

Development of biodegradable solid cosmetics: A sustainable strategy for reducing water use and environmental impacts

Desenvolvimento de cosméticos sólidos biodegradáveis: Uma estratégia sustentável para redução do uso de água e impactos ambientais

Desarrollo de cosméticos sólidos biodegradables: Una estrategia sostenible para reducir el uso de agua y los impactos ambientales

Received: 04/16/2026 | Accepted: 04/21/2026 | Published: 04/22/2026

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Abstract

The increasing environmental impacts of the cosmetics industry has driven the search for sustainable alternatives. This study aimed to develop biodegradable solid shampoo and conditioner formulations, focusing on reducing water consumption and environmental impacts. The methodology involved the formulation of products using natural and biodegradable ingredients, replacing conventional synthetic surfactants with more environmentally friendly alternatives. The products were produced and evaluated through sensory analysis, considering attributes such as hydration, softness, texture, and durability. The results demonstrated high user acceptance, particularly regarding hydration and hair softness, with performance comparable to conventional products. Notably, solid cosmetics significantly reduce water use during both production and use phases, while also eliminating the need for plastic packaging. These findings highlight the potential of solid biodegradable cosmetics as an effective strategy for promoting sustainability and reducing water dependency in the personal care industry.

Keywords: Natural cosmetics; Sustainable consumption; Waste reduction; Eco-friendly products; Green innovation.

Resumo

A crescente preocupação com os impactos ambientais da indústria cosmética tem impulsionado o desenvolvimento de alternativas sustentáveis. Este estudo teve como objetivo desenvolver shampoo e condicionador sólidos

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biodegradáveis, enfatizando a redução do uso de água e a minimização de impactos ambientais. A metodologia baseou-se na formulação de produtos com ingredientes naturais e biodegradáveis, substituindo surfactantes agressivos por compostos mais sustentáveis. Os produtos foram elaborados e submetidos à avaliação sensorial com usuários, considerando aspectos como hidratação, maciez, textura e durabilidade. Os resultados indicaram alta aceitação dos produtos, principalmente quanto à hidratação e maciez dos fios, além de desempenho comparável aos cosméticos convencionais. Destaca-se que os cosméticos sólidos reduzem significativamente o consumo de água, tanto no processo produtivo quanto no uso final, além de eliminarem a necessidade de embalagens plásticas. Conclui-se que os cosméticos biodegradáveis em barra representam uma alternativa viável e sustentável, contribuindo para a redução do consumo hídrico e para a mitigação dos impactos ambientais associados ao setor de higiene pessoal.

Palavras-chave: Cosméticos naturais; Consumo sustentável; Redução de resíduos; Produtos ecológicos; Inovação verde.

Resumen

La creciente preocupación por los impactos ambientales de la industria cosmética ha impulsado el desarrollo de alternativas sostenibles. Este estudio tuvo como objetivo desarrollar champú y acondicionador sólidos biodegradables, con énfasis en la reducción del uso de agua y los impactos ambientales. La metodología consistió en la formulación de productos con ingredientes naturales y biodegradables, sustituyendo tensioactivos sintéticos por compuestos más ecológicos. Los productos fueron elaborados y evaluados mediante análisis sensorial, considerando hidratación, suavidad, textura y durabilidad. Los resultados mostraron una alta aceptación por parte de los usuarios, especialmente en relación con la hidratación y suavidad del cabello, con un rendimiento comparable al de los productos convencionales. Además, los cosméticos sólidos reducen significativamente el consumo de agua y eliminan la necesidad de envases plásticos. Se concluye que los cosméticos sólidos biodegradables representan una alternativa viable y sostenible para reducir el impacto ambiental del sector higiene personal.

Palabras clave: Cosméticos naturales; Consumo sostenible; Reducción de residuos; Productos ecológicos; Innovación verde.

1. Introduction

The rapid expansion of the cosmetics industry has intensified concerns regarding its environmental impacts, particularly in relation to water consumption, chemical pollution, and plastic waste generation. Conventional cosmetic formulations, especially liquid shampoos and conditioners, typically contain high proportions of water, often exceeding 70–80% of their composition, contributing to inefficient resource use and increased environmental pressure (Aguiar et al., 2022; Martins & Marto, 2023). In addition, the widespread use of synthetic ingredients and non-biodegradable polymers has raised concerns about their persistence in aquatic environments and their potential ecotoxicological effects (Rozman & Kalčíková, 2021; Gillece et al., 2024).

In this context, the concept of waterless cosmetics has emerged as a key innovation strategy for reducing environmental impacts throughout the product life cycle. Waterless or low-water formulations significantly reduce water consumption not only during manufacturing but also during product use and transportation, due to their higher concentration and lower weight (Aguiar et al., 2022; Krzyżostan et al., 2024). Among these innovations, solid cosmetic formats, such as shampoo bars, conditioner bars, and anhydrous formulations, stand out as particularly promising alternatives, as they eliminate the need for water as a primary ingredient while also reducing packaging requirements (Brito et al., 2023; Kulawik-Pióro et al., 2025).

Recent studies have demonstrated that solid formulations can achieve performance comparable to conventional products while offering substantial environmental benefits. For example, Brito et al. (2023) developed a solid shampoo incorporating mango peel extract, demonstrating stability, antioxidant activity, and the elimination of both water in formulation and plastic packaging. Similarly, anhydrous cosmetic bars formulated with natural starches have shown favorable mechanical and functional properties, reinforcing the viability of solid systems in sustainable product development (Kulawik-Pióro et al., 2025).

Another critical aspect of sustainable cosmetic design is biodegradability, which has become a central parameter in

eco-design strategies. Eco-design approaches increasingly emphasize the replacement of persistent synthetic polymers with biodegradable alternatives, such as biopolymers, polysaccharides, and biosurfactants, which offer improved environmental compatibility (L'Haridon et al., 2018; Tafuro et al., 2024; Yahya et al., 2025). Biosurfactants, in particular, have gained attention due to their low toxicity, biodegradability, and potential benefits for skin health and microbiome balance (Vecino et al., 2017; Goyal & Jerold, 2021; Makwana et al., 2025).

In parallel, the use of agro-industrial by-products as cosmetic ingredients has emerged as a sustainable strategy aligned with circular economy principles. Residues such as fruit peels, seeds, and plant extracts can be valorized as sources of antioxidants, oils, and functional compounds, reducing waste generation and dependence on virgin raw materials (Krzyżostan et al., 2024; Sarah et al., 2023). This approach not only enhances sustainability but also adds value to previously discarded materials.

Furthermore, packaging plays a central role in the environmental footprint of cosmetic products. The adoption of biodegradable and compostable materials, such as bioplastics (PLA, PHA) and polysaccharide-based packaging, has been shown to reduce life cycle impacts when compared to conventional plastics, although economic and scalability challenges remain (Cinelli et al., 2019; Cubas et al., 2022; Martins & Marto, 2023).

Overall, current scientific evidence highlights that sustainable cosmetics must be designed based on a life cycle perspective, integrating formulation, ingredient selection, packaging, use phase, and post-consumption management (Aguiar et al., 2022; Goyal & Jerold, 2021). Within this framework, biodegradable solid cosmetics represent a promising pathway for reducing water dependency, minimizing waste generation, and mitigating environmental impacts.

From a knowledge management perspective, according to Dalkir, knowledge management can be understood as a systematic set of organizational processes aimed at the creation, sharing, use, and retention of knowledge to enhance organizational performance and foster innovation; this approach encompasses both explicit knowledge (formally documented) and tacit knowledge (rooted in individual experience), emphasizing that effective knowledge management depends on the integration of technologies, organizational culture, and collaborative practices, thereby constituting a continuous cycle that connects people, processes, and technology to generate value within organizations (Dalkir, 2017). In this sense, the development of sustainable cosmetic formulations can be interpreted as a knowledge-intensive process, in which scientific evidence, technological capabilities, and sustainability principles are integrated to support eco-innovation and environmentally responsible product design.

Therefore, this study aims to develop biodegradable solid shampoo and conditioner formulations, focusing on reducing water consumption and environmental impacts

2. Methodology

This study adopted an experimental and applied laboratory approach, using both qualitative and quantitative methods, aimed at developing solid cosmetic formulations with reduced environmental impact (Pereira et al., 2018; Yin, 2018). To this end, it was based on the methodology of Hernandez Sampieri et al (2014) and Risemberg et al. (2026), which classifies it as experimental and applied research, with a methodological design in applied sciences. The research focused on the formulation of a solid shampoo and a solid conditioner designed to minimize water consumption, reduce plastic packaging waste, and incorporate biodegradable, plant-based ingredients.

The conceptual framework was based on replacing conventional sulfated surfactants with milder alternatives, such as isethionate, while maintaining cleansing efficiency and improving compatibility with sustainable formulation principles, as highlighted in recent studies on waterless cosmetics (Aguiar et al., 2022; Martins & Marto, 2023).

The selection of raw materials considered their functional properties, physicochemical stability, and potential biodegradability, in accordance with eco-design principles. The shampoo formulation included components such as carnauba/beeswax, mango butter, palm kernel oil, isethionate, glycerin, sodium lactate, a vitamin blend, grape seed oil, and plant-derived extracts such as purple sweet potato powder and hibiscus (Table 1). The conditioner formulation was based on a solid conditioning base combined with cocoa butter, coconut oil, castor oil, grape seed oil, and botanical extracts. Supporting laboratory materials included an enameled heating vessel, spatulas, an electric stove, an analytical balance, beakers, and acetate molds (Table 1).

Table 1 - Raw materials and supporting equipment used in the formulation of solid cosmetic products.

Category	Components
Solid shampoo	Carnauba/beeswax; mango butter; palm kernel oil; isethionate; bidistilled glycerin; Nipaguard; sodium lactate; vitamin blend; grape seed oil; purple sweet potato extract (powder); hibiscus powder; hibiscus fragrance
Solid conditioner	Solid conditioner base; cocoa butter; coconut oil; grape seed oil; castor oil; purple sweet potato extract (powder); hibiscus fragrance
Supporting materials	Enamel-coated pan; spatula; electric stove; analytical balance; beaker; acetate molds

Source: Adapted from Beraldo (2013).

The formulations were adapted from proportional methods described by Paiva (2021a; 2021b; 2021c) and Shitsuka et al. (2014), with adjustments made to produce 500 g batches of each product. The development of the solid shampoo involved controlled melting of the lipid phase, followed by the gradual incorporation of liquid and solid components under continuous mixing to ensure homogeneity. The mixture was allowed to cool to a moderate temperature before the gradual addition of the solid surfactant, ensuring safe handling due to its particulate nature. Botanical powders were subsequently incorporated, and the formulation was homogenized under mild heating conditions before being molded and allowed to solidify at room temperature (Table 2).

Table 2 - Quantitative composition of solid shampoo and conditioner formulations (500 g batches).

Component	Shampoo (g / %)	Conditioner (g)
Carnauba/beeswax	2 g (2%)	—
Mango butter	50 g (10%)	—
Palm kernel oil	25 g (5%)	—
Isethionate	290 g (58%)	—
Bidistilled glycerin	5 g (1%)	—
Nipaguard	5 g (1%)	—
Sodium lactate	10 g (2%)	—
Vitamin blend	50 g (10%)	—
Grape seed oil	10 g (2%)	10 g
Purple sweet potato extract	30 g (6%)	10 g
Hibiscus fragrance	15 g (3%)	10 g
Hibiscus powder	1 tablespoon	—
Solid conditioning base	—	400 g
Cocoa butter	—	40 g

Component	Shampoo (g / %)	Conditioner (g)
Coconut oil	—	20 g
Castor oil	—	10 g

Source: Adapted from Paiva (2021a; 2021b; 2021c).

For the solid conditioner, the conditioning base was first melted under controlled temperature conditions, followed by the incorporation of lipidic ingredients to adjust consistency and enhance emollient properties. Functional oils and plant extracts were then gradually added, ensuring proper dispersion and preventing aggregation. The mixture was homogenized using mechanical agitation to achieve a uniform and aerated texture, after which it was transferred into molds and allowed to solidify (Table 2).

The functional role of each component in the formulations was defined according to its technological contribution. Structural agents such as waxes provided rigidity, while butters and oils contributed to emollience, conditioning, and nutrient replenishment (Table 3). The surfactant acted as the primary cleansing agent, whereas humectants such as glycerin enhanced moisture retention. Botanical extracts were incorporated as bioactive compounds with antioxidant and conditioning properties, and preservatives ensured product stability. These choices are consistent with eco-design strategies that prioritize biodegradable ingredients and reduced environmental persistence (L’Haridon et al., 2018; Rozman & Kalčíková, 2021).

Table 3 - Technological functions of ingredients used in solid cosmetic formulations.

Component	Function
Carnauba/beeswax	Structure and rigidity
Mango butter	Emollient and conditioning agent
Palm kernel oil	Hair nourishment
Isethionate	Mild cleansing agent
Glycerin	Humectant
Nipaguard	Preservative
Sodium lactate	Stabilizer and texturizing agent
Vitamin blend	Hydration
Grape seed oil	Nourishing agent
Purple sweet potato extract	Antioxidant active
Hibiscus powder	Strengthening properties
Coconut oil	Lipid replenishment
Castor oil	Antioxidant action
Cocoa butter	Moisture retention
Conditioning base	Detangling agent

Source: Adapted from Beraldo (2013).

Product performance was evaluated through a sensory analysis conducted with volunteer users. A structured evaluation form based on a nine-point hedonic scale was applied to assess attributes such as durability, texture, aroma, softness, hydration, and shine. Participants were also encouraged to provide qualitative feedback regarding their experience with the products, including perceptions of application, performance, and overall acceptability.

The collected data were analyzed using descriptive statistical approaches, including frequency distribution of responses. Qualitative observations were examined to complement the quantitative results, allowing for a broader interpretation of user acceptance and identifying potential areas for formulation improvement. This combined analytical approach enabled the evaluation of both functional performance and consumer perception, which are critical parameters in the development of sustainable cosmetic products.

3. Results and Discussion

The developed formulations resulted in physically stable solid cosmetic products with adequate structural integrity, demonstrating the feasibility of producing waterless shampoo and conditioner bars based on biodegradable and plant-derived ingredients. Both formulations exhibited satisfactory molding properties, maintaining their shape after cooling without visible phase separation or structural instability under ambient conditions.

The solid shampoo presented appropriate hardness and cohesion, which can be attributed to the balance between waxes, butters, and the surfactant matrix. The use of isethionate as the primary surfactant ensured effective cleansing performance, despite reduced foam formation compared to conventional liquid shampoos. This behavior is expected in sulfate-free formulations, as foam production is primarily related to surfactant chemistry rather than cleansing efficiency. This behavior is expected in sulfate-free formulations, as foam production is primarily associated with surfactant type rather than cleaning efficiency, which depends on the formation of micelles capable of removing oils and impurities. The incorporation of glycerin and sodium lactate contributed to moisture retention and minimized excessive brittleness.

The conditioner bar exhibited a softer consistency due to its higher lipid content and conditioning base. It showed good spreadability, facilitating uniform application along the hair shaft. The combination of cocoa butter, coconut oil, and castor oil enhanced emollient properties, resulting in improved softness, hydration, and manageability without causing excessive heaviness, a common drawback of conventional conditioners.

After one week of continuous use, both formulations demonstrated noticeable improvements in hair condition. The results indicated increased hydration, softness, and shine, particularly for dry and curly hair types. Although the formulations were initially designed for dry hair, they also performed satisfactorily on oilier and straighter hair, suggesting formulation versatility. The shampoo effectively cleansed the scalp despite low foam formation.

The findings also suggest that formulation adjustments are necessary depending on hair type. For oily hair, increasing the proportion of isethionate to approximately 70% (without exceeding 72%) may enhance cleansing efficiency and reduce residual oiliness. This highlights surfactant concentration as a critical parameter for formulation optimization according to hair type.

Sensory evaluation indicating the need for improved formulation robustness or optimized storage conditions. The attributes most positively evaluated were softness and hydration, followed by aroma, which was well accepted due to the use of hibiscus essence. Durability was also positively perceived, although with some variability among users, while texture received moderate ratings, indicating potential for further optimization.

Some limitations were identified through user feedback. Reduced foam formation in the shampoo was noted by one participant, reflecting a common perception that associates foam with cleansing efficiency. Additionally, both products showed a tendency to become brittle and crumble when exposed to prolonged humidity, indicating the need for improvements in formulation stability or storage conditions.

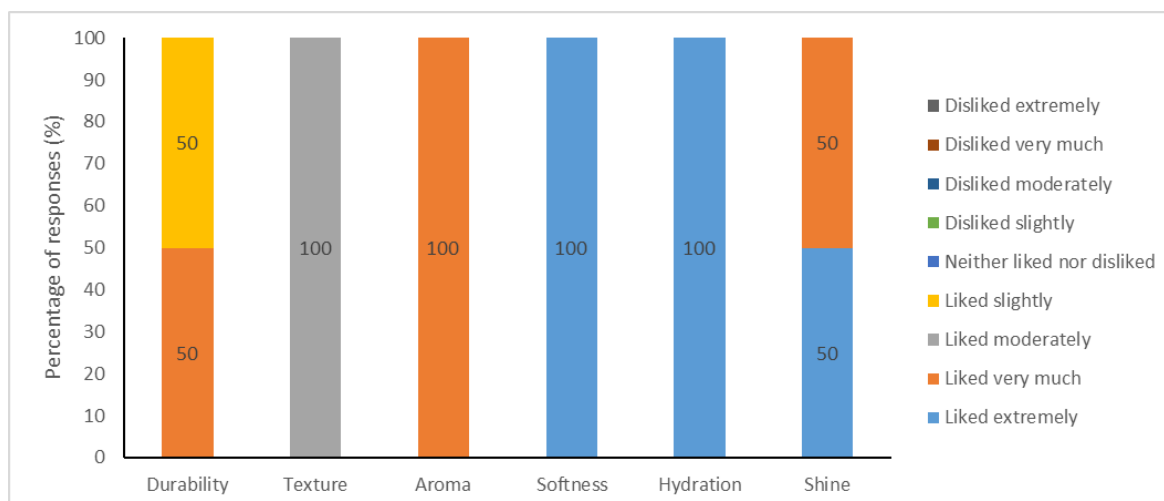
Conversely, positive feedback emphasized the long-lasting nature of the products, pleasant fragrance, and effective hydration, particularly for normal and dry hair. Users also recognized the environmental advantages of the formulations,

including the absence of plastic packaging and the use of natural ingredients.

The quantitative sensory evaluation results for the shampoo are presented in Figure 1. The data revealed a predominantly positive acceptance pattern across all evaluated attributes. Hydration and softness achieved the highest level of approval, with 100% of respondents indicating “liked extremely,” confirming the effectiveness of the formulation. Aroma was rated as “liked very much” by all participants, indicating high satisfaction with the fragrance profile. Texture was consistently rated as “liked moderately,” suggesting acceptable but improvable tactile performance.

Durability and shine exhibited more variable responses. Durability showed an equal distribution between “liked very much” and “liked slightly” (50% each), possibly reflecting the influence of product fragility under humid conditions. Shine also presented a balanced distribution between “liked extremely” and “liked very much,” indicating consistent but slightly heterogeneous perception among users. Notably, no negative or indifferent responses were recorded.

Figure 1 - Percentage distribution of sensory evaluation responses for the solid shampoo across the attributes of durability, texture, aroma, softness, hydration, and shine, based on a nine-point hedonic scale (ranging from “disliked extremely” to “liked extremely”).

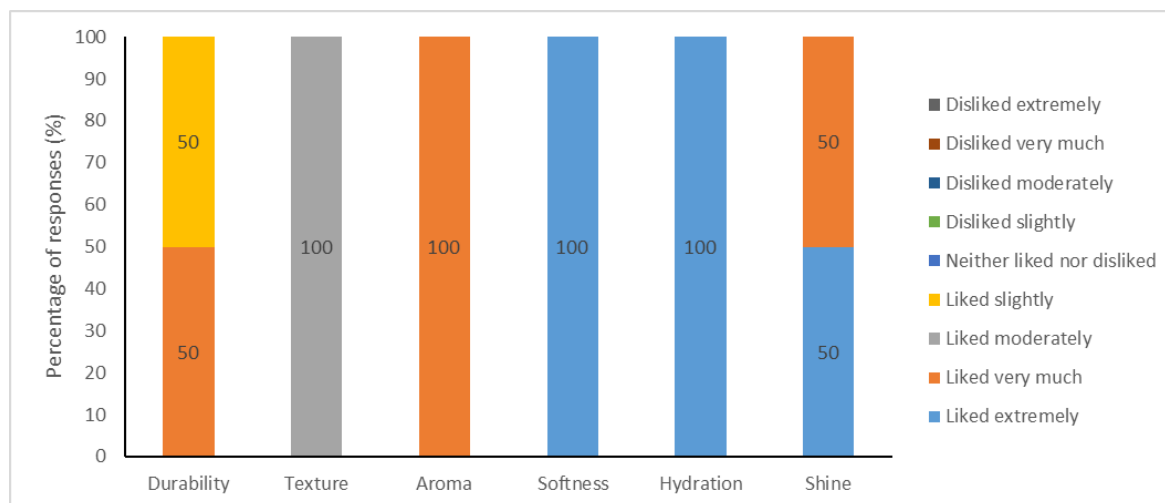


Source: Authors (2021).

The sensory evaluation of the conditioner (Figure 2) demonstrated even greater consistency. Softness and hydration achieved 100% “liked extremely” responses, confirming the strong conditioning performance of the formulation. Texture was uniformly rated as “liked moderately,” while aroma received 100% “liked very much” evaluations.

Durability and shine again showed minor variability, with balanced responses between “liked very much” and “liked slightly” for durability, and between “liked extremely” and “liked very much” for shine. No negative evaluations were observed, indicating uniformly high acceptance.

Figure 2 - Percentage distribution of sensory evaluation responses for the solid conditioner, considering the attributes durability, texture, aroma, softness, hydration, and shine, based on a nine-point hedonic scale (from “disliked extremely” to “liked extremely”).



Source: Authors (2021).

Overall, the results demonstrate that the developed solid shampoo and conditioner achieved a balance between functional performance, sensory acceptance, and sustainability principles. The formulations met, and in some cases exceeded, initial expectations, supporting the potential of waterless solid cosmetics as viable alternatives to conventional liquid products.

The results obtained in this study reinforce the growing body of evidence that solid and waterless cosmetics represent viable and sustainable alternatives to conventional liquid formulations. From a formulation perspective, the successful performance of the developed shampoo and conditioner can be explained by the combination of key structural and functional components commonly described in recent studies on solid cosmetics.

Solid cosmetic formulations rely on a carefully balanced matrix of surfactants, lipids, and functional additives to replicate the cleansing, conditioning, and sensorial properties of liquid products. In this study, the use of biodegradable surfactants, combined with vegetable oils and plant-based butters, contributed to effective cleansing and hair conditioning. This is consistent with findings reported in recent formulation studies, which emphasize the importance of surfactant matrices optimized for pH, foam stability, and user perception (Tamayo et al., 2024; Ogorzałek et al., 2024).

The inclusion of botanical extracts also played a relevant role in product performance. Natural compounds such as plant extracts are increasingly used not only as active ingredients but also as partial substitutes for synthetic preservatives due to their antioxidant properties and biodegradability (Brito et al., 2023; Lima et al., 2023). In this context, the incorporation of natural extracts in the present formulations likely contributed to the observed improvements in hair hydration and softness, aligning with the literature that highlights the multifunctional role of plant-derived ingredients.

From a sustainability perspective, the most significant advantage of the developed formulations lies in the substantial reduction of water consumption throughout the product life cycle. Solid formulations eliminate the need for water as a primary ingredient, directly reducing the product’s grey water footprint. This reduction is particularly relevant when considering the full life cycle of cosmetic products, as water is not only used in formulation but also in manufacturing processes and post-use dilution (Aguiar et al., 2022; Martins & Marto, 2023). Therefore, the adoption of waterless formulations represents a critical step toward improving resource efficiency in the cosmetics sector.

Another important environmental benefit is the reduction of plastic packaging. Solid products can be distributed using minimal or biodegradable packaging, such as paper-based materials, which significantly decreases plastic waste generation. This finding is consistent with previous studies demonstrating that solid and waterless cosmetics enable the transition to compostable or low-impact packaging systems (Cinelli et al., 2019; Cubas et al., 2022).

Additionally, the use of natural and potentially upcycled ingredients aligns with circular economy principles. The literature highlights the growing use of agro-industrial residues, such as fruit peels and plant by-products, as sources of bioactive compounds in cosmetic formulations (Krzyżostan et al., 2024). These strategies not only reduce environmental impact but also add value to waste streams, reinforcing the sustainability of cosmetic production systems.

Despite these advantages, some limitations and challenges remain. One of the most frequently reported issues is the difference in sensory perception compared to conventional products, particularly regarding foam formation. Although foam is not directly associated with cleansing efficiency, it remains a key factor influencing consumer perception and acceptance. (García et al., 2013; Romanowski, 2026). In this study, similar observations were reported by users, indicating the need for further optimization of surfactant systems to improve sensorial performance.

Another challenge concerns the physical stability of solid formulations. Factors such as hardness, resistance to moisture, and structural integrity are influenced by the composition and particle characteristics of the formulation. Studies have shown that parameters such as particle size and shape of solid additives can significantly affect texture, durability, and user experience (Ogorzałek et al., 2024). The fragmentation observed in some samples in this study suggests that further adjustments in formulation or processing conditions may be necessary.

Another important limitation concerns the assessment of biodegradability under real environmental conditions. Although the formulations developed in this study prioritize the use of biodegradable and plant-based ingredients, the evaluation of biodegradation remains complex and context-dependent. Current eco-design approaches emphasize the need to balance high biodegradability levels with product performance, often targeting values above 90–95% while maintaining functional efficacy (L'Haridon et al., 2018; Tafuro et al., 2024). However, standardized methodologies for assessing biodegradability under diverse environmental conditions are still evolving, which makes it difficult to fully validate the environmental behavior of new cosmetic formulations. Therefore, further studies are required to assess degradation pathways, rates, and impacts across different ecosystems.

Finally, aspects related to long-term stability, microbial safety, and large-scale consumer acceptance require further investigation. While preliminary results and literature data suggest promising performance, more comprehensive studies are needed to validate shelf life, preservation systems, and market viability of solid cosmetic products.

Overall, the findings of this study are consistent with current scientific advances and confirm that biodegradable solid cosmetics can combine environmental sustainability with functional performance. However, achieving widespread adoption will depend on continued innovation in formulation, improvements in sensory attributes, and robust validation of environmental benefits across the product life cycle.

4. Conclusion

The present study demonstrated that biodegradable solid shampoo and conditioner formulations can be successfully developed using natural and plant-based ingredients, achieving satisfactory performance and high user acceptance, with hydration, softness, and durability comparable to conventional cosmetics. From a knowledge management perspective, as highlighted by Dalkir (2017), these results can be interpreted as the outcome of a structured process of knowledge creation, integration, and application, in which scientific evidence, experimental practices, and user feedback are systematically

combined to generate innovation and organizational value.

From a sustainability perspective, the main contribution of these formulations lies in the reduction of water consumption and elimination of plastic packaging, significantly lowering the environmental footprint of cosmetic products. In alignment with knowledge management principles, these findings reinforce the importance of capturing, sharing, and disseminating knowledge related to sustainable materials, eco-design strategies, and life cycle thinking, enabling their replication and continuous improvement across the sector.

Therefore, biodegradable solid cosmetics represent a promising and viable strategy for promoting sustainable consumption patterns and advancing resource efficiency in the personal care industry. Moreover, when supported by knowledge management practices these innovations can be scaled and adapted, contributing to the consolidation of more sustainable and knowledge-driven production systems.

Acknowledgements

We acknowledge the Cesumar Institute of Science, Technology and Innovation (ICETI) and Fundação Araucária for the research fellowship awarded to A.L. We also acknowledge ICETI for the research fellowship awarded to T.M.T., and ICETI and the National Council for Scientific and Technological Development (CNPq) for the research support granted to R.C.G.C.

References

- Aguiar, J., Martins, A., Almeida, C., Ribeiro, H., & Marto, J. (2022). Water sustainability: A waterless life cycle for cosmetic products. *Sustainable Production and Consumption*. <https://doi.org/10.1016/j.spc.2022.04.008>
- Beraldo, E. C. L. (2013). *Estudos de pré-formulação e desenvolvimento de preparações cosméticas* [Undergraduate thesis, São Paulo State University (UNESP)]. <http://acervodigital.unesp.br/handle/11449/118277>
- Brito, I., Ferreira, S., & Santos, L. (2023). On the path to sustainable cosmetics: Development of a value-added formulation of solid shampoo incorporating mango peel extract. *Cosmetics*. <https://doi.org/10.3390/cosmetics10050140>
- Cinelli, P., Coltelli, M., Signori, F., Morganti, P., & Lazzeri, A. (2019). Cosmetic packaging to save the environment: Future perspectives. *Cosmetics*, 6(2), 26. <https://doi.org/10.3390/cosmetics6020026>
- Cubas, A., Bianchet, R., Reis, I., & Gouveia, I. (2022). Plastics and microplastic in the cosmetic industry: Aggregating sustainable actions aimed at alignment with UN sustainable development goals. *Polymers*, 14(21), 4576. <https://doi.org/10.3390/polym14214576>
- Dalkir, K. (2017). *Knowledge management in theory and practice* (3rd ed.). MIT Press.
- García, M. F., Valladares, S. M., Flores, J. Á. D., Ceconello, L., & de Gáscue, B. R. (2013). Producción de espumas sólidas de celulosa y almidón de yuca. *SABER: Revista Multidisciplinaria del Consejo de Investigación de la Universidad de Oriente*, 25(4), 439–444.
- Gillece, T., Gerardi, H., McMullen, R., Thompson, W., & Brown, D. (2024). Thermophilic composting as a means to evaluate biodegradability of cosmetic polymers. *Cosmetics*, 11(3), 99. <https://doi.org/10.3390/cosmetics11030099>
- Goyal, N., & Jerold, F. (2021). Biocosmetics: Technological advances and future outlook. *Environmental Science and Pollution Research*, 30, 25148–25169. <https://doi.org/10.1007/s11356-021-17567-3>
- Hernández-Sampieri, R., Fernández-Collado, C., & Baptista-Lucio, M. P. (2014). *Metodología de la investigación* (6th ed.). McGraw-Hill Education.
- Jiménez Tamayo, F. M., Vinocunga-Pillajo, D. R., & Gómez Zurita, S. N. (2024). Formulation of a solid shampoo with Oenocarpus bataua oil, cocoa butter, and Cinchona officinalis. *Revista Científica y Tecnológica UPSE*, 11, 26–35.
- Krzyżostan, M., Wawrzyńczak, A., & Nowak, I. (2024). Use of food industry waste and fermentation in sustainable cosmetic products: A review. *Sustainability*, 16(7), 2757. <https://doi.org/10.3390/su16072757>
- Kulawik-Pióro, A., Fryźlewicz-Kozak, B., Tworzydło, I., Kruk, J., & Ptaszek, A. (2025). Impact of starches on properties of anhydrous lotion bars. *Polymers*, 17(13), 1731. <https://doi.org/10.3390/polym17131731>
- L'Haridon, J., Martz, P., Chenéble, J. C., Campion, J. F., & Colombe, L. (2018). Ecodesign of cosmetic formulae: Methodology and application. *International Journal of Cosmetic Science*, 40(2), 165–177.

- Lima, L., Bispo-Dos-Santos, K., Trevisan, I., Rapôso, C., Velho, P., Bagatin, E., Rezende, R., Da Silva, J., & Leonardi, G. (2023). Developing botanical formulations for sustainable cosmetics. *Cosmetics*, 10(6), 159. <https://doi.org/10.3390/cosmetics10060159>
- Makwana, K., Mehta, A., & Ambechada, J. (2025). Biosurfactant-producing bacteria for sustainable cosmetics. *Journal of Advances in Microbiology Research*. <https://doi.org/10.22271/micro.2025.v6.i1b.203>
- Martins, A., & Marto, J. (2023). A sustainable life cycle for cosmetics. *Sustainable Chemistry and Pharmacy*. <https://doi.org/10.1016/j.scp.2023.101178>
- Ogorzałek, M., Klimaszewska, E., Małyś, A., Czerwonka, D., & Tomasiuk, R. (2024). Waterless cosmetics based on natural exfoliants. *Applied Sciences*, 14(23), 11329.
- Paiva. (2021a). *Técnicas do mundo da saboaria artesanal*. <https://www.peterpaiva.com.br>
- Paiva. (2021b). *Shampoo sólido – Peter Paiva* [Vídeo]. YouTube. https://www.youtube.com/watch?v=U_zjZp6_uJ8
- Paiva. (2021c). *Condicionador sólido – Peter Paiva* [Vídeo]. YouTube. https://www.youtube.com/watch?v=3iV-PPGH6_k
- Pereira, A. S., Shitsuka, D. M., Parreira, F. J., & Shitsuka, R. (2018). *Metodologia da pesquisa científica*. Editora UFSM.
- Risemberg, R. I. C., Wakin, M., & Shitsuka, R. (2026). A importância da metodologia científica no desenvolvimento de artigos científicos. *E-Acadêmica*, 7(1), e0171675. <https://doi.org/10.52076/eacad-v7i1.675>
- Romanowski, P. (2026). New and future technologies for cosmetics. In *Cosmetic science: Formulation and technologies* (pp. 409–444). Springer Nature Switzerland.
- Rozman, U., & Kalčíková, G. (2021). Ecotoxicity and biodegradability of water-soluble polymers in cosmetics. *Ecotoxicology and Environmental Safety*, 228, 113016. <https://doi.org/10.1016/j.ecoenv.2021.113016>
- Sarah, M., Paul, R., & Arif, R. (2023). Biodegradable polymers for cosmetic packaging. *Materials Research Proceedings*. <https://doi.org/10.21741/9781644902479-217>
- Shitsuka, R., et al. (2014). *Matemática fundamental para tecnologia* (2nd ed.). Érica.
- Tafuro, G., Costantini, A., Piatto, M., Lucchetti, S., Francescato, S., Busata, L., Baratto, G., & Semenzato, A. (2024). Eco-designing cosmetic products. *Cosmetics*, 11(2), 60. <https://doi.org/10.3390/cosmetics11020060>
- Vecino, X., Cruz, J., Moldes, A., & Rodrigues, L. (2017). Biosurfactants in cosmetic formulations. *Critical Reviews in Biotechnology*, 37, 911–923. <https://doi.org/10.1080/07388551.2016.1269053>
- Yahya, E., Ali, S., Lalung, J., Zain, M., Danish, M., & John, A. (2025). Biopolymers in cosmetic applications. *Polymer Engineering & Science*, 65, 2789–2802. <https://doi.org/10.1002/pen.27186>
- Yin, R. K. (2015). *Case study research: Design and methods*. Bookman.