Innovative utilization of *Moringa oleifera* in sustainable multipurpose sprays through the circular economy framework

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Abstract. In recent years, there has been a growing consumer shift toward natural and sustainable personal care products, driven by increased environmental awareness and health consciousness. This research proposes the development of a sustainable, multifunctional spray product formulated from *Moringa oleifera*, guided by the principles of the circular economy. The design process draws upon an empirical survey based on a questionnaire administered to 50 female respondents. Results revealed a significant demand for natural and environmentally friendly personal care products, particularly those enriched with antioxidant properties such as sprays intended for skin and lip application derived from *Moringa oleifera*. The proposed development model adopts the 4R framework (Reduce, Reuse, Recycle, Recover) to ensure environmentally conscious production. This includes the selection of sustainable raw materials, the application of green extraction technologies, the use of eco-friendly packaging, and the incorporation of consumer education. Moreover, residual biomass from the extraction process is innovatively utilized as a nutrient-dense supplement for animals and as organic fertilizer, thereby optimizing the value chain and minimizing environmental impact. This integrative approach presents a novel and comprehensive strategy for sustainable innovation in the personal care industry, balancing economic viability with environmental stewardship and social responsibility.

1 Introduction

Moringa oleifera, commonly referred to as Moringa, thrives in tropical and subtropical climates across regions such as Asia, Africa, and Latin America. Traditionally valued for both its medicinal and nutritional properties, Moringa is recognized for its dense composition of essential nutrients, including proteins, vitamins, minerals, and numerous bioactive substances like flavonoids and phenolics [1, 2, 3]. In recent years, scientific and commercial interest in Moringa has escalated, primarily due to its potent antioxidant capabilities.

Antioxidants play a critical biological role in neutralizing oxidative agents known as free radicals, which are implicated in the progression of various chronic illnesses, including

cancer, diabetes, and cardiovascular disorders [4]. Leaves of M. oleifera are especially rich in compounds like quercetin, kaempferol, and vitamin C, which are known to offer cellular protection from oxidative stress [5]. Numerous experimental studies have validated the strong antioxidant activity of Moringa extracts in both laboratory and applied settings [6].

Beyond its antioxidative properties, Moringa is acknowledged for its high nutritional profile. The leaves contain significant protein levels with a complete amino acid spectrum and are abundant in essential vitamins A, C, and E as well as minerals like calcium, iron, and magnesium [7]. These characteristics underscore its value in both dietary and therapeutic applications.

In alignment with sustainability goals, the circular economy aims to minimize waste by adhering to the principles of reduce, reuse and recycle [8]. Regulations need to be strengthened along the promotion of environmentally friendly [9]. The circular economy has emerged as a paradigm focused on minimizing resource depletion and maximizing product lifecycle through reuse, recycling, and efficient material utilization [10]. Within this framework, Moringa offers not only health benefits but also ecological utility, as extraction residues can be transformed into organic fertilizers [11]. High protein in Moringa also can be used as nutritional supplements for animal [12].

Given these multifaceted advantages, this research investigates the feasibility of incorporating *Moringa oleifera* as a natural antioxidant agent in the development of a multifunctional spray product, embedded within a circular economy model. The study aims to demonstrate how health functionality and sustainability can be synergistically achieved through responsible innovation.

2 Material and methods

The methodology employed in this research encompasses a multi-faceted approach, integrating empirical surveys, experimental design, and analytical techniques to develop a sustainable, multi-functional spray product derived from *Moringa oleifera*. The initial phase involves conducting an empirical survey utilizing questionnaires distributed to a sample of 50 female respondents, carefully selected to represent the target demographic for personal care products. This survey is designed to elicit comprehensive data regarding consumer preferences, needs, and perceptions concerning natural and environmentally friendly personal care products, with a specific focus on attributes such as antioxidant properties, desired application methods (e.g., skin and lip sprays), and willingness to adopt products derived from *Moringa oleifera*. The questionnaire incorporates a combination of structured (e.g., multiple-choice, Likert scale) and open-ended questions to capture both quantitative and qualitative insights into consumer behaviour and attitudes. Subsequently, the data collected from the surveys are meticulously analyzed using descriptive statistics and inferential statistical methods to identify key trends, patterns, and correlations, which inform the formulation and design of the proposed *Moringa oleifera*-based spray product. Following the survey phase, the research transitions into the design and product development stage. Dry leaf material, non-alcohol extraction methods, natural ingredients and ecofriendly product are explored to optimize the innovative utilization of *Moringa oleifera* in sustainable multipurpose sprays through the Circular Economy Framework.

3 Results

3.1 Consumer perception analysis

To evaluate market acceptance of a multifunctional spray product based on *Moringa oleifera*, a structured questionnaire was distributed among 50 female respondents. The findings are as follows:

- 76% acknowledged the potential of *Moringa oleifera* as a natural agent in health-related products.
- 80% were aware of its rich vitamin content.
- 46% had previous experience using products containing Moringa extract.
- 82% considered Moringa-based formulations safer than those containing synthetic ingredients.
- 90% expressed a willingness to recommend Moringa-based products to others

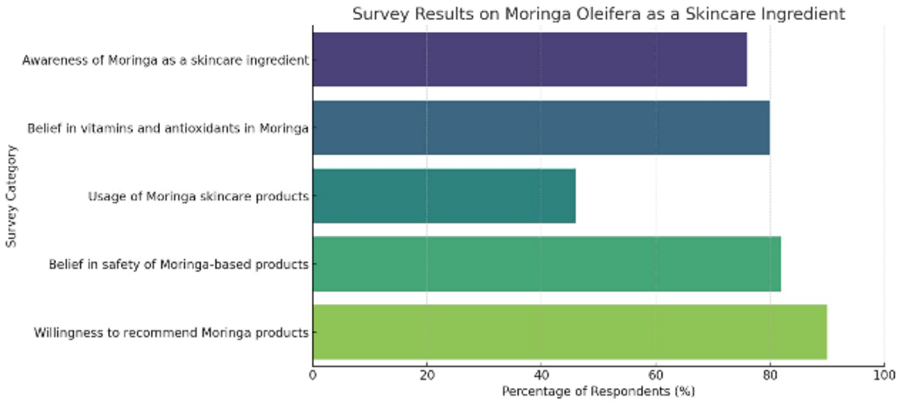

Fig. 1. Survey Results on Moringa Oleifera as a Skincare Ingredient

These outcomes highlight strong consumer receptivity toward Moringa-based personal care solutions, particularly those that align with sustainability and wellness trends. It indicates promising market potential for antioxidant-rich spray products developed through a circular economic approach.

3.2 Circular economy-based development model for moringa-based spray

3.2.1 Concept overview

The proposed innovation involves the formulation of a multifunctional spray incorporating *Moringa oleifera* extract, with design principles rooted in sustainability and circular resource management.

3.2.2 Model components

- **Raw Materials**: Moringa leaves serve as the core active ingredient due to their high antioxidant content. Natural solvents (e.g., purified water) are selected to ensure a non-toxic extraction process.
- **Extraction Process**: An eco-friendly method utilizing bromelain enzymes is applied to enhance the release of bioactive compounds without compromising

antioxidant potency. This enzymatic approach is favourable over conventional thermal extraction, which may degrade sensitive nutrients.

- **Formulation**: The Moringa extract is blended with safe and biodegradable ingredients such as water, glycerine, and plant-based preservatives. Stability assessments are conducted to validate shelf-life and product integrity.
- **Sustainable Packaging:** Environmentally responsible packaging is prioritized, including materials that are recyclable or biodegradable to reduce the ecological footprint.

3.2.3 Circular economy integration

- **Minimizing Waste**: By-products from Moringa extraction are reprocessed into organic fertilizers and livestock feed, ensuring full resource utilization.
- **Recycling Strategy**: A consumer-return system for used packaging is recommended to enhance recyclability and reduce plastic waste.

3.2.4 Marketing and public engagement

- **Promotion Strategy**: Targeted campaigns focus on health-conscious and eco-aware consumers, highlighting the dual benefits of the product: skincare and sustainability.
- **Educational Initiatives**: Informative programs such as workshops and community outreach aim to increase public understanding of Moringa's benefits and environmental significance.

3.2.5 Feedback mechanism

- **User Feedback:** Periodic consumer surveys are planned to collect evaluations regarding product performance, usability, and sustainability impact.

3.3 Moringa utilization model diagram without circular economy approach and new moringa utilization model diagram with circular economy approach

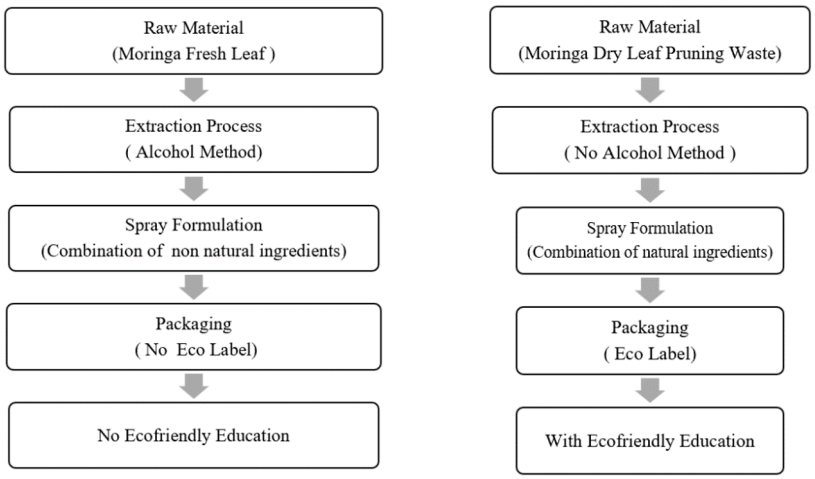

Fig. 2. Moringa Utilization Model Diagram without Circular Economy Approach (Left) and New Moringa Utilization Model Diagram with Circular Economy Approach (Right)

4 Discussion

4.1 Antioxidant efficacy of moringa

Moringa oleifera is renowned for its rich antioxidant profile, which includes compounds such as phenolic acids, flavonoids, and vitamin C. These agents contribute to cellular defense mechanisms against oxidative stress, a major contributor to chronic diseases [5].

4.2 Extraction and formulation considerations

The success of botanical product formulation hinges on the extraction methodology. Selecting natural and non-toxic solvents like water or food-grade ethanol not only ensures safety but also enhances the yield of active [2]. Stability testing of the final spray formulation is essential to guarantee that antioxidant activity remains intact over the product's intended shelf life. Additionally, factors such as pH balance, ingredient compatibility, and preservation systems must be optimized.

4.3 Circular economy strategy

Applying circular economy principles to Moringa utilization provides tangible environmental and economic benefits. Post-extraction residues are repurposed into agricultural resources such as compost or feed, thereby preventing waste and supporting regenerative practices [11]. This closed-loop model aligns with current industry trends that prioritize eco-efficiency. Recyclable and biodegradable packaging further complements this approach, responding to increasing consumer concern about packaging waste and carbon footprint.

4.4 Consumer behavior and awareness

Survey data affirm the growing consumer interest in natural and sustainable products [13]. However, widespread adoption may be hindered by limited public knowledge about Moringa's full benefits. Therefore, proactive educational outreach is crucial to building trust and awareness. Programs that demonstrate the science behind the product and its environmental merits can facilitate deeper consumer engagement.

4.5 4R Model Analysis

This study employs the 4R framework—Reduce, Reuse, Recycle, Recover—to evaluate the potential of Moringa-based multifunctional spray products from both ecological and economic perspectives.

- **Reduce: Minimizing Chemical Inputs**
  By replacing synthetic additives commonly used in skincare products with Moringa leaf extract, the formulation significantly reduces exposure to harmful chemicals. Moringa's naturally occurring phytochemicals including alkaloids (anti-inflammatory), flavonoids (antioxidant), and tannins (astringent) offer comparable or superior functional benefits to conventional agents.
- **Reuse: Residue Utilization in Agriculture**
  Following the extraction process, Moringa biomass remains rich in essential nutrients such as nitrogen, phosphorus, calcium, and iron. These can be repurposed as organic fertilizers to enhance soil fertility and support sustainable farming.

Organic amendments derived from plant waste improve water retention and soil microbial activity, reducing reliance on chemical fertilizers.

- **Recycle: Livestock Feed Application**
  The nutrient-dense residual biomass from Moringa extraction is also suitable for use as animal feed. With a protein content of approximately 25% (dry basis), the feed supplement contributes to improved animal health, immunity, and growth rates. Utilizing this waste stream can reduce feed costs and add value to agricultural systems.
- **Recover: Health and Environmental Restoration**
  The multifunctional spray offers numerous skincare benefits, including antibacterial properties to address antioxidant effects that combat signs of aging [14]. Environmentally, waste recovery through composting or animal supplementation reduces landfill pressure and mitigates pollution, while fostering resource circularity.

5 Conclusion

This study concludes that the development of a multifunctional spray product based on *Moringa oleifera*, when integrated with a circular economy framework, holds significant promise not only for enhancing consumer health but also for offering an environmentally responsible solution aligned with sustainability goals.

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