

Protocol

A Conceptual Engineering Approach to Developing a Bio-Based Hair Mask

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Abstract: Developing innovative cosmetics products is essential for businesses in the beauty industry, influencing their ability to grow, remain competitive, and respond to rapidly shifting market trends. A structured, customer-oriented approach to product design and development is particularly crucial in cosmetics, where factors such as product safety, regulatory compliance, and sustainability are paramount. In this context, Conceptual Engineering offers a valuable early-phase framework for cosmetics design, providing a foundation to define the structure, functionality, and feasibility of product concepts prior to detailed development. This study focuses on the application of Conceptual Engineering to the creation of a bio-based cosmetic product, specifically a hair mask. Here, we address unique challenges in cosmetics design, including strict health regulations, ingredient safety, environmental considerations, and cost management in generating and validating product concepts. To meet these demands, we propose an iterative concept development process tailored to cosmetics: a single concept is generated and iteratively refined through feasibility testing, physical validation, and further adaptation based on feedback. Each successful iteration brings the concept closer to market readiness, bridging the gap between sustainable product innovation and practical industrialization. This structured process, implemented in collaboration with an industry partner, underscores the potential of Conceptual Engineering to support sustainable cosmetics design. The case of the bio-based hair mask illustrates how aligning design innovation with environmental and regulatory requirements can enhance the responsiveness of cosmetics companies to consumer demand for eco-friendly products.

Keywords: product design; conceptual engineering; bio-based cosmetic; hair mask



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1. Introduction

Developing new products is essential for companies aiming to remain competitive, meet evolving customer demands, and seize emerging market opportunities. Systematic methods are critical in making this process efficient, innovative, and aligned with real-world needs [1]. In practice, these methods provide several advantages [2]: (i) informed decision-making, ensuring that products address actual market needs rather than relying

on assumptions; (ii) risk and cost reduction by identifying potential issues early, allowing teams to resolve them before they escalate; (iii) enhanced creativity and innovation through a structured approach to exploring new ideas and overcoming design challenges; (iv) scalability and consistency by maintaining high quality across products and markets, enabling teams to replicate successful strategies across different contexts; and (v) adaptability to market changes, allowing companies to swiftly respond to shifts in consumer preferences or technological advances.

Conceptual Engineering is becoming an essential systematic strategy in product development, particularly within complex, high-stakes industries where precision, user alignment, and continuous innovation are critical. This approach involves critically analyzing and refining the core concepts or “building blocks” that shape a product’s design, functionality, and purpose [3]. By targeting foundational ideas rather than merely surface-level features, Conceptual Engineering enables the creation of products that more effectively meet user needs, stand out in competitive markets, and evolve alongside changing demands.

This methodology is especially powerful in the design of customized products, such as pharmaceuticals and cosmetics, where success hinges on precisely tailoring products to individual needs, health requirements, and personal preferences [4,5]. Through a careful examination and refinement of a product’s underlying concepts, Conceptual Engineering allows developers to adapt ingredients, formulation methods, and technologies to meet specific, often highly nuanced, criteria. This structured approach ensures that products are not only highly personalized but also scientifically robust and ethically responsible. Conceptual Engineering provides a valuable framework for developing products that are both effective and aligned with individual consumer profiles in industries where personalization and precision are crucial [6].

Practically, various product development methodologies are employed in the design of cosmetic products, including: (i) the *stage-gate process* (S-GP), a structured framework that organizes product development into sequential stages, ranging from idea generation and market research to post-marketing monitoring, with decision gates at each phase determining whether to proceed [7]; (ii) *design thinking* (DeT), a structured, user-centered approach to innovation that balances desirability (consumer needs), feasibility (technical capabilities), and viability (business constraints) [8]; (iii) *quality by design* (QbD), a scientific, risk-based approach focused on formulation control, beginning with target definition and culminating in formulation optimization. This method often requires extensive experimental designs and the application of statistical principles, making it resource- and time-intensive [9].

A comparison of these methods highlights key distinctions:

- Conceptual Engineering (CE) offers moderate flexibility through iterative conceptual adjustments.
- S-GP has low flexibility due to its sequential, predefined structure.
- DeT is highly flexible, dynamically adapting to customer needs.
- QbD provides moderate flexibility, as it follows a structured approach but allows for statistical refinements.

Regarding time and resource demands, both CE and S-GP require a moderate investment, whereas DeT and QbD are more intensive. In the cosmetics sector, these methodologies serve distinct purposes: (i) S-GP ensures structured decision-making throughout the product life-cycle; (ii) DeT fosters innovation and user-driven product design; (iii) QbD guarantees robust, high-quality formulations that meet regulatory standards; and (iv) Conceptual Engineering provides a systematic framework for refining design processes and quality criteria, ensuring effective product development aligned with consumer needs and regulatory requirements.

The current literature on applying Conceptual Engineering to cosmetic product development is limited. Nonetheless, several key ideas and methods associated with Conceptual Engineering are being applied in areas such as personalized beauty, innovation, and sustainability within cosmetics development (see Degouy et al. [10]). A closer analysis reveals that the cosmetics industry has distinct characteristics necessitating adaptations in conceptual engineering approaches. Specifically, the industry faces complex challenges in producing formulations that address individual needs, maintain physical and biological stability, and meet strict health and regulatory standards, all within budget constraints [11].

Bio-based, or eco-based cosmetic formulations are increasingly pursued by companies aiming for sustainable, health-conscious, and consumer-preferred products [12]. These formulations typically use renewable resources—such as plant oils, extracts, and other organic ingredients—that support sustainability goals and have a lower carbon footprint [13,14]. This aligns with broader industry shifts toward reducing reliance on fossil fuels and minimizing environmental impact.

Some systematic methodologies have been introduced to cosmetic design, as noted in studies by Arrieta-Escobar et al. [15], Bernardo and Saraiva [16], Zhang et al. [17]. However, these studies generally address isolated aspects, focusing on factors like feasible formulations based on physical properties and foundational knowledge, rather than encompassing the full design process. This illustrates a significant gap in the literature, as a comprehensive approach to systematizing the entire cosmetic development process using Conceptual Engineering—from eliciting needs to validating concepts before industrialization—has yet to be fully explored. To our knowledge, no research has demonstrated the application of Conceptual Engineering across the full spectrum of cosmetic product development. This paper aims to bridge this gap by offering a systematic algorithm adaptable to various products and contexts. Additionally, it aligns the complete design and development process with established industry practices and knowledge frameworks for new product design.

This study focuses primarily on the conceptual development of a cosmetic product as an initial step in the structured process leading to its ramp-up and production phases. Specifically, we adopt a systematic approach based on Conceptual Engineering to account for critical aspects, including key factors, stakeholders, and regulatory considerations during the development phase. This methodology is designed to ensure a smooth transition from conceptualization to the early stages of industrialization; however, it does not extend beyond this phase. While aspects such as industrial scalability, consumer feedback, and detailed economic analysis are undoubtedly important, they fall outside the scope of this work. Our primary objective is to establish a structured framework for product concept development, ensuring that the foundational principles align with industry standards and best practices.

Novelty Statement and Organization

This paper presents several key contributions:

1. A comprehensive, systematic approach for developing and designing cosmetics using Conceptual Engineering;
2. An alternative concept selection phase specifically tailored to address the unique health and regulatory requirements of the cosmetic industry; and
3. A practical demonstration of the systematic procedure through the design of a bio-based hair mask.

The paper is structured as follows. Section 2 provides an overview of the standard procedures in Conceptual Engineering as applied to product design and development. Section 3 discusses the adaptation of these procedures for product design in the cosmetics industry, highlighting the specific adjustments required. Section 4 outlines the methods

used for testing and validation throughout all phases of product development. Section 5 presents a real-world application of the procedure: the design of a bio-based hair mask. Finally, Section 6 summarizes the key findings and highlights the primary contributions of this work.

2. Design and Development Procedure in Conceptual Engineering

The Conceptual Engineering process is illustrated in Figure 1 (see Ulrich and Eppinger [1], Otto and Wood [18]). This process begins with the mission statement of the product, which outlines the product's fundamental purpose, its position within the company's portfolio, and the anticipated timeline for its market launch. The process then follows a sequence of six key steps:

1. Identifying consumer needs;
2. Defining product specifications;
3. Generating a set of concepts by combining solutions to address the product's functional requirements;
4. Selecting concepts for industrialization based on expected performance;
5. Assessing economic feasibility through an exploratory model; and
6. Detail design and optimization.

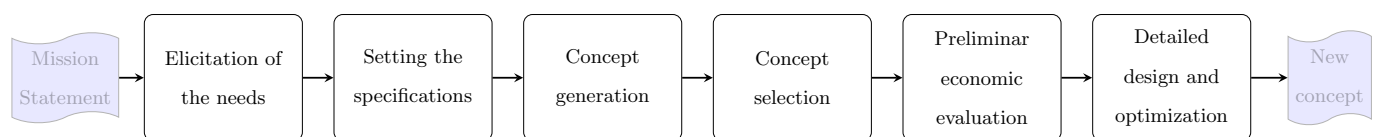


Figure 1. Fluxogram based on Conceptual Engineering used in the development of new products.

Before delving into the details of each task, we introduce two key concepts that will be used throughout the following sections. Specifically, we differentiate between an internal client and an external client, following the terminology commonly used in Quality Management [19].

An internal client refers to an individual or department within the same organization that depends on the outputs or services of others to carry out their responsibilities. In contrast, an external client is a customer or end-user who receives the final product or service provided by the organization (often referred to as the producer or service provider).

The elicitation of needs is the process of identifying and clarifying the requirements, expectations, and priorities of stakeholders to ensure that a product or system is effectively designed to fulfill its intended purpose. This step is essential, as it directs the development of solutions that are both functional and aligned with user expectations. Typically, this process involves: (i) identifying needs from potential users; (ii) organizing these needs hierarchically to create a structured set of meaningful requirements; and (iii) ranking them according to their importance.

A variety of tools can facilitate the elicitation of needs in product development, with the most common methods including [20]: (i) interviews and focus groups, (ii) surveys and questionnaires, (iii) mock-ups and prototypes, and (iv) observation and ethnographic studies. In recent years, several ontological tools have also been introduced to more effectively identify and categorize consumer needs, providing structured frameworks for capturing and analyzing these requirements [21].

The task of setting specifications involves defining precise, measurable, and actionable criteria that a product, system, or service must meet to effectively satisfy the identified needs. Specifications transform the abstract needs gathered during the elicitation phase into well-defined, structured parameters, guiding the design and development process while ensuring that the final outcome aligns with stakeholder expectations. This task acts

as a bridge between the conceptual and detailed design phases, with a focus on functional, performance, and quality attributes [3]. The full process includes defining: (i) metrics to measure satisfaction with respect to each need; (ii) appropriate measurement systems for accurately assessing these metrics; (iii) target values for each specification; and (iv) standard values to ensure consistency and compliance with industry norms.

Common tools used for setting specifications include: (i) benchmarking; (ii) feasibility analysis; and (iii) prototyping and testing.

Concept generation focuses on refining and enhancing concepts to increase their usefulness, precision, and effectiveness in communication, understanding, and problem-solving. It involves the creation, proposal, or exploration of new concepts designed to address specific theoretical, practical, or communicative needs [18]. In this context, a *concept* is defined as a mental or linguistic representation that categorizes or structures particular aspects of reality, facilitating understanding, communication, and reasoning about those aspects. Concepts are often subject to revision, improvement, or replacement to better fulfill their purpose, either through refinement or the creation of entirely new ones, in response to evolving theoretical or practical demands [22].

Concept generation includes several key activities, such as:

- decomposing the product, for instance, through functional decomposition;
- identifying solutions for each functional element; and
- combining these solutions into a physically realizable linguistic representation—the concept.

There are various approaches that can be used to generate concepts. Among them, as outlined by Kossiakoff [23], are: (i) conceptual mapping and mind mapping; (ii) analogy and metaphor; (iii) problem-based analysis, which involves partitioning the product into atomic functions (designated as problems) and finding solutions for each. A potential concept arises from combining these solutions.

Concept selection is the process of evaluating and choosing the most appropriate concept(s) from a set of generated alternatives based on predefined criteria that address the identified needs. The goal of concept selection is to identify the concept that most effectively meets the project's objectives, constraints, and requirements, while maximizing value and minimizing risks [1]. Several approaches can be used for concept selection, including [24]: (i) decision matrix (also known as the Pugh matrix); (ii) weighted scoring method; (iii) cost–benefit analysis; (iv) conjoint analysis; and (v) expert judgment.

In Conceptual Engineering, the Preliminary Economic Evaluation (PEE) is a foundational financial analysis used to determine the economic feasibility of a proposed concept. The primary objective is to assess whether a concept could be economically viable before advancing to detailed design or significant capital investment. This assessment includes estimates of initial costs, operating expenses, potential revenues, and expected economic returns, providing stakeholders with a preliminary understanding of the project's financial viability [25]. Key components of the evaluation typically include: (i) cost estimation; (ii) revenue forecasting; (iii) profitability assessment; and (iv) sensitivity analysis.

Among the most commonly applied metrics and methods are: (i) Cost–benefit analysis (CBA); (ii) Net present value (NPV); (iii) Internal rate of return (IRR); and (iv) Profitability index (PI).

The task of detailed design and optimization follows the preliminary phases, where a concept has been assessed for feasibility and determined to be viable. This phase focuses on refining the selected concept into a fully developed, optimized design that meets performance, cost, and other specific project criteria. The detailed design process transforms initial ideas into precise, actionable specifications, addressing all critical aspects needed for implementation [3]. Key activities include: (i) setting detailed specifications and tolerances;

(ii) applying robust optimization techniques; (iii) optimizing for both performance and cost; and (iv) integrating individual components into a cohesive system. For a comprehensive discussion of the initial conceptual stages, refer to Duarte et al. [26].

3. Design and Development Procedure Adaptations

The design and development of new products in the cosmetics industry involve some unique considerations, despite similarities in the tasks up to the *concept generation* stage. A key modification to the procedure outlined in Section 2 is that generating concepts can be costly, primarily due to the need for validation. To minimize both costs and time, the process is iterative: only one concept is generated at a time. This concept undergoes a series of validation tests, and if it fails any of them, a new concept is created, and the validation process starts again. Additionally, concept selection is not required, as validation and selection occur simultaneously—only one concept is evaluated at a time. Figure 2 illustrates this adapted process until a physically realizable concept (i.e., one that successfully passes all tests) is identified. The blue box details the concept selection and validation module.

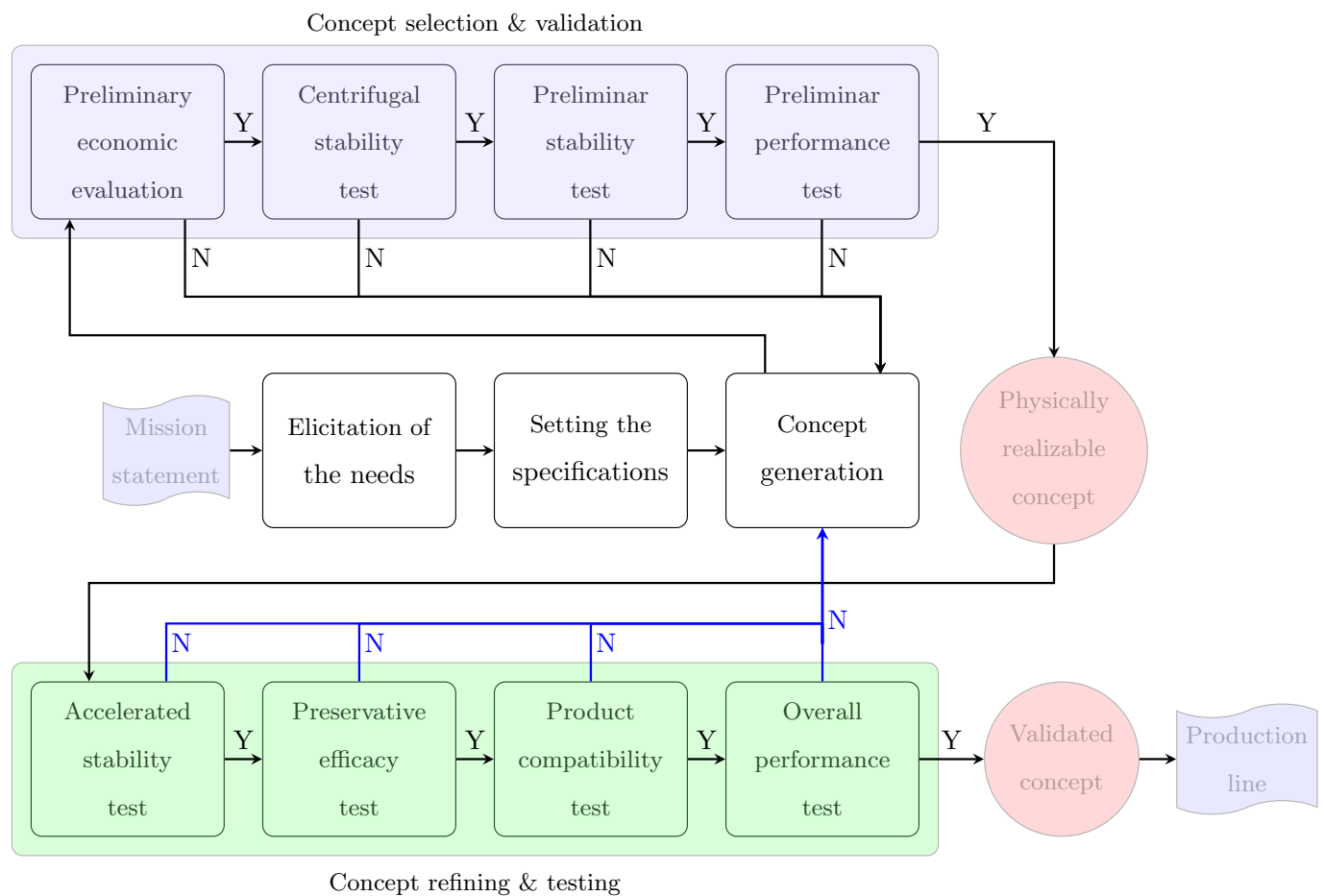


Figure 2. Adapted Conceptual Engineering flowchart for product development. In the diagram, “Y” denotes “Yes” (success), while “N” represents “No” (failure). The blue box encompasses all tasks related to Concept selection & validation, whereas the green box includes tasks for Concept refinement & testing.

The fluxogram illustrates that the *Concept selection and validation* module receives a concept generated during the *Concept generation* stage, where combinatorial approaches are applied. The validation process consists of a sequence of four tests:

1. Preliminary Economic Evaluation: This step uses the methods outlined in Section 2 to create a preliminary economic exploitation model. The model helps predict outcomes by considering costs such as raw materials, production, and workforce expenses.
2. Centrifugal stability test: This test evaluates how well a product maintains its physical stability under conditions of accelerated stress. It simulates the effects of various forces on the formulation, helping to predict stability under handling and transportation. The test is described in Section 4.2.
3. Preliminary stability test: An initial assessment of the product's physical, chemical, and microbiological stability is conducted under various conditions. This test predicts how the product will behave over time and in different environmental settings. Further details are provided in Section 4.3.
4. Preliminary performance test: Conducted early in the product development process, this test ensures that the cosmetic formulation meets its intended claims and performs as expected. This test is described in Section 4.7.

If the concept succeeds in the *Preliminary performance test*, a physically realizable concept is obtained, which is then submitted to the *In-depth testing and refinement* phase. The objective at this stage is to evaluate additional complementary properties of the cosmetic product. The flowchart for this process is illustrated in Figure 2 (see the green box). As in the previous phase, the process is structured as a sequence of four tests. If the product fails any one of these tests, the procedure is restarted, meaning a new concept is generated for further evaluation.

The refinement test phase consists of the following:

1. Accelerated stability test: This test simulates the effects of aging on the product in a shortened time frame, allowing manufacturers to predict how the product will behave under typical storage and usage conditions over time. The goal is to identify potential issues with the product's physical, chemical, or microbiological properties that may arise during its shelf life. The test is described in Section 4.4.
2. Preservative efficacy test: The preservative efficacy test ensures that cosmetic products remain free from harmful microbial contamination throughout their shelf life. Preservatives are added to cosmetics to prevent the growth of bacteria, fungi, and yeast, which could lead to spoilage, reduced product efficacy, or health risks to consumers. This test evaluates whether the preservatives in the formulation effectively control microbial growth under realistic usage conditions. The test is described in Section 4.5.
3. Product compatibility test: The product compatibility test ensures that cosmetic products maintain their quality and safety when in contact with various materials, including packaging and human skin. This test is crucial for products containing sensitive ingredients or packaging, as compatibility issues can lead to degradation of the product's efficacy, safety, or appearance. Further details are provided in Section 4.6.
4. Overall performance test: The overall performance test is a comprehensive evaluation designed to assess the effectiveness, safety, and consumer satisfaction of the cosmetic product. This test helps determine whether the product delivers on its claims and is essential before the product is released to the market. The test is described in Section 4.7.

Once a physically feasible concept successfully passes all required tests, it is considered validated and ready for the next steps: integrating the product with the necessary production line setup and progressing toward industrialization.

This study incorporates consumer insights during both the concept selection and validation, as well as the refining phases. Initially, feedback from internal company stakeholders is gathered to assess the feasibility and potential of the product concept. In the subsequent refining and testing phase, a selected group of anonymous voluntary con-

sumers, not affiliated with the company, participate in concept assessment during testing and refinement phase. These insights are essential for guiding the transition from the conceptualization phase to the early stages of industrialization. However, long-term consumer feedback and broader market acceptance will be addressed in later stages of product development, once the concept has advanced beyond this initial phase.

4. Testing Methods

In this section, we outline the testing methods employed during the *Concept Validation* and *Concept Refinement* stages. Section 4.1 details the equipment, measurement conditions, and reagents used in the study. The subsequent sections describe the experimental methods for each test, which are summarized in Table 1 along with their respective abbreviations.

Table 1. Test characterization and acronyms.

Test	Abbreviation	Section
Study of economic feasibility	EC Assessment	Section 2
Centrifugal Stability Test	CS Test	Section 4.2
Preliminary Stability Test	PS Test	Section 4.3
Accelerated Stability Test	AS Test	Section 4.4
Preservative Efficacy Test	PE Test	Section 4.5
Product Compatibility Test	PC Test	Section 4.6
Overall Performance Test	OP Test	Section 4.7

The tests performed in our study align with the legal requirements prescribed by European Union Regulation (EC) No 1223/2009 [27], which governs the safety of cosmetic products within the EU. The regulation mandates several key assessments, including: (i) safety assessment by a qualified safety assessor; (ii) microbiological testing, including preservative efficacy testing, to ensure biological stability; (iii) stability testing to verify the product's physical and chemical integrity over time; and (iv) toxicological evaluation of ingredients to assess potential health risks. These tests collectively establish compliance with safety and efficacy standards, ensuring that the final product meets both consumer expectations and regulatory obligations.

4.1. Equipment, Measurement Conditions, and Reagents

The density was measured using a *Densito 30PX Portable Density Meter* (Mettler Toledo, Columbus, OH, USA), with a precision of $2 \times 10^{-5} \text{ g} \cdot \text{cm}^{-3}$. Viscosity was measured with an *AMETEK Brookfield DV-E Viscometer* (AMETEK Brookfield, Middleborough, MA, USA), offering a precision of $\pm 1.0\%$ and reproducibility of 0.2% . pH was determined using a *Crison Basic 20 pH Meter* (Crison, Barcelona, Spain). Ingredients in small proportions were weighed on an *AS 60/C/2 Precision Balance* (Radwag®, Radom, Poland), with a capacity of 60 g and a precision of 0.01 mg. The centrifuge used in the tests was an *Anke TDL-80-2B Low Speed Desktop Centrifuge* (Anke, Zhongshan, China), with a speed range of 100–400 rpm. Measurements of consistency, odor, and color were performed by experienced technicians.

All measurements using laboratory equipment were conducted under controlled conditions, with regular monitoring of temperature and humidity. The laboratory temperature was maintained at approximately 20 °C, with relative humidity at 55%. Samples subjected to specific conditions in the tests were allowed to acclimate to the ambient laboratory conditions before measurements, and measurements were only taken once all samples reached 20 °C.

The distilled water used in the experiment underwent a deionization process. The cetearyl alcohol utilized is 100% vegetable-based, Kosher, and HALAL certified (Full specification: *ThaiOL 1618*, Global Green Chemicals (PTTGC Group, Bangkok, Thailand).

The cetrimonium chloride used is an aqueous-based 30% active quaternary ammonium conditioning and antistatic agent, suitable for hair conditioner/rinse formulations (Full specification: *Microcare® Quat CTC30*, Thor, England, UK). The glyceryl stearate is an emulsifier recommended for cosmetic applications, derived from coconuts (Full specification: *ERCAWAX GMS V*, ErcaWilmar, Grassobbio, Italy). The behentrimonium chloride used is an 80% active quaternary ammonium conditioning and antistatic agent, suitable for hair conditioner/rinse formulations, and is derived from the canola plant (Full specification: *Microcare® Quat BHQ*, Thor, England, UK). The citric acid used was produced through the fermentation of carbohydrates derived from citric fruits (Full specification: *Citric acid*, MakingCosmetics Inc., Redmond, WA, USA). The isopropyl myristate used is a fast-spreading emollient suitable for all cosmetic applications and is vegetable-derived (Full specification: *Isopropyl myristate*, MakingCosmetics Inc., Redmond, WA, USA). The Shea Butter used is obtained from the kernel or almond seed of the Shea (*Butyrospermum parkii*) tree (Full specification: *Refined butyrospermum parkii butter*, Interfat, Barcelona, Spain). The glycerin used is derived from vegetable oils (Full specification: *Glicerina USP Vegetal*, RNM, Vila Nova de Famalicão, Portugal). The Aloe barbadensis M. Leaf Juice used was sourced from ecological agriculture (Full specification: *Aloe Vera Puro Bio*, Querlan, Badajoz, Spain). The tocopherol (vitamin E) is an active ingredient specifically used in cosmetic products (Full specification: *Cosroma® Natural VE70*, COSROMA®, Shanghai, China). The pinus oil used was obtained through steam distillation of *Pinus pinaster* twig leaves (Full specification: *Óleo Essencial de Pinheiro BIO* (100%), Proentia, Proença-a-Nova, Portugal). The garlic extract used contributes to skin health and hair vitality (Full specification: *Extracto de Alho*, Proaromática—Aromas Alimentares Lda., Lisboa, Portugal). The parfum used has notes of vanilla, raspberry, and peach (Full specification: *Melba*, F. Mesquita Araújo, Porto, Portugal).

4.2. Centrifugal Stability Test

Each sample is subjected to 3000 rpm centrifugation for 3 min, and its appearance is then analyzed [28]. The instability of an emulsion is visually determined by the presence of phase separation and/or particle precipitation.

4.3. Preliminary Stability Test

For a period of 15 days, a sample portion is subjected to a 24-h cycle at $45 \pm 2^\circ\text{C}$, followed by 24 h at $8 \pm 2^\circ\text{C}$. This cycle is repeated until the end of the 15-day period. Simultaneously, a portion of the sample is stored at room temperature ($20 \pm 2^\circ\text{C}$, without stress conditions) as an experimental control. The evaluation criteria for the sample are divided into two main categories of parameters:

- physicochemical parameters: pH, density, and viscosity; and
- organoleptic parameters: consistency, color, and odor.

For the physicochemical parameters, the pH, density, and viscosity of the sample are analyzed and compared with those of the control sample. The test is considered “OK” when the values of the sample do not deviate significantly from those of the control, and they must fall within the acceptable range defined in the concept specifications [29].

Organoleptic parameters are evaluated through visual and olfactory analysis. Since these parameters are subjective, all evaluations for the same concept must be performed by the same person. The color, odor and consistency of the sample are compared to the control, and each characteristic is classified according to the criteria in Table 2. For approval, the sample must only be classified as “OK” for the organoleptic parameters.

Table 2. Classification of organoleptic parameters in preliminary stability tests.

Classification	Color/Odor/Consistency Appearance
OK	Normal
M	Modified (for Color/Odor/Consistency)
M+	Positively Modified (for Color/Odor/Consistency)
M−	Negatively Modified (for Color/Odor/Consistency)
LM+	Slightly Positively Modified (for Color/Odor/Consistency)
LM−	Slightly Negatively Modified (for Color/Odor/Consistency)
IM+	Intensively Positively Modified (for Color/Odor/Consistency)
IM−	Intensively Negatively Modified (for Color/Odor/Consistency)

The classification scheme presented in Table 2 is somewhat vague, as it measures the tester’s perception relative to a reference. In practice, it serves as a substitute for measuring complex variables or those that are physically impractical to quantify, which are strongly linked to perception. This approach requires trained testers. Despite this requirement, perception-based measurement systems are widely used in various fields of product development, such as cosmetics and food [30,31].

4.4. Accelerated Stability Test

The testing begins with the preparation of four sample portions, each subjected to different conditions as described below [32]:

1. Sample 1: Room temperature (control: $20 \pm 2^\circ\text{C}$);
2. Sample 2: Stored in the incubator at $45 \pm 2^\circ\text{C}$;
3. Sample 3: Placed in the refrigerator at $8 \pm 2^\circ\text{C}$;
4. Sample 4: Exposed to solar radiation.

Samples from each formulation were simultaneously exposed to different conditions and monitored at regular time intervals. Each sample is analyzed at time 0 and on the 7th, 15th, 30th, 60th, 90th, and 120th days, and the results are documented accordingly. Similar to the preliminary stability test, the organoleptic parameters of the samples (color, odor, and consistency) are classified according to the nomenclature in Table 2. As for the physicochemical parameters, all are measured throughout the course of the test, except for density, which is only measured at time 0 and again at the end of the test (120 days).

For the test to proceed and be approved, the organoleptic results must only include classifications of “OK”, “LM−” or “LM+”, and the physicochemical parameters must not show significant variation when compared to the control sample values.

4.5. Preservative Efficacy Test

This test consists of two main parts: validating neutralization efficacy and conducting the preservative efficacy test itself. The methodology for this test should align with guidelines from pharmacopeias, though many companies now follow the ISO 11930:2019 standard [33], which pertains to microbial assessment and protection in cosmetics. The test microorganisms include *Staphylococcus aureus*, *Candida albicans*, *Pseudomonas aeruginosa*, *Escherichia coli*, and *Aspergillus brasiliensis*.

4.5.1. Part 1: Neutralization Efficacy Validation

In this step, a solution with neutralizing properties (medium A) is used to inhibit the preservative in the product, allowing for microbial growth of inoculated strains. This step confirms that the inoculated microorganisms can grow in the sample when the preservative is neutralized. Each microorganism is tested with three samples: a positive control (medium A inoculated with the microorganism), a negative control (medium A only), and the test

samples (inoculated solution, medium A, and the cosmetic sample). Samples are incubated based on the conditions appropriate for each microorganism, as specified in Table 3.

Table 3. Incubation conditions for bacteria, yeasts, and fungi.

Microorganism	Culture Media	Incubation Temperature	Incubation Period
Bacteria	TSA	30–35 °C	2–3 days
Yeast	SDA	30–35 °C	2–3 days
Fungus	PDA	20–25 °C	3–5 days

TSA—Tryptic Soy Agar; SDA—Saboraud Dextrose Agar; PDA—Potato Dextrose Agar.

Results are analyzed by counting colony-forming units (CFU/g_{product}) in each sample and calculating the recovery rate (T) as shown in Equation (1):

$$T(\%) = \frac{U}{Z} \times 100 \quad (1)$$

where T represents the recovery rate, U is the CFU/g_{product} count in the sample, and Z is the CFU/g_{product} count in the positive control. The methodology is validated only if the recovery rate (T) falls between 50% and 200%.

4.5.2. Part 2: Preservative Efficacy Test

Once the neutralization medium has been validated, the preservative efficacy test (PET) can proceed. Product samples are inoculated with microorganisms at a concentration equivalent to 1% of the sample. Negative controls are prepared, and all samples are incubated according to the specific requirements for each microorganism, as outlined in Table 3.

The test spans 28 days, with samples analyzed on days 0, 7, 14, 21, and 28. Sampling and monitoring of microbiological activity involve counting colonies in a portion of the sample. The process begins by mixing the sample with a neutralizing medium (Medium A), followed by serial dilutions. These dilutions are plated and incubated to allow microorganisms to develop into colonies. The colonies are subsequently counted using a colony counter and expressed as colony-forming units (CFU) per gram of product (CFU/g_{product}).

The results are converted to a logarithmic scale to calculate the decimal reduction in CFU (CFU/g_{product}) from $t = 0$ to t , denoted as ΔU_t , using:

$$\Delta U_t = \log_{10} \left(\frac{U_0}{U_t} \right) = \log_{10}(U_0) - \log_{10}(U_t), \quad (2)$$

where U_0 and U_t represent the colony concentrations at times $t = 0$ and t , respectively. The acceptable tolerance for the decimal logarithmic reduction is ± 0.5 . The calculated ΔU_t values are then compared to the criteria outlined in Table 4. The target values in Table 3 are ≥ 3 for bacteria and ≥ 1 for yeast, establishing the lower specification limits of 2.5 for bacteria and 0.5 for yeast, respectively.

If criterion A is met, the preservative efficacy test is passed. If only criterion B is met, the formulation does not meet the requirements, and additional justification is needed to demonstrate microbiological protection. Failure to meet both criteria results in a failed test.

Table 4. Criteria for ΔU_t reduction values for bacteria, yeasts, and fungi (adapted from ISO 11930:2019). A tolerance of ± 0.5 is accepted.

Parameter	Bacteria			Yeast			Fungi	
Sampling time	T7	T14	T28	T7	T14	T28	T14	T28
Criterion A	≥ 3	≥ 3 and NI	≥ 3 and NI	≥ 1	≥ 1 and NI	≥ 1 and NI	≥ 0	≥ 1 and NI
Criterion B	—	≥ 3	≥ 3 and NI	—	≥ 1	≥ 1 and NI	≥ 0	≥ 0 and NI

NI—No increase in count from the previous time point; 0—No increase in count from initial time point. ——No specification; T7—7th day; T14—14th day; T28—28th day.

4.6. Product Compatibility Test

The formulation is packaged and subjected to the following conditions [29]:

1. 7 days at room temperature (control: $20 \pm 2^\circ\text{C}$);
2. 7 days in an incubator at $45 \pm 2^\circ\text{C}$;
3. 7 days in a refrigerator at $8 \pm 2^\circ\text{C}$;
4. 7 days with exposure to solar radiation.

The sample is analyzed at baseline (time 0) and on days 7, 14, 21, and 28. At time 0 and day 28, viscosity and density of the product are measured. On the other sampling days, organoleptic parameters (color, odor, and consistency) are assessed using the criteria outlined in Table 2, along with pH measurements.

For the packaging to be deemed functional, the physicochemical parameters must not show significant variation (relative to the control sample values) and must remain within the acceptable range specified in the concept specifications. The organoleptic parameters should receive an assessment of OK only.

4.7. Overall Performance Test

The performance test involves a group of volunteers who use the developed product and provide feedback on their experience. Instructions for product use are provided, with a recommendation to use the product at least three times before evaluation [34]. Each test is tailored to the specific characteristics of the product, using a rating scale from 1 to 5 with only integer values.

5. Application of the Procedure

In this Section, we apply the procedure outlined in Section 3 to design a bio-based hair mask. The tests presented in Section 4 are used to evaluate the product's ability to meet the specified requirements.

5.1. Product Mission Statement

The procedure began with defining the product's mission statement: to expand the company's portfolio with a bio-based hair mask. The DT, which participated in an internal focus group, emphasized the use of natural ingredients—such as essential oils and plant extracts—to target a niche market focused on sustainability. This vision extended to the product's appearance and perception, with a nature-inspired color palette chosen for its public presentation. Additionally, the packaging featured neutral tones and organic shapes, reinforcing the sustainability. The product was designed for all hair types, with its primary goals being to enhance shine and softness. The product was named *Origins*.

5.2. Needs Elicitation

Next, the DT identified the product's needs. The internal client's needs were defined through a series of focus group sessions involving various company collaborators, ensuring

a thorough understanding for informed decision-making. The external client's needs were determined through a two-step process. The first step involved a literature review to identify relevant market trends. A key insight was the rise of the “clean beauty” and “green cosmetics” movements, which reflect growing consumer awareness and emphasize natural, sustainable ingredients. The review also highlighted that, despite the importance of sustainability, the market places greater emphasis on price and product efficacy than on formulation. This information was supplemented by a survey.

The survey results indicated that respondents prioritized product efficacy above all, followed by price. While the use of natural ingredients and low environmental impact were considered less critical, they remained important factors. The needs identified from both internal and external clients were categorized into four primary needs (see Table 5): (i) regulatory requirements; (ii) physical-chemical properties; (iii) performance and consumer perception; and (iv) commercial and economic impacts on the company.

Each primary need encompasses several secondary needs, which are detailed in the third column of the table. The second column provides a numbering system for the secondary needs, simplifying their reference in subsequent sections.

Table 5. Elicited product needs.

Primary Needs	Number	Secondary Needs	Source
1. Regulatory	1.1	Ensure biological stability	IC
	1.2	Maintain short-term physical, chemical, and sensory stability	IC
	1.3	Maintain long-term physical, chemical, and sensory stability	IC
	1.4	Use ingredients suitable for industrial-scale production	IC
2. Physical-chemical properties	2.1	Achieve an optimal pH	IC
	2.2	Exhibit ideal viscosity	IC
	2.3	Exhibit ideal density	IC
	2.4	Ensure product homogeneity	IC
	2.5	Use ingredients of natural origin	EC
3. Performance/Perception	3.1	Provide a softening effect on hair	EC
	3.2	Enhance hair shine	EC
	3.3	Deliver a pleasant fragrance	EC
	3.4	Feature a smooth and appealing texture	EC
	3.5	Exhibit a visually attractive appearance	EC
	3.6	Include practical and functional packaging	IC
	3.7	Reinforce and seal the hair strands	IC
4. Commercial	4.1	Offer competitive and affordable pricing	EC
	4.2	Present an aesthetically pleasing design	EC

IC—Internal client; EC—External client.

5.3. Setting the Specifications

In the next task, the design team developed specifications—at least one for each secondary need—to assess client satisfaction. The resulting specifications are summarized in Table 6. Many of these specifications are based on tests mandated by international standards, as detailed in the second column, which also indicates the physical units used to measure quantitative variables. The third column lists the specific tests described in Section 4. The fourth column presents the measurement units or possible outcomes of these tests, while the fifth column specifies the target values. Standard values, which ensure the product's physical feasibility, are also included in the fifth column after the “/” symbol. These values were established by integrating experience-based knowledge with benchmarking practices. Finally, it is worth noting that most of the standard tests yield binary results, where OK indicates compliance and NOK signifies non-compliance.

Table 6. Specifications of the *Origins* hair mask concept, including standards, testing protocols, target values, and acceptable ranges.

Need	Standard/Metric	Test (Table 1)	Unit/Result	Target/Standard Values (Ranges)
1.1	ISO 11930:2019	PE Test	{OK, NOK}	OK/OK
1.2	ISO/TR 18811:2018	PS Test	{OK, NOK}	OK/OK
1.3	ISO/TR 18811:2018	AS Test	{OK, NOK}	OK/OK
1.4	EC Regulation No 1223/2009	EC Assessment	{OK, NOK}	OK/OK
2.1	pH (Sørensen scale)	Measurement	Unitless	[3.5, 4.0]/[3.5, 5.0]
2.2	Viscosity	Measurement	cP	$[2.0, 3.0] \times 10^4 / [1.0, 4.0] \times 10^4$
2.3	Density	Measurement	g/cm ³	[0.95, 0.98]/[0.90, 0.99]
2.4	Homogeneity	CS Test	{OK, NOK}	OK/OK
2.5	Ingredient Origin	Chem. Analysis	{OK, NOK}	OK/OK
3.1	Hair Smoothness	OP Test	{OK, NOK}	OK/OK
3.2	Hair Shine	OP Test	{OK, NOK}	OK/OK
3.3	Fragrance	OP Test	{OK, NOK}	OK/OK
3.4	Product Texture	OP Test	{OK, NOK}	OK/OK
3.5	Product Appearance	OP Test	{OK, NOK}	OK/OK
3.6	Packaging Functionality	CPE	{OK, NOK}	OK/OK
3.7	Cuticle Sealing	OP Test	{OK, NOK}	OK/OK
4.1	Price	EC Assessment	EURO	≤6.56/≤8
4.2	Commercial Appearance	OP Test	{OK, NOK}	OK/OK

OK—"OK"; NOK—"Not OK"; Chem. Analysis—chemical analysis.

5.4. Generating Concepts

In this phase, the DT focused on concept generation. First, they decomposed the product into atomic functional elements following the guidelines provided in Baki and Kenneth [11], Benson et al. [35]. Next, they outlined potential solutions for each functional subproblem. The results are summarized in Table 7, where: (i) the first column lists the ten identified product functions; (ii) the second specifies the corresponding functional requirements; and (iii) the third presents the technical alternatives available for addressing each subproblem.

All the proposed solutions are distinct, with the exception of the following: (i) the *Emulsifier* function, which utilizes a blend of cetrimonium chloride and glyceryl monostearate, with adjustable weight fractions; (ii) the *Conditioner* function, based on a combination of shea butter, glycerin, and aloe vera; and (iii) the *Preservative* function, incorporating a mixture of pine needle oil of *Pinus pinaster* species as discussed in Tümen et al. [36], Mimoune et al. [37] and garlic (*Allium sativum*) extract as in Rybczyńska-Tkaczyk et al. [38]. Solutions that combine multiple raw materials are grounded in the principle of raw-material synergy [39,40]. Moreover, the company's track record confirms that integrating several ingredients with the same function consistently produces superior results compared to using these ingredients individually.

While the solutions are generally distinct, they can be combined in various weight fractions, enabling the creation of different concepts with unique properties. Thus, beyond selecting alternatives for each functional element, an additional dimension in concept generation involves optimizing the weight fractions to achieve the desired outcomes. A key aspect is that all the components listed in Table 7 are naturally derived, aligning the concept with the requirements for bio-based products as outlined in the product's mission statement.

Table 7. Functional decomposition of the *Origins* hair mask concept.

Function	Functional Requirement	Solution	Abbreviation
Solvent	Emulsion base	Water	WAT
Viscosity Regulator	Control viscosity	Cetostearyl Alcohol	CSA
Emulsifier	Promote emulsification	Cetrimonium Chloride + Glyceryl Monostearate	CTAC + GMS
Antistatic	Reduce hair static	Behentrimonium Chloride	BTC
pH Regulator	Adjust pH	Citric Acid	CA
Emollient	Soften hair	Isopropyl Myristate	IPM
Conditioner	Condition hair	Shea Butter + Glycerin + Aloe Vera	SHB + GLY + ALV
Antioxidant	Prevent oxidation	Tocopherol (Vitamin E)	TOC
Preservative	Ensure product stability	Pine Needle Oil + Garlic Extract	PNO + GAE
Fragrance	Provide scent	Perfume	PER

The functional decomposition was then employed to generate concepts. In practice, a concept corresponds to a formulation in which constituents are combined in specific weight fractions. Throughout the project, multiple concepts were developed; however, many were discarded during the concept selection or test refinement phases due to their unsuitability. In this particular case, three concepts were sequentially generated: the first did not pass the concept selection phase, the second failed during concept validation, and the third successfully completed the entire sequence of tests. While details of the first two are omitted in this paper, they played a crucial role in determining the components and concentrations used in the final formulation.

To streamline the discussion, we focus on the generation, selection, and testing of the successful concept—the third one. Its composition is detailed in Table 8, where: (i) the first column lists the functional elements (or subproblems); (ii) the second specifies the constituent selected as the solution; and (iii) the third indicates the corresponding weight fraction. Each concept is commonly referred to as a formula. The pH of the formula in Table 8 is 3.7, which falls within the target range specified in Table 6. The procedure for its production is outlined in Table 9, and its appearance is illustrated in Figure 3.

Table 8. Formulation of concept *Origins*: adopted solutions and corresponding percentages.

Function	Adopted Solution	%w/w
Solvent	Water (WAT)	80.69
Viscosity Regulator	Cetostearyl Alcohol (CSA)	7.00
Emulsifier	Cetrimonium Chloride (CTAC) + Glyceryl Monostearate (GMS)	2.00 [†] + 0.40
Antistatic	Behentrimonium Chloride (BTC)	1.00 [‡]
pH Regulator	Citric Acid (CA)	0.20
Emollient	Isopropyl Myristate (IPM)	0.20
Conditioner	Shea Butter (SHB) + Glycerin (GLY) + Aloe Vera (ALV)	1.00 + 4.00 + 1.00
Antioxidant	Tocopherol (TOC)	0.01
Preservative	Pine Needle Oil (PNO) + Garlic Extract (GAE)	0.80 + 0.50
Fragrance	Perfume	1.20

[†]—The raw material used is composed of 30% active cetrimonium chloride; [‡]—The raw material used is composed of 80% active behentrimonium chloride.

Our formulation is predominantly water-based (above 80%), which significantly reduces its environmental footprint. The remaining ingredients, including garlic extract and pine needle oil, are derived from renewable sources, ensuring biodegradability and minimizing long-term ecological impact. Furthermore, our formulation is nearly free from synthetic additives known to contribute to pollution. While a full life-cycle assessment could provide a more detailed quantification, the renewable, biodegradable, and non-persistent nature of our ingredients suggests a negligible environmental burden.

To further improve the sustainability of raw-materials in our formulation, we could consider: (i) Sustainable sourcing—prioritizing suppliers that adhere to environmentally responsible practices; and (ii) Using green extraction methods—exploring solvent-free or low-energy extraction techniques to further reduce environmental impact during ingredient processing.

Additionally, we acknowledge that other bio-based ingredients could serve the same functions as those we have selected. Our choices are based on the prior experience of a specific company, the availability of raw materials, and the company’s strategic focus on sourcing ingredients that align with the product categories it seeks to emphasize in its geographic region. For instance, pine needle oil could be replaced by lavender oil, garlic extract by rosemary extract, and alternatives such as chitosan or propolis could also be considered.

Table 9. Procedure to obtain the formula of the concept *Origins*.

1.	Preparation of Water Phase:
	- Place approximately 70% of the water into a mechanical agitator with heating. Reserve the remaining 30% of water for later use. - To the 70% water, add citric acid, glycerin, and cetrimonium chloride. Set the temperature to 80% and adjust the agitation speed to a low setting (around 300 rpm).
2.	Preparation of Other Ingredients:
	Simultaneously, place all other ingredients, except for the fragrance, preservatives, antioxidant, and aloe vera, into a water bath at 80 °C.
3.	Combining Phases:
	- Once the water phase reaches 80 °C, increase the agitation speed to 1200 rpm. - Remove the other ingredients from the water bath and cool them manually with stirring until they reach 78 °C. - Quickly add the cooled ingredients to the water phase, which is still under agitation, and continue stirring for 90 s.
4.	Final Steps:
	- After 90 s, reduce the agitation speed to 500 rpm. - Gradually add the remaining 30% of water (previously reserved). - Allow the emulsion to cool to 20 °C. - Introduce the fragrance, preservatives, antioxidant, and aloe vera while maintaining mechanical agitation. - Measure the pH of the emulsion—use a pH adjuster, if necessary—to bring it within the target range (see Table 6).

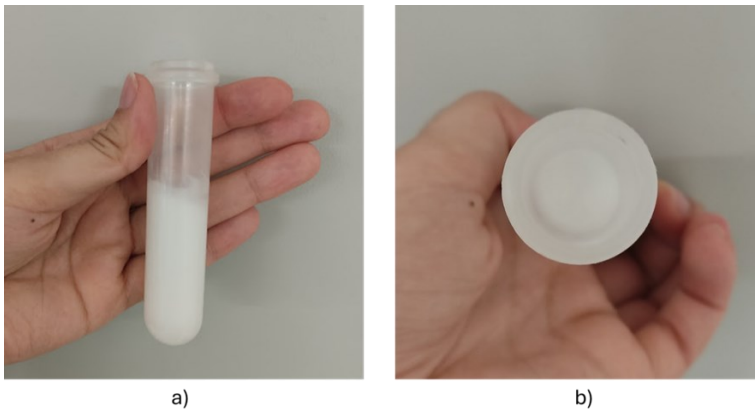


Figure 3. Aspect of the formula: (a) lateral perspective; (b) above perspective.

5.5. Concept Selection and Validation

In this Section, we follow the sequence of sub-tasks outlined in concept selection and validation phase and report the results for the concept *Origins*.

The concept was initially subjected to an economic analysis, which included forecasting the costs of raw materials, production, and packaging. The estimated cost was

5.36 EUR/package, with each package containing 250 g. This value is below the target cost of 6.56 EUR/package as outlined in Table 6.

Next, the concept was evaluated for centrifugal stability using the test described in Section 4.2. The results showed that the emulsion maintained a homogeneous appearance, with no visible phase separation or precipitation of ingredients. Therefore, the result was deemed satisfactory (OK). All tests, except for the preservative efficacy test, were conducted with a single replicate. This approach aligns with industry practices, aiming to save resources and streamline development time.

Subsequently, the concept underwent a preliminary stability test as detailed in Section 4.3. The results, presented in Table 10, demonstrate that the color, odor, and consistency of the concept sample were indistinguishable from the control sample. Additionally, the pH and density values were nearly identical. These findings confirm the success of the preliminary stability test, and overall, the result is deemed satisfactory (OK).

Table 10. Preliminary stability test results for *Origins* hair mask (tests conducted at 20.4 °C and relative humidity of 56%).

Property	Control Sample Appearance	Concept Sample Appearance	Test Result
Color	Whitish Cream	Indistinguishable from Control	OK
Odor	Characteristic	Identical to Control	OK
Consistency	Creamy, Homogeneous Emulsion	Identical to Control	OK
pH	3.71	3.73	OK
Density (g/cm ³)	0.9687	0.9690	OK

The difference in pH between the control and concept samples is 0.02 units, corresponding to a 0.54% variation. For density, the observed difference is 0.03%. Both variations are minimal, indicating that the emulsions exhibit comparable physical properties.

Finally, the concept progressed to the preliminary performance test, which follows the same protocol as the overall performance test described in Section 4.7, with the main difference being the group of participants. In this phase, the product was tested exclusively by company employees, whereas in the final testing phase, volunteers included potential consumers. The volunteers assessed the product's performance based on both organoleptic and functional characteristics. To randomize the test, two distinct samples with the same formula were produced and evaluated, with each participant providing their classification for each sample. The point scale used in Table 11 corresponds to the sensory evaluation of the samples, with a 250 g emulsion batch produced for each test. The results show that the test is deemed satisfactory (OK). As a result, the concept *Origins* successfully passed the concept selection phase.

Table 11. Results of the evaluations of the *Origins* hair mask in the preliminary performance test.

Property Type	Characteristic	Evaluator 1	Evaluator 2
Organoleptic	Visual Appearance	5	5
	Color	4	4
	Odor	4	5
	Consistency	5	5
Functional	Hair Shine	5	5
	Hair Softness	5	5

Scale: 1—Strongly Dislike; 2—Moderately Dislike; 3—Neutral; 4—Moderately Like; 5—Strongly Like.

5.6. Concept Refining and Testing

We now follow the sequence of sub-tasks outlined in the concept refining and testing phase and present the results for the concept *Origins*.

The concept was first subjected to the accelerated stability test, as described in Section 4.4. The results are summarized in Table 12. The table's first column details the test conditions, while the second column provides the sampling times. Columns 3 to 5 present the results for organoleptic properties, and the final three columns display the quantitative metrics: pH, density, and viscosity.

The organoleptic test results remained within the validation range, except for the 90 days and 120 days sampling, where the hair mask, when exposed to solar radiation, showed a color classification below the approval target. These changes were observed only during the final months of analysis and occurred in a single sample. Consequently, the DT approved the test on the condition that the product would be marketed exclusively in opaque packaging to prevent solar exposure. In all other cases, the results were predominantly classified as OK, with a few instances of LM+ and LM−. Meanwhile, the quantitative metrics—pH, density, and viscosity—showed no significant deviations from the control sample values listed in Table 10 (for pH and density) across all comparisons made relative to day 0. These findings collectively confirm the success of the accelerated stability test. Overall, the concept *Origins* is considered satisfactory (OK).

Table 12. Results of the *Origins* hair mask in the preliminary performance test (comparisons relative to day 0).

Conditions	Time (Days)	Color	Odor	Consistency	pH	Density (g/cm ³)	Viscosity (×10 ⁴ cP)
$T = 20 \pm 2^\circ\text{C}$	0	OK	OK	OK	3.71	0.9687	2.7409
	7	OK	OK	OK	3.77	0.8965	2.2460
	15	OK	OK	OK	3.78	0.9163	2.3104
	30	OK	OK	OK	3.76	0.9484	2.0791
	60	OK	OK	OK	3.81	0.9599	2.0677
	90	OK	OK	OK	3.84	0.9584	2.0396
	120	OK	OK	OK	3.83	0.9643	1.7102
$T = 8 \pm 2^\circ\text{C}$	0	OK	OK	OK	3.71	0.9687	2.7409
	7	OK	OK	OK	3.65	0.8742	5.4935
	15	OK	OK	OK	3.68	0.8933	4.8434
	30	OK	OK	OK	3.70	0.9127	4.4744
	60	OK	OK	OK	3.76	0.9144	4.1990
	90	OK	OK	OK	3.81	0.9249	3.9877
	120	OK	OK	OK	3.88	0.9354	3.9122
$T = 45 \pm 2^\circ\text{C}$	0	OK	OK	OK	3.71	0.9687	2.7409
	7	OK	OK	OK	3.62	0.8755	2.6835
	15	OK	OK	OK	3.64	0.8694	2.4473
	30	OK	OK	OK	3.59	0.9183	2.2606
	60	OK	LM−	OK	3.73	0.9120	2.1464
	90	OK	OK	OK	3.88	0.9307	1.9201
	120	OK	LM−	OK	3.94	0.9345	1.6744
Solar exp.	0	OK	OK	OK	3.71	0.9687	2.7409
	7	OK	OK	OK	3.74	0.9485	2.3983
	15	OK	OK	OK	3.74	0.8974	2.3661
	30	OK	OK	OK	3.81	0.8699	2.4949
	60	LM+	LM−	OK	3.80	0.8976	2.1769
	90	M+	LM−	OK	3.78	0.9284	2.1394
	120	M+	LM−	OK	3.78	0.9984	1.9098

Next, we conducted the preservative efficacy test, as outlined in Section 4.5. The first step involved validating the neutralization efficacy (see Section 4.5.1). The results, presented in Table 13, demonstrate that the recovery rates fall within the required range of 50–200%, confirming the success of this phase. As a result, we can proceed to Part 2 of the test.

Table 13. Recovery rate of the neutralization efficacy test (values expressed in %).

Microorganism	Type	Family	T (%)
<i>Escherichia coli</i>	Bacteria	<i>Enterobacteriaceae</i>	153.13
<i>Staphylococcus aureus</i>	Bacteria	<i>Staphylococcaceae</i>	50.72
<i>Pseudomonas aeruginosa</i>	Bacteria	<i>Pseudomonadaceae</i>	51.06
<i>Candida albicans</i>	Yeast	<i>Saccharomycetaceae</i>	51.90

Part 2 of the test, the preservative efficacy test, was conducted as described in Section 4.5.2. Colony-forming units were counted on days 0, 7, 14, 21, and 28, and the decimal logarithmic reduction (ΔU) was calculated to assess antimicrobial efficacy. The tests were performed in triplicate, and the results, shown in Figure 4, confirm that criterion A was met, demonstrating the concept's successful performance in the PET. Error bars represent the standard deviation of the mean.

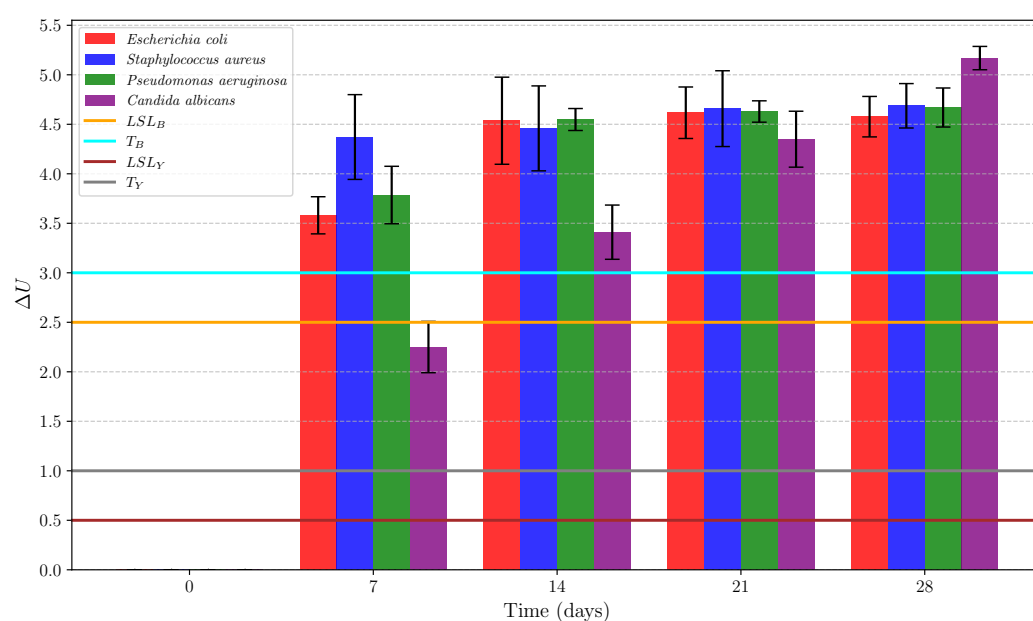


Figure 4. Decimal logarithmic reduction (ΔU) of microorganisms over the duration of the preservative efficacy test (PET). Horizontal lines indicate the specification limits and target values in Table 4: LSL_B (lower specification limit for bacteria), T_B (target for bacteria), LSL_Y (lower specification limit for yeast), and T_Y (target for yeast). Error bars represent the standard deviation of the mean.

Next, the *Origins* concept underwent the product compatibility test, following the methodology detailed in Section 4.6. The formulation was packaged in containers and exposed to the specified test conditions. The physicochemical parameters remained within acceptable variation ranges, and all organoleptic evaluations were rated as satisfactory. Consequently, the *Origins* concept successfully passed this phase. A notable observation from this test was the effectiveness of using opaque packaging and flasks to protect the product from solar radiation. This approach also addressed the issue identified during the accelerated stability test, demonstrating its viability as a solution.

Subsequently, it was evaluated in the overall performance test as described in Section 4.7. The test involved five external volunteers who used the formula. Limiting the test to five anonymous volunteers was intended to minimize both costs and the time required to organize the experiential meeting. The results are presented in Table 14. The average rating from the volunteers was 4.43 out of 5, indicating a positive response. Consequently, the product successfully passed the concept testing and refinement phase and is now ready to enter the production pipeline.

Table 14. Results of the *Origins* hair mask evaluation in the overall performance test.

Attribute	Volunteer 1	Volunteer 2	Volunteer 3	Volunteer 4	Volunteer 5
Visual Appeal (attractiveness)	5	5	5	5	5
Product Consistency	5	5	4	4	5
Scent of the Product	5	4	3	3	3
Color of the Product	5	4	4	5	4
Hair Shine Post-application	5	5	4	5	4
Hair Softness Post-application	5	5	5	5	5
Product Image (appeal)	5	5	4	4	4

Scale: 1—Strongly Dislike; 2—Moderately Dislike; 3—Neutral; 4—Moderately Like; 5—Strongly Like.

6. Conclusions

We applied the Conceptual Engineering methodology to systematically design a bio-based cosmetic product—a hair mask. To address the unique challenges of product development in the cosmetics sector, including meeting individual needs, ensuring physical and biological stability, complying with strict health and regulatory standards, and maintaining budget constraints, we tailored the methodology accordingly.

Instead of generating multiple concepts and selecting the best for refinement, we adopted an iterative process. In this approach, each concept is developed and evaluated through a *Concept Selection & Validation* phase. Concepts that pass this phase advance to the *Concept Refining & testing* stage. If successful, the product moves into the production ramp-up phase. At each stage, a series of physical and sensorial tests are conducted to ensure that the concept meets specifications and satisfies customer expectations. If a concept fails to pass a test, the process is re-initiated, allowing for adjustments and improvements.

As far as we know, the primary limitation of the proposed approach is that it does not inherently guarantee a successful formulation. Despite multiple iterations aimed at refining the concept to meet all predefined goals, some uncertainty remains as to whether the final formulation will be viable within the given time and budget constraints. However, we believe this challenge is not unique to our approach but is a common aspect of any development method in the cosmetics sector. One possible strategy to improve formulation success is the integration of computational tools to assist in component selection.

We demonstrated this proposed procedure through the development of a bio-based hair mask tailored to a specific market niche aligned with the “clean beauty” and “green cosmetics” movements. All raw materials used in the composition of the emulsion are of natural origin, with the exception of a few synthetic ingredients, such as centrimonium chloride, behentrimonium chloride, and isopropyl myristate. However, the quantities of these synthetic components in the formulation are minimal. The procedure enables the early elimination of physically or sensorially unsatisfactory solutions, thereby minimizing costs and shortening time to market. Regarding the bio-based mask *Origins*, it passed all tests; however, two aspects require further attention: (i) the product tends to degrade when exposed to solar radiation, necessitating its marketing exclusively in opaque packaging; and (ii) the preservative efficacy test included three microorganisms from the bacterial group and one from the yeast group (*Candida albicans*). Although there are similarities between *Candida albicans* and certain mold microorganisms, such as *Aspergillus niger*, including their fungal nature, environmental adaptability, and resistance mechanisms, there are also key differences. These differences suggest that additional testing with at least one mold microorganism may be required.

This systematic procedure ensures the reproducibility of the final solution, aligns with customer needs, and enables the company to gather knowledge for use in subsequent product design projects. While the approach was applied here to the development of

a cosmetic product, it can be generalized to other sectors where regulatory and health standards are restrictive, and where the cost and time required for product development are high.

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