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ORIGINAL ARTICLE / ÖZGÜN MAKALE

Environmentally Friendly Zero Waste Cosmetics with Low Biological and Chemical Oxygen Demand

Biyolojik ve Kimyasal Oksijen İhtiyacı Düşük, Çevre Dostu Sıfır Atık Kozmetikler

Sevde Nur Aksoy[1,2], İsmail Bayır[3,4], Ertuğrul Osman Bursalıoğlu[5], Ahmet Arif Kurt[6,7], Ebrar Panka[8]
Mustafa Eray Bozyel[2], İsmail Aslan[2,9]

[1] Pharmacy Program, Hamidiye Faculty of Pharmacy, University of Health Sciences, Istanbul, Turkey
[2] SFA R&D Private Health Services, Teknopark Istanbul, Pendik, Istanbul, Turkey
[3] Department of Veterinary Medicine Laboratory and Veterinary Health Program, Kemaliye Hacı Ali Akın Vocational School, Erzincan Binali Yıldırım University, Erzincan, Turkey
[4] Department of Medical Services and Techniques, Hamidiye Vocational School of Health Services, University of Health Sciences, Istanbul, Turkey
[5] Department of Medical Services and Techniques, Vocational School of Health Services, Sinop University, Sinop, Turkey
[6] Department of Pharmaceutical Technology, Faculty of Pharmacy, Suleyman Demirel University, Isparta, Turkey
[7] Research laboratory, R&D unit, Polisome R&D Pharmaceutical Industry Trade Company, Isparta, Turkey
[8] Hamidiye Vocational School of Health Services, University of Health Sciences, Istanbul, Turkey
[9] Department of Pharmaceutical Technology, Hamidiye Faculty of Pharmacy, University of Health Sciences, Istanbul, Turkey

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Abstract

Objectives: Cosmetics; once they enter the body, they can be metabolised and re-enter the environment through sweat, urine, or faeces; therefore, disposal of these waste products using conventional methods is not always possible. This study aims to reduce the potential harm of chemicals in cosmetic products, prevent environmental pollution from packaging and contents, and minimise problems arising from their return to living organisms through environmental cycles.

Methods: Biochemical oxygen demand (BOD), a bioanalytical method, is used to interpret the biodegradability capacity of products at treatment plants and to assess the effectiveness of treatment. BOD is an indicator that reflects the amount of organically easily degradable compounds and is widely used in assessing water quality; in practice, it is usually expressed in mg O2/L. In this study, the aforementioned risks will be addressed preventively through in silico modelling and in vitro validation before use, during the development process of natural-based and zero-waste products, rather than after the use of cosmetic products. By adopting a zero-waste approach, efficiency and performance increase, while costs decrease and environmental risks are reduced through the prevention of waste.

Results: The inability to remove non-metabolised compounds during wastewater treatment, combined with the effects of pollutants, particularly on air, water, and soil, can seriously threaten living organisms and natural resources in the long term. The results obtained are expected to shed light on the effects of different formulations associated with chemical risks on environmental sustainability (e.g., possible changes in carbon footprint). Conclusion: The study is expected to contribute to the development of new methods in zero-waste cosmetics research and reduce environmental risks by preventing waste.

Keywords: Zero waste, Biological Oxygen Demand, Chemical Oxygen Demand, Cosmetics, In-vitro/in-silico testing, Sustainability.

Corresponding Author: İsmail Aslan, SFA R&D Private Health Services, Teknopark Istanbul, Pendik, Istanbul, Turkey. Department of Pharmaceutical Technology, Hamidiye Faculty of Pharmacy, University of Health Sciences, Istanbul, Turkey. E mail: eczismailaslan@gmail.com

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Öz

Amaç: Kozmetikler vücuda girdiklerinde metabolize olabilir ve ter, idrar veya dışkı yoluyla tekrar çevreye karışabilirler; bu nedenle bu atık ürünlerin geleneksel yöntemlerle bertarafı her zaman mümkün değildir. Bu çalışmanın amacı, kozmetik ürünlerdeki kimyasalların potansiyel zararını azaltmak, ambalaj ve içeriklerden kaynaklanan çevre kirliliğini önlemek ve bu maddelerin çevresel döngülerle tekrar canlılara dönmesinden kaynaklanan sorunları en aza indirmektir. Yöntem: Biyokimyasal oksijen ihtiyacı (BOİ), bir biyoanalitik yöntem olarak, ürünlerin arıtma tesislerindeki biyobozunabilirlik kapasitelerini yorumlamak ve arıtmanın etkinliğini değerlendirmek için kullanılır. BOİ, organik olarak kolayca parçalanabilen bileşiklerin miktarını yansıtan ve su kalitesinin değerlendirilmesinde yaygın olarak kullanılan bir göstergedir; uygulamada genellikle mg O2/L cinsinden ifade edilir. Bu çalışmada, bahsedilen riskler, kozmetik ürünlerin kullanımı sonrasında değil, doğal bazlı ve sıfır atık ürünlerin geliştirilme sürecinde, kullanım öncesinde in siliko modelleme ve in vitro doğrulama ile önleyici olarak ele alınacaktır. Sıfır atık yaklaşımı benimsenerek verimlilik ve performans artarken, maliyetler azalacak ve atığın önlenmesiyle çevresel riskler azaltılacaktır.

Bulgular: Atık su arıtımı sırasında metabolize olmayan bileşiklerin uzaklaştırılamaması ve kirleticilerin özellikle hava, su ve toprak üzerindeki etkileri, uzun vadede canlıları ve doğal kaynakları ciddi şekilde tehdit edebilir. Elde edilen sonuçların, kimyasal risklerle ilişkili farklı formülasyonların çevresel sürdürülebilirlik üzerindeki etkilerine (örneğin, karbon ayak izindeki olası değişiklikler gibi) ışık tutması beklenmektedir.

Sonuç: Çalışmanın, sıfır atık kozmetik araştırmalarında yeni yöntemlerin geliştirilmesine katkı sağlaması ve atığın önlenmesi yoluyla çevresel riskleri azaltması beklenmektedir.

Anahtar Kelimeler: Sıfır Atık, Biyolojik Oksijen İhtiyacı, Kimyasal Oksijen İhtiyacı, Kozmetikler, İn-vitro/in-silico test, Sürdürülebilirlik.

INTRODUCTION

The history of cosmetic products is as old as human history itself, and the popularity of such products have increased in line with the development of societies. The use of natural components in cosmetic products can be traced back to the earliest periods of human history, with scientists playing a pivotal role in this practice. For instance, plant-derived raw materials have been extensively used in the cosmetics industry for centuries (1). The evolution of cosmetic and skin care practices has been closely linked to technological advancements. Over time, this field has involved professionals such as perfumers, barbers and cosmetologists. Archaeological findings show that cosmetic products were already used in Ancient Egypt. Evidence of the importance attributed to physical appearance in Ancient Egypt can be found in archaeological artefacts. These include face paint and ointment containers dating back to 4000 BC, as well as the Ebers Papyri (2-4).

The societal perception of older individuals is predominantly influenced by the prevailing standards of physical attractiveness. It is often assumed that individuals prefer to maintain a youthful appearance, as the societal perception of unattractive older people is more negatively influenced. The hypothesis that a youthful and healthy appearance is associated with positive personal characteristics even in old age is one that merits further investigation. Consequently, efficacious cosmetic products have the capacity to enhance not only an individual's physical appearance, but also their psychological and social well-being. In this context, cosmetics can be regarded not only as a means of aesthetic enhancement, but also as a therapeutic and supportive instrument (5-7).

In cosmetic product development, an important consideration is the use of natural, biocompatible and recyclable materials. This approach addresses both consumer concerns and environmental sustainability requirements (8). In recent years, the significance of preventive cosmetic care has increased in parallel with the recognised effectiveness of nutrition in preventing diseases (9). Growing environmental and health concerns have led to a shift in consumer preferences toward natural, safe and environmentally friendly anti-aging cosmeceutical products. Cosmeceuticals have been shown to improve skin appearance and provide therapeutic benefits. Recent studies also highlight increasing interest in new generation products derived from sustainable sources that are biodegradable and free of harmful chemicals (10). Aslan and Tarhan Celebi sought to formulate an antiperspirant that is natural, microbiome-friendly, sustainable, free of aluminium, new generation, and non-systemic. This alternative to aluminium salts does not participate in systemic circulation and contains no harmful metals. The present study aimed to contribute to the development of cosmetic products that are more sustainable, effective and environmentally responsible. The ultimate goal is to support a more sustainable legacy for future generations (11).

Sustainable cosmetics shouldn't be reduced to whether the packaging is recyclable. A more defensible view is life-cycle based: the environmental profile of a product is shaped by ingredient sourcing, manufacturing, consumer use, and what happens after use (e.g., residues entering wastewater and downstream environments) (12). From a post-use perspective, this issue is important because ingredients from personal care products can enter municipal sewer systems after everyday use. These substances may reach receiving waters through treated effluents or incomplete removal during wastewater treatment, creating pathways for ecological exposure (13). Within this framework, an "oxygen-demand" perspective can help make certain aquatic impacts more measurable. Oxygen depletion is commonly evaluated using indicators such as biochemical oxygen demand (BOD) and chemical oxygen demand (COD). These indicators are also related to dissolved oxygen (DO), which is a key parameter for assessing water quality (14).

Studies suggest that some cosmetic ingredients are metabolised by the body. Unused components may be excreted through sweat, urine and faeces. After exiting the body, the waste materials reach the sewerage system and, from there, to the treatment plants. At this point, they become part of the environmental cycle and, by indirect means, cause harm to living organisms through the air, water and food. Plants play an important role in protecting this pollution and ensuring the sustainability of the chain (15). The use of conventional disposal methods for these wastes, that are released back into nature through sweat, urine or stool after entering the living body and undergoing metabolism, is rendered unfeasible. Long-term exposure to multiple chemical components in cosmetic products may lead to adverse health effects. This phenomenon is known as the "cocktail effect" (16,17). A substantial proportion of cosmetic packaging, specifically 95%, is disposed of after a single use. Only 14 per cent of plastic is recycled, and only 9 per cent of plastic waste generated in general is recycled (18-20). Consequently, companies have begun to transition to environmentally sustainable packaging solutions (21,22). The development of biodegradable packaging is underway, with the use of materials such as chitin and lignin, that are derived from food by-products (23,24). The extraction of active ingredients from food waste is a subject under investigation for use in natural cosmetics (25-27). Biochemical and enzymatic technologies have been demonstrated to produce safe, pure and environmentally friendly ingredients (28-30). The use of biotechnology in the formulation of preservative-free natural cosmetic products (e.g. smart cosmeceutical tissues) has been shown to facilitate sustainable development (31,32).

The efficiency with which products are removed from treatment plants varies considerably depending on a number of factors. These include the composition of the products, the biological treatment process used, and the technology and operating conditions (33,34). BOD is a widely used bioassay method for evaluating the biological treatability and performance of wastewater treatment plants. It quantifies the amount of oxygen consumed by aerobic bacteria over a defined period (5 days) and at a controlled temperature (20°C) during the degradation of organic matter. As a measure of biodegradable organic compounds in a water sample, BOD serves as a key indicator of water quality. In practice, the measurement is typically expressed in milligrams of O2 per liter (35).

In light of the accelerated development witnessed across diverse industrial sectors, a substantial volume of fresh water is employed as a raw material, in production equipment, and for cooling processes. The resultant industrial wastewater is recognised as a significant contributor to water pollution (36). One of the main challenges in treating cosmetic wastewater is the presence of various chemical compounds. These include detergents, hormones, surfactants, personal care products (PPCP), pharmaceutical compounds, preservatives (mostly phenol derivatives), dyes, fragrances and co-solvents. These substances are frequently non-biodegradable and/or toxic to microorganisms in biological systems (37-40).

Failure to remove non-metabolised compounds during wastewater treatment allows pollutants to migrate into groundwater and surface waters. This situation poses a significant threat to the sustainability of these resources. It is particularly concerning that the effects on air, water and soil have the potential to pose a long-term threat to life and to have a destructive impact on natural resources. The consequences of this include the deterioration of soil content, alterations to air quality and the pollution of water resources. In order to prevent pollution, it is vital to pay close attention to the content and packaging of products to be used, and to prioritise product preference within the framework of zero waste (10,33,34,41). The following section presents a study aimed at preventing issues arising from cosmetic product manufacturing. Monsalvo and colleagues evaluated the treatment of wastewater from a personal care products factory using a full-scale intermittently fed side-flow membrane bioreactor (MBR). The MBR system demonstrated consistent and reliable performance in the treatment of wastewater from a personal care products factory. The resultant wastewater has been shown to comply with the criteria for reuse as stipulated by the relevant authorities for municipal, agricultural and recreational purposes (33).

The objective of this study is to mitigate the adverse effects of chemical substances in cosmetic products, to prevent environmental contamination caused by packaging and its contents, and to address the concerns associated with re-entering the living body through environmental cycles. In this study, the focus is on the prevention of risks prior to the use of cosmetic products containing natural ingredients and products under development in accordance with the zero waste approach.

The zero-waste approach has been shown to deliver several key benefits, including enhanced efficiency and performance in the context of a clean environment Furthermore, this approach has been shown to result in a reduction in costs, as well as environmental risks, due to the prevention of waste (33).

A review of the national and international literature reveals a paucity of research on environmentally friendly zero-waste cosmetics with low biological and chemical oxygen demand. In view of the data obtained, it is hypothesised that the calculations and studies on reduction do not provide sufficient information (33).

Chemicals in cosmetic products have been identified as a major contributor to environmental pollution. This study aims to investigate the role of BOD and COD in environmentally friendly zero-waste cosmetics. To achieve this, in vitro and in silico BOD and COD calculation methods, which are effective experimental models for formulation analysis, will be used. The study systematically examines pollution-related issues and the factors influencing the BOD-COD relationship. These objectives can be listed as: 1- The establishment of an experimental model with in silico calculations. 2-The demonstration of the damage caused by the chemical substance in the in vitro model by cell culture staining. 3- The provision of staining methods to show the relationship with the formulation change by converting to clean ingredients. 4- The contribution to literature on the establishment of the relationship between BOD, COD and zero-waste cosmetics. 5- The role as a source for the development of alternative formula production methods for the prevention of environmental pollution (33,36,42). This study aims to shed light on previously unexamined factors, with a view to offering alternative solutions to problems in non-environmental formulation (33,42). The objective of this study is to establish a foundation for the development of novel, eco-friendly cosmetic products, thus reducing the strain on the national economy and the components that constitute our environment (41,43).

Recent studies have highlighted that microplastics, commonly incorporated into cosmetic formulations, represent a significant environmental concern (44-46). Polyethylene is identified as the predominant polymer, constituting over 80% of the microplastics detected in such products (47). Other prevalent polymers include polypropylene, polyethylene terephthalate, and polymethyl methacrylate (48). Due to their inherent resistance to biodegradation, these substances persist in aquatic ecosystems following their release into the environment via wastewater, thus posing a substantial and long-lasting risk of environmental contamination (49). As Ayyadurai and Ragavendran (50) demonstrate, cosmetic wastewaters contain a variety of recalcitrant organic compounds, including synthetic surfactants, preservatives and fragrances. These are resistant to conventional treatment methods. As demonstrated in the research by Gong et al. (51), advanced oxidation processes (AOPs) and membrane-based technologies have been identified as the most promising approaches for the effective removal of such contaminants from cosmetic wastewater.

In this study, the raw materials and components associated with zero waste will be systematically investigated for the first time. In the formulation, the relationship with the theoretical calculations will be taken as a reference and its change will be analysed comparatively with cell culture and BOD calculation methods. For the first time, the raw materials and components that accompany the cosmetic formulation will be practically associated with BOD calculations. The findings of this study will provide a novel perspective on the pursuit of a cleaner world and the production of waste-free cosmetic products. Examining the relationship between BOD and COD content and the structure and activity of the system may provide a pioneering approach for developing new formulations. Computational theoretical calculations are expected to support this process (36,52). The findings of this study will provide insights into the impact of various formulations with chemical risks on the natural environment and the alteration of the carbon footprint. The results obtained will serve as an intermediate step in the development of new methods for zero waste cosmetic studies (33,36). It may serve as a preliminary study to comprehend the mechanisms of BOD and COD, in addition to elucidating the principles of sustainability in cosmetic products. Furthermore, it has been determined that sustainable packaging solutions are of paramount importance in the reduction of the overall carbon footprint of cosmetic products (53). A recent life cycle assessment by Thomassen et al. (54) demonstrated that utilising packaging entirely composed of recycled materials can result in a reduction of environmental impacts up to 60%. The most recent scientific literature indicates an imperative for a comprehensive transformation of the cosmetics industry (55). This transformation involves replacing harmful chemical components with biodegradable alternatives. It also requires aligning production processes with circular economy principles and complying with emerging environmental regulations (56).

MATERIAL AND METHODS

Material

All raw materials related to the study were obtained from SFA R&D, located within the Health Sciences University Technology Park. Importantly, all materials used in this study are of both cosmetic and analytical purity. The BOD and COD kits to be procured were meticulously prepared for in vitro and in silico testing of numerous cosmetic formulations methodically developed through various procedures.

Preparation and characterisation of sample formulations

The components of cosmetic formulations will be prepared in various ratios, and optimised codes will be determined. After this, theoretical in silico calculations of the formulations will be conducted. Physical parameters such as density, viscosity, surface tension and electrical conductivity will be measured using a density flask (10 mL specific density flask, Boru Cam Inc., Türkiye), a viscometer (Brookfield Rheometer, Harlow, UK) and an electrical conductivity probe (Mettler Toledo, UK). It is imperative to reiterate that all measurements will be conducted on three separate occasions at ambient temperature (25°C). Prior to the measurement process, the equipment will undergo a calibration procedure.

Table 1. Sample formulation of two-phase cream shampoo.

Material names	Trade names	%	Function
Phase A			
Coco Glycoside	Plantaren 818 UP 1	12.00	Non-ionic surfactant; gentle cleanser; stabilizes foam and enhances mildness.
Cocamidopropyl Betaine	Cocamidopropyl Betaine	10.00	Amphoteric surfactant; improves foam; reduces irritation; enhances viscosity.
Glycerine	Glycerine	5.00	Humectant; attracts moisture to the skin and hair; provides hydration and softness.
Sodium Lauryl Sarcosinate	Perlastan L 30 [2]	5.00	Mild anionic surfactant; enhances cleansing and foam; gentle alternative to SLS.
Coco Glycoside and glyceryl- oleate	Lamesoft PO 65 [1]	3.00	Co-surfactant and skin conditioning agent; helps smooth skin/hair; enhances mildness.
Phase B			
Cetearyl Alcohol	Cetearyl Alcohol	35.00	Fatty alcohol; thickener, emulsion stabilizer; provides creamy texture; skin/hair conditioning.
Behentrimonium Chloride	Behentrimonium Chloride	10.00	Cationic conditioning agent; detangles hair; reduces static; improves softness and manageability.
Behenyl Alcohol and Polyglyceryl-3 Stearate	Costol Natural E 3	3.00	Emulsifier and stabilizer; provides smooth texture; helps form stable oil-in-water emulsions.
Aqua	Water	17.00	Solvent; primary carrier phase for water-soluble ingredients.
	Total	**100**	

Experimental Design and Analytical Procedures

The study was designed to evaluate the environmental impact of a zero-waste cosmetic formulation by analyzing its biochemical oxygen demand (BOD) and chemical oxygen demand (COD) parameters. A combined in silico and in vitro approach was used.

In the in silico phase, the theoretical BOD values of formulation components were estimated based on their molecular formulas and stoichiometric oxygen demand calculations. The oxygen requirement for complete oxidation of organic compounds was determined using standard theoretical BOD estimation approaches reported in environmental chemistry studies.

For experimental verification, COD measurements were performed using a dichromate oxidation method with commercially available cuvette tests (LCK014 COD kits). Samples were digested under controlled conditions and analyzed spectrophotometrically according to the manufacturer's protocol. The developed zero-waste cosmetic formulation and a commercially available shampoo product were analyzed under identical experimental conditions to allow comparative evaluation.

Theoretical BOD Estimation

The biochemical oxygen demand (BOD) of the cosmetic formulation components was estimated theoretically based on their molecular formulas and stoichiometric oxygen demand calculations. The theoretical oxygen demand required for the complete oxidation of organic compounds was determined according to standard environmental chemistry principles.

The general stoichiometric equation used for calculating the theoretical oxygen demand of an organic compound can be expressed as follows:

$$C_aH_bO_c + \left(a + \frac{b}{4} - \frac{c}{2}\right) O_2 \rightarrow aCO_2 + \frac{b}{2} H_2O$$

Based on this equation, the theoretical oxygen requirement for each formulation component was estimated and used to calculate the expected BOD contribution of the formulation.

To provide experimental support for these theoretical calculations, chemical oxygen demand (COD) measurements were performed using the dichromate oxidation method. The COD analysis provides an experimental indicator of the total oxidizable organic matter present in the samples and therefore serves as a complementary parameter for evaluating theoretical BOD estimations.

Chemical Oxygen Demand (COD) Analysis

The chemical oxygen demand (COD) of the cosmetic formulations was determined using the dichromate oxidation method, which is widely used for evaluating the amount of oxidizable organic matter in aqueous samples.

COD measurements were performed using commercially available cuvette test kits (LCK014, Hach-Lange, Germany) following the manufacturer's instructions. Briefly, a defined volume of the sample was transferred into the COD test cuvette containing potassium dichromate, sulfuric acid, and catalytic reagents. The samples were then digested at 148°C for 2 hours in a thermostatic digestion block to ensure complete oxidation of organic compounds.

After digestion, the cuvettes were cooled to room temperature and the absorbance values were measured using a spectrophotometric measurement system at the appropriate wavelength specified by the test kit protocol. COD concentrations were calculated automatically by the instrument software based on calibration curves provided with the test system.

All measurements were performed in triplicate (n = 3) to ensure reproducibility of the results, and the data were expressed as mean ± standard deviation (SD).

The dichromate method used in this study is considered the standard method for COD determination in environmental and wastewater analysis and provides reliable information about the total oxidizable organic load of the tested samples.

In silico calculations

The following calculations are given for the two-phase cream shampoo formulation shown in Table 1. The present case study will be used to make in silico calculations in five different formulations. These calculations will then be verified using in vitro applications.

In this direction, the BOD test, in which living organisms serve as a vehicle for the oxidation of organic matter to water and carbon dioxide, can be defined as a wet or wet oxidation procedure. Studies suggest that there exists a numerical relationship between a given amount of any given organic matter and the amount of oxygen required for its conversion to water, carbon dioxide and ammonia. The generalised equation is as follows:

$$C_nH_aO_bN_c + \left(n + \frac{a}{4} - \frac{b}{2} - \frac{3}{4}c\right)O_2 \rightarrow nCO_2 + \left(\frac{a}{2} - \frac{3}{2}c\right)H_2O$$

In accordance with the aforementioned reaction, it is feasible to evaluate the BOD data in terms of the quantity of oxygen used during the oxidation process, as well as the organic matter present. This reaction equation constitutes the fundamental basis for comprehending the reaction rate in BOD consumption. The in silico BOD data for the components is presented in the following section (35).

COCO GLYCOSIDE: $C_{18}H_{36}O_6$

$C_{18}H_{36}O_6$ + (18+ 36/4 – 6/2)O_2 → 18CO_2 + (36/2 – 3/2x0)H_2O

In this equation, the coefficient of oxygen should be 24. The amount of oxygen required to oxidise one mole of organic matter is 24x32=768

COCAMIDOPROPYL BETAINE: $C_{19}H_{38}N_2O_3$

$C_{19}H_{38}N_2O_3$ + (19+ 38/4 – 3/2 – 3/4x2)O_2 → 19CO_2 + (38/2 – 3/2x2)H_2O + 2NH_3

In this equation, the coefficient of oxygen should be 17.5. The amount of oxygen required to oxidise one mole of organic matter is 17.5x32= 560

GLYCERINE: $C_3H_8O_3$

$C_3H_8O_3$+ (3+ 8/4 – 3/2)O_2 → 3CO_2 + (8/2 – 3/2x0)H_2O

In this equation, the coefficient of oxygen should be 3.5. The amount of oxygen required to oxidise one mole of organic matter is 3.5x32= 112

SODIUM LAURYL SARCOSINATE: $C_{15}H_{28}NNaO_3$

$C_{15}H_{28}NNaO_3$ + (15+ 28/4 – 3/2 – 3/4x1)O_2 → 15CO_2 + (28/2 – 3/2x1)H_2O + 1NH_3

In this equation, the coefficient of oxygen should be 13.75. The amount of oxygen required to oxidise one mole of organic matter is 13.75x32= 440

GLISERINE OLEATE: $C_{21}H_{42}O_5$

$C_{21}H_{42}O_5$ + (21+ 42/4 – 5/2)O_2 → 21CO_2 + (42/2 – 3/2x0)H_2O

In this equation, the coefficient of oxygen should be 29. The amount of oxygen required to oxidise one mole of organic matter is 29x32= 928

CETEARYL ALCOHOL: $C_{34}H_{72}O_2$ ($C_{16}H_{34}O.C_{18}H_{38}O$)

$C_{34}H_{72}O_2$+ (34+ 72/4 – 2/2)O_2 → 34CO_2 + (34/2 – 3/2x0)H_2O

In this equation, the coefficient of oxygen should be 51. The amount of oxygen required to oxidise one mole of organic matter is 51x32= 1632

BEHENTRIMONIUM CHLORIDE: $C_{25}H_{54}ClN$

$C_{25}H_{54}ClN$ + (25+ 54/4 – 3/4x1)O_2 → 25CO_2 + (54/2 – 3/2x1)H_2O + 1NH_3

In this equation, the coefficient of oxygen should be 37.75. The amount of oxygen required to oxidise one mole of organic matter is 37.75x32= 1208

BEHENYL ALCOHOL: $C_{22}H_{46}O$

$C_{22}H_{46}O$ + (22+ 46/4 – 1/2)O_2 → 22CO_2 + (46/2 – 3/2x0)H_2O

In this equation, the coefficient of oxygen should be 33. The amount of oxygen required to oxidise one mole of organic matter is 33x32= 1056

Following the formulation of the product, the COD of the product was calculated using the device illustrated in Figure 1 and the LCKO14

COD cuvette test, as shown in Figure 2. The measurement range of this cuvette test is as follows: The range of oxygen levels in this study was from 1000 to 10,000 mg/L. The test is based on the principle of COD determination by dichromate method. The summary of this method is as follows: The reaction of oxidisable substances with a sulphuric acid-potassium dichromate solution is catalyzed by the presence of silver sulphate. It has been demonstrated that chloride is masked by mercury sulphate. The green colour of Cr^{3+} is evaluated.

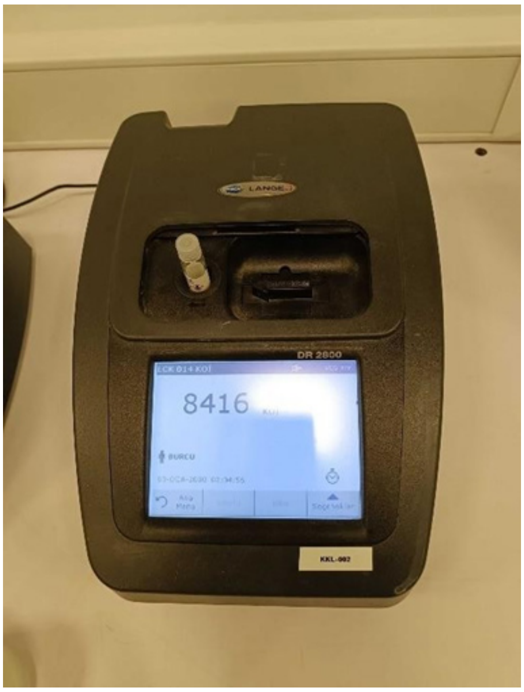

Figure 1: COD Measurement Device

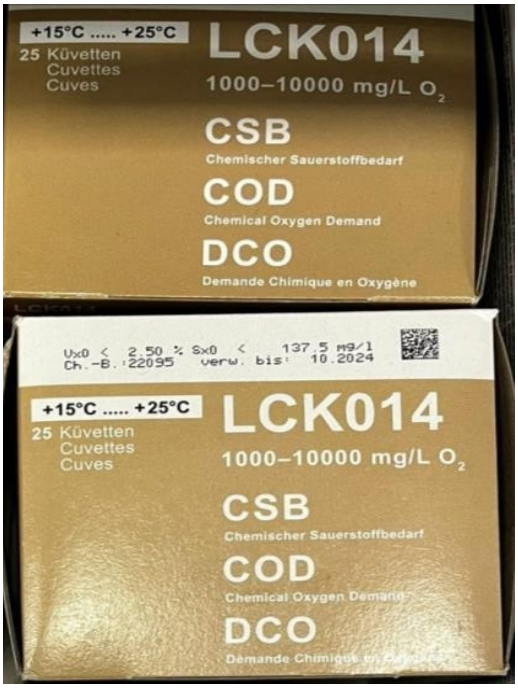

Figure 2: LCK 014 Test Kits

Statistical Analysis

All COD measurements were performed in triplicate (n = 3) to ensure reproducibility. Results were expressed as mean ± standard deviation (SD). Statistical comparisons between the developed formulation and the commercial product were evaluated using an independent sample t-test, and a p value < 0.05 was considered statistically significant.

RESULTS

The global use of cosmetic products is on an upward trajectory. BOD and the COD of a wastewater sample are amongst the various parameters that are used to indicate the level of pollution in the water sample. The COD value of shampoo 1, the product developed in this project, was measured at 5300 mg/L, while the COD value of shampoo 2, an ordinary cosmetic product currently on the market, was measured at 8416 mg/L. The reduced chemical oxygen demand of the developed product is indicative of a reduced chemical footprint, resulting in a diminished environmental impact. The objective of this project was to raise awareness of cosmetic formulations that are suitable for achieving zero waste targets and which have low BOD and COD. Following a comprehensive programme of research and experimentation, it was determined that the lower the BOD and COD values of a product, the greater its purity. In the future, studies will continue to develop cosmetic product formulations with low BOD and COD.

Shampoo 1 is the product that was developed in-house, while shampoo 2 is an ordinary shampoo that is currently available in the cosmetic market. It is clear that elevated COD values are indicative of heightened levels of pollution. According to the test, the following values are obtained for the COD of the product formulations:

Shampoo 1 LCK 014: 5300 mg/L COD

Shampoo 2 LCK 014: 8416 mg/L COD

The chemical oxygen demand (COD) value of the developed zero-waste cosmetic formulation was determined as 5300 ± SD mg/L, while the COD value of the commercial cosmetic product was 8416 ± SD mg/L. The measurements were performed in triplicate (n = 3) and expressed as mean values. The results indicated that the developed formulation exhibited a significantly lower COD value compared with the commercial product ($p < 0.05$), suggesting a reduced potential environmental impact.

DISCUSSION

Cosmetics are defined as preparations that improve and beautify the appearance of body parts such as skin, nails and hair. The use of cosmetic products has been observed to rise from early ages to the present day (57). The by-products resulting from the use of cosmetic products, which have become increasingly prevalent with the aim of enhancing the appearance of hair, skin and nails, have the capacity to contaminate water resources and induce toxicity through the process of re-entry into the living body via environmental cycles (58,59). The presence of these chemicals in the environment has the potential to exert detrimental effects on both the natural world and human health (60,61).

This study aims to contribute towards achieving zero waste targets by evaluating the environmental impact of cosmetic formulations through the analysis of biochemical BOD and COD parameters. The COD value of the developed shampoo formulation (Shampoo 1) was significantly lower (37% reduction) compared to the market product (Shampoo 2), indicating that the use of natural and biodegradable ingredients is effective in reducing the chemical footprint (33). This finding is consistent with the findings of other studies (36) and supports the hypothesis that sustainable cosmetics can be processed more efficiently in wastewater treatment plants. In addition, the optimisation of formulations through in silico calculations and cell culture staining methods has the potential to yield predictable and environmentally friendly solutions in the domain of cosmetic development (35). The low BOD and COD values highlighted in the study may reduce the risk of environmental toxicity by increasing the activity of microorganisms in biological treatment processes (34). In particular, formulations that avoid harmful components such as aluminium salts and microplastics are predicted to play a critical role in preventing persistent pollution in water resources (44,47). In addition, the strategic incorporation of recyclable materials in the design of cosmetics packaging can be regarded as a complementary step in the transition of the cosmetics industry to a circular economy (54).

The chemical oxygen demand (COD) value of the developed zero-waste cosmetic formulation was lower than that of the commercial cosmetic product analyzed in this study. The developed formulation showed a COD value of 5300 mg/L, whereas the commercial product exhibited a higher COD value of 8416 mg/L. These findings suggest that the composition of cosmetic formulations plays an important role in determining their potential environmental impact.

The lower COD value observed in the developed formulation indicates a reduced organic load and potentially lower environmental burden in wastewater systems compared with the commercial product.

The COD value of the developed zero-waste formulation was determined as 5300 mg/L, whereas the commercial cosmetic product showed a higher COD value of 8416 mg/L. These results indicate that the developed formulation has a lower oxygen demand and potentially reduced environmental impact compared with the commercial product.

The use of biotechnology-based production methodologies (enzymatic hydrolysis, among others) has the potential to facilitate the achievement of zero waste targets by enhancing the bioavailability of ingredients (29). In conclusion, this study provides a theoretical and practical basis for the environmental sustainability transformation of the cosmetics industry and suggests new methodological approaches for future research (41).

In addition to these findings, the environmental implications of cosmetic and personal care products have attracted increasing attention in recent years due to their continuous discharge into aquatic environments through domestic wastewater streams. The growing global demand for these products has resulted in the widespread presence of surfactants, preservatives and fragrance compounds in wastewater effluents. Several studies have reported that these substances may contribute to increased organic load in aquatic systems, particularly when they exhibit limited biodegradability or persist during wastewater treatment processes (62). Consequently, the assessment of environmental indicators such as biochemical oxygen demand (BOD) and chemical oxygen demand (COD) has become an important approach for evaluating the ecological impact of cosmetic formulations.

Previous research investigating wastewater generated from cosmetic production and rinse-off products has demonstrated that formulations containing synthetic surfactants and petrochemical-derived additives may produce relatively high COD levels in untreated effluents (63). Elevated oxygen demand values may place additional pressure on biological wastewater treatment systems by increasing the amount of oxidizable organic matter that must be processed by microorganisms. In contrast, formulations developed with biodegradable surfactants and naturally derived ingredients have been reported to show improved degradability and reduced oxygen demand values, thereby facilitating more efficient treatment in biological processes (64). These observations are in agreement with the findings obtained in the present study, where the formulation based on environmentally compatible ingredients exhibited lower COD values compared with the commercial product.

Recent studies have also highlighted that environmental sustainability in cosmetic product development should be evaluated not only in terms of toxicity but also with respect to the degradability and environmental behaviour of ingredients after use. Certain components frequently used in cosmetic formulations, such as microplastics, persistent preservatives and some UV-filter compounds, have been identified as emerging contaminants because of their resistance to degradation and their potential to accumulate in aquatic ecosystems (65). Their continuous release into wastewater streams may lead to long-term ecological consequences, including alterations in microbial communities and reduced efficiency of wastewater treatment systems. Therefore, reducing the organic load associated with cosmetic products through the design of formulations with lower BOD and COD values represents an important strategy for minimizing their environmental impact.

Furthermore, the increasing interest in green chemistry and sustainable formulation strategies has encouraged the replacement of conventional petrochemical-based ingredients with biodegradable or bio-based alternatives. In this context, biosurfactants and plant-derived functional ingredients have been suggested as promising components for environmentally responsible cosmetic formulations because of their higher biodegradability and lower toxicity toward aquatic organisms (66). The integration of such ingredients into cosmetic formulations may therefore contribute to lowering the oxygen demand generated during wastewater treatment processes.

Taken together, these findings support the importance of incorporating environmental performance indicators such as BOD and COD into cosmetic formulation research. Evaluating these parameters provides valuable insight into the potential behaviour of cosmetic products in wastewater treatment systems and aquatic environments. Consequently, the approach presented in this study contributes to the development of environmentally sustainable cosmetic formulations and offers a practical framework for assessing the ecological impact of cosmetic products within the broader context of zero-waste and green chemistry initiatives. Although the present study compared the developed zero-waste cosmetic formulation with a single commercially available cosmetic product, this comparison was intended to provide a preliminary evaluation of the environmental performance of the proposed formulation. Including additional formulation variations and multiple commercial products may provide a more comprehensive understanding of the environmental impacts of cosmetic formulations. Therefore, future studies may focus on evaluating a wider range of cosmetic products and formulation compositions to obtain a broader assessment of their potential environmental effects. Such comparative analyses may contribute to the development of more environmentally sustainable cosmetic formulations. In addition to BOD and COD parameters, future studies evaluating sustainable cosmetic formulations may benefit from integrating broader environmental assessment tools. Life Cycle Assessment (LCA), carbon footprint analysis, and biodegradability testing can provide more comprehensive information about the environmental impact of cosmetic products throughout their entire lifecycle. The integration of these approaches may contribute to the development of environmentally responsible cosmetic formulations within the framework of zero-waste production strategies. The agreement between the theoretical oxygen demand estimations and the experimentally measured COD values supports the reliability of the proposed environmental evaluation approach for cosmetic formulations. In addition to conventional wastewater parameters such as biochemical oxygen demand (BOD) and chemical oxygen demand (COD), broader environmental assessment tools can be used to evaluate the sustainability of cosmetic formulations. Life Cycle Assessment (LCA) is widely applied to analyze the environmental impacts of products throughout their entire lifecycle, including raw material sourcing, production, distribution, use, and disposal stages. Incorporating LCA into cosmetic research may provide a more comprehensive understanding of the ecological footprint of personal care products. Furthermore, biodegradability testing is an important parameter for determining how quickly cosmetic ingredients can be broken down by microorganisms in aquatic environments. Ingredients with higher biodegradability are generally associated with lower environmental persistence and reduced ecological risk. Another important sustainability indicator is the carbon footprint, which reflects the total greenhouse gas emissions associated with the production and use of cosmetic products. Future studies integrating LCA, biodegradability analysis, and carbon footprint assessment may provide a more comprehensive environmental evaluation of zero-waste cosmetic formulations. Such integrated environmental assessment approaches may contribute to the development of more sustainable and environmentally responsible cosmetic products.

CONCLUSION

The findings of this study indicated that the use of natural and biodegradable ingredients in the development of cosmetic products results in a substantial reduction in chemical and biological oxygen demand. In particular, the developed shampoo formulation exhibited a lower COD value in comparison to its market counterparts, thus substantiating the efficacy of sustainable production methodologies in mitigating environmental impacts. The use of recyclable materials in packaging, along with the alignment of production processes with circular economy principles, will serve to further minimise the ecological footprint of the sector. In the future, the widespread use of biotechnology-based methods and similar analyses in different product categories has the potential to play a critical role in achieving zero waste targets. These findings signify a significant advancement in the globalisation of clean and environmentally friendly cosmetics production.

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Conflict of interest statement:

The authors declare that there is no conflict of interest.

Author Contributions:

Conception: SNA, İA, Design: SNA, İA, İB, Supervision: İA, EOB, AAK, Data collection and processing: SNA, İA, EOB, Analysis and interpretation: SNA, İA, EOB, AAK, Literature review: SNA, İA, EOB, MEB, EP, Writing: SNA, İA, EOB, MEB, EP, Critical Review: İA, İB, AAK, MEB, EOB.

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