusion assays - and by enhancing antioxidant activity, indicating a potential protective effect against free radicals and oxidative stress on the skin.

To ensure the safety and functionality of the soap formulations, it was essential to assess key physicochemical parameters, such as pH, moisture content, total fat percentage, residual alkalinity, and foaming capacity. These factors reflect both the extent of the saponification reaction and the technological efficiency of the production process, while also influencing the product's interaction with human skin.

Recent studies (Antonić et al., 2020; Zayed et al., 2024; Nova et al., 2025) emphasize the importance of reusing natural resources and vegetable oils in combination with polyphenol-rich extracts to produce eco-friendly cosmetic products with enhanced performance. In this context, the integration of *Rumex acetosa* and *Rumex sanguineus* extracts aimed to leverage their known antioxidant and antimicrobial potential, contributing to a formulation with both sustainability and efficacy.

1. Formulation and Processing Stages of Sorrel-Enriched Soaps

The soaps obtained through cold saponification exhibited a uniform and smooth texture, free of granules, cracks, or surface roughness - characteristics that are essential for ensuring a pleasant tactile experience during use. The incorporation of *Rumex* extracts, regardless of the extraction solvent used (distilled water, ethanol, or methanol) and the plant material's form (fresh or dried leaves), did not negatively impact the texture. This highlights a good level of compatibility between the added bioactive components and the base formulation, as well as a controlled manufacturing process. A smooth consistency contributes to the ease of application and enhances the perception of quality in cosmetic soap products (Figure 1).

Figure 1. Bar soaps after 5 weeks of maturation - Control and soaps enriched with *Rumex* extracts (from fresh/dried leaves; extracted in water, ethanol, and methanol)

From an olfactory perspective, the soaps maintained a pleasant and characteristic aroma throughout the storage period. The presence of *Rumex* extracts subtly enriched the fragrance profile without becoming overpowering or unpleasant. This aromatic stability suggests good preservation of volatile aromatic compounds and an absence of oxidative or degradative processes that could otherwise compromise the sensory appeal. Maintaining a consistent and agreeable scent is critical for consumer satisfaction and product marketability.

Regarding the physical appearance, the soap bars presented a visually appealing and homogeneous surface, devoid of visible defects such as cracks, blooming (efflorescence), spots, or irregularities. These features reflect not only the quality of the raw materials but also the efficiency of the formulation and curing processes. The uniform hardening and crystallization observed during the 4-5 weeks maturation period contributed to structural integrity. Additionally, the absence of efflorescence indicates chemical stability and surface protection, factors which directly influence product durability and shelf life, while enhancing its commercial value.

2. Physicochemical Characterization of the Soap

2.1. *pH Value Determination*

pH is a key parameter in assessing the quality of solid soaps, as it directly affects both skin compatibility and the chemical stability of the final product. Optimal pH values for commercial solid soaps typically range between 9.0 and 11.0 (Antonić et al., 2020), with a recent trend toward slightly lower values (9.0-10.0), as suggested by Nova et al. (2025), aiming to minimize skin irritation risks. In the case of artisanal (homemade) soaps, pH values are generally within the same range (Tarun et al., 2014).

The pH of soaps enriched with *Rumex* extracts was measured to assess the influence of the plant-based ingredients on this critical parameter and to verify whether the values fall within the recommended range (Tabel 4).

Table 4. pH values of solid soaps enriched with *Rumex* extracts (fresh/dried leaves; water, ethanol, methanol)

Experimental variants	*pH value*
CONTROL	10.49
FPRAAP	10.02
FPRAET	10.13
FPRAMEOH	10.4
FURAAP	10.54
FURAET	10.26
FURAMEOH	10.26
FPRSAP	10.21
FPRSET	10.36
FPRSMEOH	10.14
FURSAP	10.47
FURSET	10.47
FURSMEOH	10.46

The pH values measured for the analyzed soap samples ranged from 10.02 to 10.54, indicating a moderately alkaline character typical of cold-processed solid soaps. The control sample (pH 10.49) exhibited one of the highest values within this range, suggesting complete saponification and minimal residual alkalinity - parameters that are desirable for personal care products.

Soaps formulated with *Rumex* extracts showed slightly lower pH values compared to the control (e.g., FPRAAP - 10.02, FPRAET - 10.13, FPRSAP - 10.21). This moderate decrease may be attributed to the buffering effects of phenolic compounds and organic acids present in the plant extracts. Despite the slight variations, the pH levels remain within the acceptable range for solid soap, ensuring effective cleansing properties while potentially reducing the risk of skin irritation that might occur with excessively high alkalinity.

The highest pH values were recorded in the FURAAP (10.54) and FURSAP/FURSET samples (10.47), indicating efficient saponify-cation of the oils used and a corresponding level of residual alkalinity. These variations can be explained by differences in extract compo-sition - specifically, the use of fresh vs. dried leaves and solvent type (water, ethanol, or methanol) - as well as potential partial neutrali-zation reactions between free alkalis and the bioactive compounds present in the extracts.

Overall, a pH range between 8.0 and 11.0 is considered appropriate for solid soaps, offering a balance between cleansing efficiency, foaming ability, and microbiological stability (Tarun et al., 2014; Oyekunle et al., 2021). The pH values obtained in this study fall within these limits, confirming both the technological quality of the formulations and their suitability for external use.

2.2. *Moisture Content Analysis*

Moisture content is a critical quality parameter in the assessment of solid soaps, as it directly influences their physicochemical stability, resistance to microbial degradation, and shelf life. According to Nova et al. (2025), the moisture level in commercial solid soaps should not exceed approximately 15%, to prevent premature degradation and ensure a satisfactory duration of use. Excessive moisture can lead to softening of the soap during application, compromising its structural integrity, and may promote microbial growth over time.

Maintaining moisture within the recommended range is therefore essential for producing a final product with optimal functional and sensory characteristics, while also complying with quality and safety standards. In this context, the moisture content was determined for both the control soap and the formulations enriched with *Rumex* extracts, in order to evaluate the influence of these botanical additions on

product stability and to verify compliance with accepted industry thresholds (Figure 2).

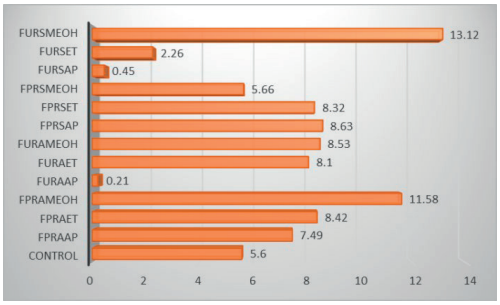

Figure 2. Moisture content of control and *Rumex*-enriched soap formulations (%)

The moisture content of the soap samples analyzed in this study ranged from 0.21% to 13.12%, demonstrating considerable variability dependent on formulation parameters. The control soap exhibited a relatively elevated moisture level (5.6%), indicative of substantial residual water - an expected characteristic of cold-processed soaps subjected to limited curing periods.

Samples enriched with *Rumex* extracts showed significant fluctuations in moisture content, strongly suggesting that the type of plant extract, solvent used (water, ethanol, methanol), and the physical form of the botanical material (fresh vs. dried leaves) directly influenced the soap matrix's water retention capacity. Notably, formulations such as FPRAMEOH (11.58%) and FURSMEOH (13.12%) displayed the highest moisture values, which may be attributed to the hygroscopic nature of organic compounds present in methanolic extracts, facilitating increased water retention within the soap structure.

Conversely, the lowest moisture levels were recorded for FURAAP (0.21%) and FURSAP (0.45%), indicating an extremely low water content. Such minimal hydration could adversely affect the physicomechanical properties of the soap, potentially leading to increased brittleness, reduced plasticity, and compromised storage stability. These findings may be associated with more efficient water evaporation during curing, or the presence of more hydrophobic constituents in aqueous extracts derived from dried leaves.

The majority of the remaining samples, including FPRAAP, FPRAET, FURAET, FURAMEOH, FPRSAP, and FPRSET, exhibited intermediate moisture values ranging from 7.5% to 8.6%. These results suggest a favorable balance between water retention, saponification degree, and integration of plant-based additives. According to Antonić et al. (2020) and Nova et al. (2025), artisanal soaps with moisture content below 15% are considered technologically stable and functionally efficient, offering enhanced hardness, suitable foaming behavior, and improved microbiological resistance during storage (Antonić et al., 2020; Nova et al., 2025).

2.3. *Total Fatty Mater Content Determination*

The total fatty matter (TFM) content represents a fundamental metric in the qualitative assessment and characterization of solid soaps, as it reflects the proportion of saponified fatty acid salts within the formulation. TFM serves as a direct indicator of both the purity level and the efficiency of the saponification process, exerting a significant influence on the functional and sensorial attributes of the final product. Elevated TFM levels are typically associated with enhanced foaming capacity, improved emollient properties, and a more favorable interaction with the skin's lipid barrier - ultimately contributing to gentler cleansing and superior skin hydration.

According to established literature, conventional commercial soaps generally exhibit TFM values ranging between 63% and 76% (Betsy et al., 2013), a range indicative of moderate to lower quality formulations. Products within this interval often contain a higher proportion of non-fatty additives - such as fillers, binders, or synthetic agents - which can negatively impact the overall performance, consistency, and dermatological tolerability of the soap. In contrast, high-end commercial soaps are characterized by TFM values exceeding 77%, a benchmark correlated with rich lather formation, smoother texture, and enhanced cutaneous compatibility.

Recent investigations by Nova et al. (2025) suggest a broader TFM range - spanning 64% to 92% - in current market offerings, reflecting a diversification of formulations driven by the incorporation of alternative raw materials and

the growing consumer demand for cleaner-label, naturally-derived products. This shift underscores a trend toward reduced synthetic processing and increased reliance on plant-based or less refined ingredients.

In contrast to industrial formulations, handcrafted (homemade) soaps consistently exhibit TFM values exceeding 90% (Zayed et al., 2024). This elevated content is largely attributed to the use of high-quality unrefined vegetable oils and natural fats, often combined with phytochemical-rich botanical extracts that provide additional dermatological benefits. The resulting products typically display superior moisturizing and softening effects, aligning with the expectations of consumers who prioritize sustainability, transparency in ingredient sourcing, and minimal skin barrier disruption (Table 5).

Table 5. TFM values of solid soaps enriched with *Rumex* extracts (fresh/dried leaves; water, ethanol, methanol)

Experimental variants	*Value (%)*
CONTROL	79
FPRAAP	81
FPRAET	81
FPRAMEOH	92
FURAAP	80
FURAET	79
FURAMEOH	88
FPRSAP	84
FPRSET	88
FPRSMEOH	90
FURSAP	77
FURSET	80
FURSMEOH	81

The total fatty matter (TFM) content determined in the analyzed soap samples exhibited moderate variation, ranging between 77% and 92%. The control soap recorded a TFM value of 79%, which is characteristic of soaps produced by the cold-process method. This range reflects the presence of partially unsaponified base oils that impart beneficial emollient and moisturizing properties to the final product.

Soap samples enriched with *Rumex* extracts generally showed slightly higher TFM values compared to the control, indicating that the addition of these extracts did not significantly interfere with the saponification reaction. For instance, the FPRAAP and FPRAET formulations both registered identical TFM values of 81%, while FURAAP and FURSET hovered around 80%. These results confirm efficient conversion of the initial fats and a consistent technological process throughout the production stages.

The highest TFM levels were found in the FPRAMEOH (92%) and FPRSMEOH (90%) formulations, which may suggest either a deliberately calculated surplus of residual oils to enhance emollient effects or a slightly diminished saponification efficiency, potentially due to interactions between methanolic extracts and the alkaline base. Soaps with TFM values above 90% are typically ideal for skin care applications due to their rich moisturizing qualities; however, they tend to be less effective as intense cleansing agents, being perceived more as emollient, cosmetically oriented products rather than traditional detergents.

Similarly, the FURAMEOH and FPRSET samples exhibited TFM levels of approximately 88%, maintaining a favorable balance between unsaponified compounds and the solid soap matrix.

Conversely, FURSAP demonstrated the lowest total fatty matter content at 77%, indicative of nearly complete saponification. This level often correlates with a firmer soap texture and a less pronounced moisturizing effect on the skin. A TFM content of 77% is considered a balanced value, representing an efficient cleansing agent that also preserves a degree of mildness suitable for skin care. Such a soap is typically durable, stable, and recommended for regular use, although it may require supplementary skin hydration (via creams or lotions) post-application, especially for sensitive skin types.

Overall, TFM values ranging between 77% and 88% are widely regarded as appropriate for artisanal soap formulations, ensuring both structural stability and emollient benefits alongside a gentle, moisturizing effect (Popescu et al., 2011; Zhang et al., 2020).

2.4. *Free Alkali Content (NaOH, KOH)*

The content of free alkalis is a critical parameter for assessing soap quality, as it directly influences both the safety and skin

compatibility of the final product. Excessive alkalinity can provoke skin irritation and dryness; therefore, maintaining free alkali levels below a defined threshold is paramount for ensuring user comfort as well as the chemical stability of the soap.

In commercial solid soaps, the optimal range for free alkali content is generally kept under 2%, with reported values typically between 0.12% and 0.99% (Onyango et al., 2014). This range balances the soap's cleansing efficacy with protection against the detrimental effects associated with high alkalinity.

Similarly, artisanal (homemade) soaps exhibit free alkali concentrations within a comparable window, ranging from 0.78% to 1.14% (Adane, 2020). These figures reflect effective control over the saponification process and formulations tailored for safe, direct skin application with minimal disruption to the skin's natural barrier integrity.

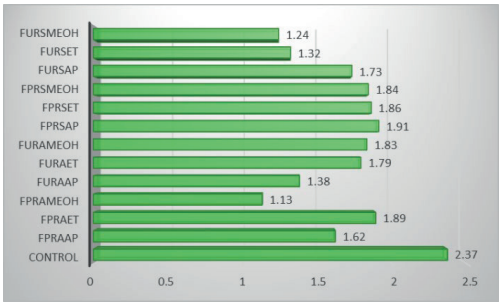

Figure 3. Free alkali content of control and *Rumex*-enriched soap formulations (%)

The measured alkalinity values for the analyzed soap samples (Figure 3) range from 1.13% to 2.37%, reflecting the residual amount of alkaline substances - primarily unreacted sodium hydroxide - remaining after the saponification process. Elevated alkalinity levels can compromise the gentleness of the soap during use, potentially causing skin irritation; hence, moderate alkalinity is generally preferred to ensure product safety and user comfort (Betsy et al., 2021).

The control sample exhibits the highest alkalinity at 2.37%, suggesting an excess of residual base. This could indicate either an incomplete or imbalanced saponification reaction or a deliberate formulation choice incorporating a slight surplus of caustic soda to achieve a firmer soap texture.

Samples enriched with extracts from *Rumex acetosa* and *Rumex sanguineus* generally show lower alkalinity compared to the control. For instance, FPRAAP (1.62%) and FURAAP (1.38%) suggest that the incorporation of plant extracts may promote more efficient consumption of the alkali, potentially due to interactions between acidic phytochemicals and the excess sodium hydroxide.

The lowest alkalinity levels were recorded in FPRAMEOH (1.13%) and FURSMEOH (1.24%), indicating effective neutralization of residual base, a favorable attribute enhancing product safety and skin mildness. This trend may also reflect the influence of methanolic extracts, which likely introduce mildly acidic or buffering compounds that reduce excessive alkalinity.

Values within the range of 1.3% to 1.9%, such as those for FPRSAP (1.91%), FPRSET (1.86%), and FURAMEOH (1.83%), are generally considered optimal for artisanal soaps, striking a balance between cleansing efficacy and skin tolerance.

2.5. *Foaming Capacity Evaluation*

The foam-generating capacity of solid soaps pertains to their ability to produce foam - defined as the volume of air entrapped within the liquid phase - when interacting with water and subjected to mechanical agitation. This foaming capacity serves as both a quantitative and qualitative metric for assessing soap performance during use, significantly influencing consumer perception by enhancing the sensory experience, as well as indirectly correlating with cleansing efficiency. Although foam itself does not possess intrinsic cleaning properties, it is psychologically associated with product effectiveness. The foam capacity of solid soaps can exhibit considerable variability depending on the formulation components and manufacturing techniques employed. For artisanal (homemade) soaps, the foaming capacity documented in the scientific literature ranges widely, from approximately 6.83 to 15.16 cm, reflecting the heterogeneity of raw materials and their respective physicochemical characteristics (Oyekunle et al., 2021).

In the present study, the foaming capacity of the control soap and those enriched with *Rumex* extracts was systematically evaluated to elucidate the influence of botanical additives on both foam formation and stability. The data presented in Figure 4 illustrate the differential impacts of various formulations on the foaming performance, underscoring the importance of this parameter not only from a technical standpoint but also in terms of consumer acceptance and satisfaction with the final product.

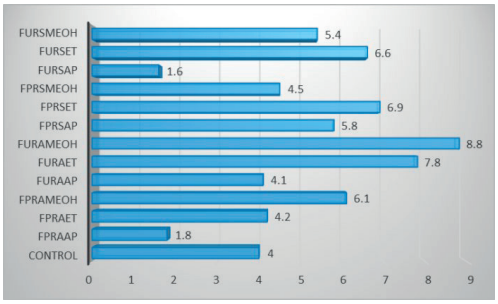

Figure 4. Foaming capacity (foam height in cm) of control and *Rumex*-enriched soap formulations

The foam generation capacity exhibited notable variability among the different soap formulations evaluated. The control sample demonstrated a foam height of 4 cm, representing a moderate foaming ability that serves as a baseline reference for comparative analysis. In contrast, formulations incorporating extracts from fresh leaves of *Rumex acetosa* and *Rumex sanguineus* processed with organic solvents (e.g., FPRAMEOH - 6.1 cm, FURAET - 7.8 cm, FURAMEOH - 8.8 cm) showed significantly enhanced foaming capacities. This increase suggests that the inclusion of organic solvent-derived extracts potentially augments the soap's surface-active properties, likely attributable to the enriched presence of natural surfactant compounds such as saponins and flavonoids, which are more efficiently extracted via organic methods.

Conversely, formulations containing aqueous extracts (e.g., FPRAAP - 1.8 cm, FURAAP - 4.1 cm) or simple aqueous-based soaps (e.g., FURSAP - 1.6 cm) exhibited lower foam heights compared to the control. This reduction in foaming ability may be indicative of dilution effects on the fatty base or possible interference from water-soluble constituents that disrupt the foam matrix. Intermediate foam capacities were observed in samples such as FPRSAP (5.8 cm), FPRSET (6.9 cm), FURSET (6.6 cm), and FURSMEOH (5.4 cm), underscoring that both the botanical species and the solvent type exert a direct influence on the surfactant efficacy and overall foaming behavior of the soap formulations.

Foaming capacity thus plays a pivotal role not only in shaping the sensory and aesthetic experience for the end user but also in contributing to the perceived effectiveness of the cleansing action.

2.6. *Antimicrobial Activity*

The antimicrobial efficacy of soap formulations enriched with extracts from *Rumex acetosa* (common sorrel) and *Rumex sanguineus* (red sorrel) was comprehensively assessed against a diverse panel of pathogenic bacteria. The evaluation was performed by measuring the diameters of inhibition zones, which were subsequently categorized using a semi-quantitative rating scale to enable standardized comparative analysis across samples. The results indicated that the antimicrobial efficacy of the soaps was strongly influenced by multiple factors, including the plant species, the extraction solvent employed, and the physical state of the plant material, particularly distinguishing between fresh and dried leaves.

In the case of *Staphylococcus aureus*, the soaps containing *Rumex* extracts manifested pronounced bacteriostatic properties, significantly outperforming the control soap, which exhibited only a minimal inhibition zone of 11 ± 1 mm. This baseline activity in the control is likely attributed to inherent physicochemical features rather than true antimicrobial effects. Among the formulations tested, methanolic extracts derived from fresh *R. acetosa* leaves demonstrated the most potent inhibitory effect, producing zones of 32 ± 3 mm, substantially exceeding those obtained with ethanolic extracts (22 ± 1 mm) and aqueous extracts (19 ± 1 mm). Furthermore, extracts from fresh leaves consistently surpassed their dried counterparts, a discrepancy presumably arising from thermal

degradation or volatilization of sensitive phenolic constituents during the drying process. When challenged with *Escherichia coli*, the soaps generally displayed moderate to weak antimicrobial efficacy, a phenomenon consistent with the intrinsic defense mechanisms of Gram-negative bacteria, notably their robust lipopolysaccharide-rich outer membranes. The control formulation produced an inhibition zone of 6.25 ± 1.25 mm. Notably, most extract-enriched soaps exceeded this threshold, with ethanolic and methanolic extracts from *R. sanguineus* fresh and dried leaves eliciting the most substantial zones of inhibition, measuring 12.5 ± 2.5 mm (FPRAET), 12.75 ± 2.75 mm (FURSMEOH), and 9.25 ± 0.25 mm (FPRAMEOH). The heightened antimicrobial action of *R. sanguineus* may be correlated with its elevated anthocyanin and polyphenol content, aligning well with existing literature which reports moderate antimicrobial activity for natural extracts against *E. coli* within the 10 to 15 mm inhibition range.

Antimicrobial activity against *Pseudomonas aeruginosa* demonstrated marked variability dependent on species and extraction solvent. The control soap yielded a baseline inhibition zone of 8.5 ± 0.5 mm. Extracts from *R. acetosa* exhibited moderate antibacterial activity, with inhibition diameters ranging from 10 ± 0 mm to 13 ± 1 mm depending on the solvent and leaf status: methanolic extracts from fresh (FPRAMEOH: 12 ± 1 mm) and dried leaves (FURAMEOH: 13 ± 1 mm), and ethanolic extracts (FPRAET: 11.5 ± 0.5 mm; FURAET: 12.5 ± 1.5 mm) all showed comparable efficacy. Contrastingly, *R. sanguineus* extracts, especially the methanolic extract from fresh leaves (FPRSMEOH), exhibited robust antibacterial effects, producing a notably large inhibition zone of 28 ± 1 mm. Ethanolic (FPRSET: 23.5 ± 1.5 mm) and methanolic extracts from dried leaves (FURSMEOH: 21.5 ± 0.5 mm) also demonstrated significant activity. These observations underscore the critical role of organic solvents in efficiently extracting bioactive phenolic compounds that can overcome the intrinsic resistance mechanisms of *P. aeruginosa*.

In the context of *Salmonella enterica* subsp. *enterica* serovar *Typhimurium*, antimicrobial efficacy was distinctly species- and solvent-dependent. The negative control displayed no inhibition (0 ± 0 mm), confirming that observed effects are solely attributable to plant-derived bioactive constituents. Fresh *R. acetosa* leaf extracts demonstrated modest inhibition, with zones measuring 5.5 ± 0.5 mm (FPRAAp), 8.5 ± 0.5 mm (FPRAET), and 7.5 ± 0.5 mm (FPRAMEOH). However, dried leaf extracts from *R. acetosa* were completely inactive (0 ± 0 mm), likely due to degradation or insufficient concentration of active compounds post-drying. Conversely, extracts from *R. sanguineus* exhibited superior antimicrobial performance: fresh leaf aqueous extract (FPRSAp) produced a 9.5 ± 0.5 mm inhibition zone, while ethanolic (FPRSET: 11 ± 1 mm) and methanolic (FPRSMEOH: 14.5 ± 0.5 mm) extracts demonstrated enhanced potency. Dried leaf ethanolic and methanolic extracts (FURSET: 10 ± 0 mm; FURSMEOH: 10.5 ± 0.5 mm) retained moderate activity, suggesting a richer or more stable phytochemical composition in *R. sanguineus* that effectively targets this Gram-negative pathogen.

In the case of *Staphylococcus epidermidis*, methanolic extracts from fresh leaves exhibited the strongest antimicrobial effect. For *R. acetosa*, the methanolic extract (FPRAMEOH) generated a remarkable inhibition zone of 37 ± 2 mm, significantly larger than those produced by ethanolic (FPRAET: 25 ± 5 mm) and aqueous extracts (FPRAAp: 21.5 ± 3.5 mm). Extracts from dried leaves also showed relevant activity (FURAET: 29 ± 1 mm; FURAMEOH: 30 ± 1 mm), whereas aqueous extracts were less effective (FURAAp: 15.5 ± 0.5 mm). For *R. sanguineus*, methanolic extracts again dominated, with fresh leaf extracts (FPRSMEOH) yielding inhibition zones of 32 ± 0 mm, and dried leaf extracts (FURSMEOH) achieving 25.5 ± 1.5 mm. Interestingly, ethanolic extracts from fresh leaves (FPRSET: 11.5 ± 0.5 mm) were less active than those from dried leaves (FURSET: 23 ± 0 mm), indicating potential compositional shifts in phytochemical profiles upon drying.

Table 6. Evaluation of the antimicrobial effectiveness of soaps on an intensity scale (− / +)

Sample code/Bacterial strain	*Staphylococcus aureus ATCC 43300*	*Escherichia coli ATCC 8739*	*Pseudomonas aeruginosa ATCC 1544*	*Salmonella typhimurium ATCC 14028*	*Staphylococcus epidermis ATCC 51625*
Control	++	+	+	-	+
FPRAAp	+++	+	+	+	+++
FPRAET	+++	+	++	+	+++
FPRAM EOH	++++	+	++	+	++++
FURAAp	++	+	+	-	++
FURAET	+++	+	++	-	+++
FURAM EOH	+++	+	++	-	+++
FPRSAp	++	+	+	+	++
FPRSET	+++	++	+++	++	++
FPRSM EOH	+++	++	+++	++	++++
FURSAp	++	+	+	-	++
FURSET	+++	++	++	+	+++
FURSM EOH	+++	++	+++	+	+++

[-(diameter < 5 mm/no activity); + (diameter < 5 mm/no activity); ++ (diameter = 11–20 mm/moderate activity); +++ (diameter = 21–30 mm/good activity); ++++ (diameter = 31–40 mm /strong activity)]

Numerous studies highlight the antimicrobial activity of plant extracts against pathogenic bacteria such as *Staphylococcus aureus*. For example, garlic (*Allium sativum*) extract showed significant activity (inhibition zone of 28 mm), while onion (*Allium cepa*) extract had a weaker effect (14 mm) (Rapuntean, 2020). Other studies confirm the efficacy of plant-derived compounds in combating *Escherichia coli*, suggesting their potential to reduce bacterial resistance.

Centauria damascena has demonstrated notable antibacterial effects against multiple strains, including *E. coli ATCC 11293*, with methanolic extracts showing MIC values between 60-1100 µg/mL (Mosleh al Ja'afreh et al., 2019). Similarly, ethanol and methanol extracts from *Rumex cyprius* seeds inhibited *S. aureus* and *E. coli* growth, with inhibition zones ranging from 14 to 19 mm and MIC/MBC values of 62.5 mg/mL and 125 mg/mL, respectively (Pouremadi et al., 2017).

Research on plants from the *Polygonaceae* family has revealed the presence of bioactive compounds with strong antimicrobial potential, particularly against *Pseudomonas aeruginosa*, a common nosocomial pathogen. Extracts from *Polygonum aviculare* proved effective due to the presence of flavonoids and alkaloids (Salama et al., 2020). Moreover, *Rumex alveollatus* and related species have shown promising results in fighting multidrug-resistant strains of *P. aeruginosa* (Jahani et al., 2016).

Regarding *Salmonella typhimurium*, extracts from *Polygonum persicaria* demonstrated significant antibacterial activity, with inhibition zones up to 16 mm, attributed to flavonoids and saponins (Al-Joburi & Al-Mandeel, 2023). Similar results were reported in Brazil, where *Polygonum* extracts inhibited *Salmonella* growth at 50 mg/mL, with inhibition zones of approximately 14 mm (Bouzada et al., 2009).

For *Staphylococcus epidermidis*, a pathogen frequently associated with medical implants, Polygonaceae extracts have also shown relevant antimicrobial effects. In Burkina Faso, extracts from several medicinal species, including members of the Polygonaceae family, significantly inhibited *S. epidermidis*, with inhibition zones reaching 17 mm (Ouattara et al., 2022). Furthermore, other studies demonstrated anti-biofilm effects of Polygonaceae species against multidrug-resistant strains of *Staphylococcus* and *Pseudomonas*, due to the presence of active compounds such as flavonoids and alkaloids (Mehrishi et al., 2020).

CONCLUSIONS

The formulation of soaps enriched with extracts derived from *Rumex acetosa* (common sorrel) and *Rumex sanguineus* (red sorrel) entailed standardized extraction protocols employing distinct solvents - namely water, ethanol, and methanol - followed by their incorporation into a cold-process soap base. The choice of extraction solvent significantly influenced the yield and composition of bioactive phytochemicals, with alcoholic solvents (methanol and ethanol) exhibiting superior efficacy in isolating functional compounds compared to aqueous extracts, a trend that was reflected in the enhanced antimicrobial properties observed subsequently.

Empirical findings corroborate that the cold saponification process not only preserves the integrity of the bioactive constituents within the *Rumex* extracts but also confers considerable antioxidant and antimicrobial functionalities to the resultant soap matrices. This substantiates

the rationale for advancing natural, sustainable, and efficacious cosmetic formulations, providing a robust framework for further optimization of recipe parameters and functional enhancements.

pH measurements of the produced soaps indicate a moderately alkaline milieu, ranging between 10.02 and 10.54, consistent with typical cold-process solid soaps. The control soap manifested a marginally elevated pH, indicative of complete saponification, whereas the formulations containing *Rumex* extracts demonstrated slightly attenuated pH values. This buffering effect is attributable to the phenolic and organic acid constituents inherent in the extracts, which likely mitigate potential skin irritation by tempering the alkalinity.

Dry matter content varied distinctly in correlation with the extract type; methanolic extracts imparted a higher dry residue, contributing to augmented hardness and structural stability of the soaps. Conversely, aqueous extracts retained increased moisture levels, potentially compromising textural integrity and mechanical resilience of the product.

Total lipid content within the soap formulations ranged from 77% to 92%, reflecting an optimal balance between saponified triglycerides and residual unsaponified oils that impart emollient properties. Notably, certain methanolic extract-based formulations exhibited elevated lipid content, plausibly enhancing their moisturizing capacity and skin feel.

Alkalinity levels in *Rumex* extract-enriched soaps were consistently lower than in the control, signifying a more effective neutralization of alkaline agents. This phenomenon is posited to improve dermatological tolerance and minimize irritation risk, with methanolic extracts exerting a pronounced buffering role, likely due to the presence of acidic or zwitterionic phytochemicals.

Foaming capacity assessments revealed marked improvements in soaps containing alcoholic extracts, attributable to the efficient extraction of natural surfactant compounds by organic solvents. In contrast, aqueous extracts detrimentally impacted foaming ability, possibly by diluting the lipid matrix or disrupting foam microstructure.

Microbiological evaluations demonstrated a variable antimicrobial spectrum dependent on *Rumex* species, leaf condition (fresh versus dried), solvent polarity, and bacterial strain. Maximum inhibitory zones were recorded against Gram-positive bacteria such as *Staphylococcus aureus* and *Staphylococcus epidermidis*, notably with methanolic extracts from fresh *R. acetosa* leaves (FPRAMEOH, 32-37 mm) and dried *R. sanguineus* leaves (FURSMEOH, 25.5 mm). Conversely, Gram-negative bacteria including *Escherichia coli* and *Salmonella typhimurium* exhibited lower susceptibility, albeit with significant antimicrobial effects observed in alcoholic extract-based soaps, predominantly methanolic.

The diminished or absent antimicrobial activity in certain aqueous extracts and dried leaf preparations - particularly in *R. acetosa* - suggests that post-harvest processing and extraction methodology critically affect the preservation and availability of bioactive compounds. Consequently, methanolic extracts from fresh leaves emerge as the most promising candidates for the development of functional cosmetic products with targeted antimicrobial properties.

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