Arh. farm. 2024; 74: 735 – 757 *Review article/Pregledni rad*

Challenges and advances in waterless cosmetic product development – raising awareness of water sustainability

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Received: 14 August 2024; Revised in revised form: 23 September 2024; Accepted: 3 October 2024

Abstract

Water conservation is an essential strategy for managing the world's limited water resources. The life cycle of cosmetic products, which are used in immeasurable quantities in everyday life, involves significant water consumption. Water is a common ingredient in cosmetic products, and it is also used in the manufacturing process. Numerous strategies are being developed to reduce water consumption in the life cycles of different cosmetic products. This paper therefore focuses on efforts to minimize water use in formulation development and challenges which accompany these efforts. Waterless cosmetic products are a trend that started with less motivation for sustainability, but combined with the global awareness of environmental benefits, it has become an attractive formulation strategy for water sustainability. Waterless cosmetic formulations reduce direct water footprint by not using water as a main ingredient in the formulations. Nevertheless, designing waterless cosmetics is a great challenge. This paper summarizes the tendencies, principles and key considerations of formulation, as well as the benefits and advantages of waterless cosmetic products. It points out the importance of reducing both the water and carbon footprint of cosmetic products, and consequently the contribution cosmetics can make to quality of life and sustainable development.

Key words: topical formulations, cosmetic products design, waterless products, water sustainability

https://doi.org/10.5937/arhfarm74-52750

Water and sustainability

Water is essential for all life on Earth and without this remarkable substance life as we know it could not exist (1). It is estimated that 97% of global water is in the ocean – salt water, while only 3% is freshwater, whereas 1% of this water is in rivers and lakes, 12% is groundwater and 87% is icewater (2). This means that less than 1% of Earth's water is easily accessible freshwater extensively used for drinking, industry and watering (3). With accelerated urbanization, increased water usage in agriculture and industry, and excessive water pollution combined with climate changes affecting the Earth's water cycle, freshwater has become a critical resource in recent decades, and maintenance of water resources worldwide is one of the greatest challenges of sustainable development (4-5).

The most common model of sustainable development focuses on the interdependent relationships between the environment, economy and society, and it can be defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (6). Consequently, given that freshwater resources are necessary to meet the social, economic and environmental needs of a growing world population, water sustainability is a necessity for sustainable development. The United Nations "Water for Life" initiative from 2005 to 2015 was the beginning of initiatives and projects focused on various water issues. The United Nations Educational, Scientific and Cultural Organization (UNESCO) publishes reports on "World Water Development" that present current knowledge, challenges and opportunities for improved water management in the context of sustainable development (7).

Water conservation is an essential strategy for managing the world's limited water resources. There are a number of strategies on the challenges and opportunities for improved water management in the context of the water-energy-food nexus, the agricultural, industrial and urban sectors, the policy and institutional dimensions of the water-energy nexus, and the role of the United Nations' Sustainable Development Goal 6 in promoting sustainable water management (8-13). These strategies underscore the importance of a holistic and integrated approach for water management that considers the linkages between water, energy, land, and food production, as well as the social, economic, and environmental dimensions of water use. Collaboration among sectors and stakeholders is necessary to promote sustainable water management practices and achieve global development goals.

In addition to all the global goals and approaches, household water consumption should not be neglected. Crouch et al. provide insights into personal water use activities that are important for understanding household water use (14). Understanding the factors that influence water use behaviours is critical for designing effective water conservation strategies. The study found that factors such as household size, income, and access to water-efficient appliances such as low-flow showerheads and faucets can significantly influence water use behaviours.

Water consumption in the cosmetic product lifecycle refers to the amount of water used during the production, use, and disposal of cosmetic products. Water is a common ingredient in many cosmetic products, and it is also used in the manufacturing process and in cleaning equipment. The amount of water consumed in the cosmetic product lifecycle varies depending on factors such as the type of product, the manufacturing process, and consumer behaviour. Reducing water consumption in the cosmetic product lifecycle is an important sustainability goal. Key strategies to achieve this goal include using waterless or concentrated products, optimizing manufacturing processes to minimize water consumption, and educating consumers about the importance of water conservation.

Sustainability in the cosmetic industry

Without undertaking a comprehensive review of the importance of sustainability in all aspects of human behaviour and actions, it should be emphasized that the concepts of sustainability strongly influence the cosmetic industry. Cosmetic products are part of consumers' everyday life and are essentially created to meet their needs and expectations. Along with the existing but slow mindset shifts in the general population, cosmetic companies are striving to develop innovative sustainable cosmetic products in response to a significant number of consumers seeking sustainability through their purchases and opting for more eco-conscious lifestyles (15-16).

Based on the personal care association Cosmetics Europe economic overview, the European cosmetics and personal care market is estimated to be worth €80 billion at retail sales price in 2021, bringing at least €29 billion in added value to the European economy annually (17). If perceived only through the financial lens, it is clear that the cosmetic industry must adopt sustainable practices in order to remain profitable in the long term (18).

Water in the cosmetic industry

Being the most common cosmetic ingredient, water is considered necessary in each life cycle phase of cosmetic products; it is necessary in the processing of cosmetic ingredients and products manufacturing, for cooling and heating processes, equipment cleaning, and packaging production (19).

A very important step in the manufacturing process, especially for emulsion systems, is the cooling period. The conventional method used for cooling, which involves the use of an electric fan, is replaced with a water-cooling system (20). For example, it has been reported that a cosmetic brand which uses 3 stainless steel jacketed vessels with a 1200 l capacity and jacket pressure of 6 barg and 3 stainless steel pre-mix jacketed vessels with a 252 l capacity and jacket pressure of 3.5 barg to produce creams has used tons of water for cooling the jacketed vessels, resulting in 16 million liters of wastewater a year (21). Although improvements in cooling for jacketed vessels are being made, like the one in the previous example, which enabled 25% of total water used on site to be saved, this approach still requires water.

Strategies developed in order to reduce water consumption consider optimizing cleaning procedures, rainwater harvesting, recycling the factory's wastewater, with simultaneous efforts to minimize water use in formulation development, as well as efforts to perform production at room temperature, are necessary (15, 22).

Water in cosmetic products

For the majority of cosmetic products, water is a common ingredient, and especially for liquid and semi-solid cosmetics, for which the cosmetic industry relies on water as the main ingredient of the product. Cosmetic products available on the market must have a list of ingredients labelled on the product or on the packaging itself (23). The list of ingredients in a cosmetic product is established in descending order according to their weight. The fact that the term "Aqua/Water", which is the International Nomenclature of Cosmetic Ingredients (INCI) name for water, is usually listed first in ingredient list implies that this is the most prevalent ingredient in most cosmetic products.

Water is the major solvent for hydrophilic cosmetic ingredients and an inevitable component of emulsions' water phase (24). In such cosmetic formulations, water contributes to the overall characteristics, microstructure, viscosity, sensory attributes and overall volume of the product (25). Considering that water is an inexpensive ingredient with a high content in products such as creams, shower gels, toners, and shampoos, high profitability can be expected in such cases.

The water used in cosmetic products must meet the minimum quality requirements that apply to drinking (tap) water. However, *ISO 22716 – cosmetic industry guidelines for GMP* include a demand for water quality control measurements in order to maintain water quality (26). Water for cosmetic products is obtained from tap water by filtration, disinfection, softening and dechlorination, and its quality usually complies with the pharmacopeia quality for purified water (27-28). Instead of purified water, there is a current trend for using thermal spring water in cosmetics in order to make the product more attractive due to its recognizable curative properties, as well as due to consumers' request for natural products (29-30).

Whenever water is the major constituent of a product, it could be easily contaminated by micro-organisms, which is why preservatives are necessary in water-based formulations (31). Preservatives are recognized as a common source of allergies in cosmetic products (32). Moreover, due to their intended purpose – inhibition of microbial growth, preservatives are able to interfere with metabolic processes and interact with biomolecules. There is a strong relationship between the preservatives' antimicrobial effect and their ability to induce toxic effects (33). Without comprehensive contemplation of the safety of preservatives, it is a fact that the absence of preservatives in waterless formulations is beneficial for consumers as well as for the environment.

Waterless cosmetic products

Waterless cosmetic products are a trend that originated from Asia a few years ago, with a genuine aim to provide cosmetic products that are more concentrated in

cosmetic actives, and consequently more effective. Although it was initially not primarily motivated by sustainability, in combination with the global awareness of its environmental benefits it become an attractive formulation strategy, and we are therefore witnessing the popularity of cosmetic products with “waterless” claims. Waterless literally implies formulations that do not contain water, but from this perspective, “waterless” claims indicate products without water, as well as with a reduced water content (34). In theory, a waterless cosmetic product is a product with less water. It reduces the direct water footprint by not using water as a main ingredient in the formulations. Water footprint is defined as an indicator of freshwater use that takes into account not only direct water use by a consumer or manufacturer, but also indirect water use (35). In addition, waterless cosmetics have less packaging, fewer preservatives and a lower environmental impact. In the following section, the principles and challenges of waterless cosmetic product formulations are explained. The importance of waterless cosmetics for lowering both the water and carbon footprint, and hence enhancing quality of life and sustainable development, will be pointed out.

As stated in Regulation 1223/2009 on cosmetic products, the manufacture of cosmetic products shall comply with Good Manufacturing Practices (GMP) with a view to ensuring safety for human health when used under normal or reasonably foreseeable conditions of use (23). Although GMP gives guidelines for the production, control, storage, and shipment of cosmetic products and covers the quality assurance (QA) aspects of the product, it does not cover aspects of protection of the environment and/or sustainability (26). To make the manufacturing process more environmentally friendly and sustainable, one should embrace new technology strategies which reduce water and energy consumption, as well as emissions and waste (15). These strategies diminish the environmental, carbon, and water footprint.

Waterless cosmetic products include either anhydrous or concentrated formulations. Anhydrous systems are completely free of water and they may be liquid, semi-solid or solid. Liquid waterless cosmetic formulations are cosmetic oils and serums; semi-solids are serums, ointments, silicone-based emulsions and gels, as well as sticks, while solid, dry products are powders and tablets (compressed powders) (36). Concentrated products may contain a small amount of water.

The waterless cosmetics sector is witnessing remarkable expansion, presenting a plethora of market prospects. Market estimates vary across sources, illustrating the dynamic and burgeoning nature of this industry. As an illustration, in 2023 the global waterless cosmetics market was appraised at USD 10.85 billion and is forecasted to ascend to USD 23.90 billion by 2031, as per a recent study by IMIR Market Research (37).

The waterless cosmetics market is segmented into various categories such as skincare, haircare, makeup, and others, with skincare often being the largest segment. This market is driven by factors like the demand for sustainable and eco-friendly products, innovation in product formulations, and growing awareness of water

conservation. However, challenges such as perceived lack of hydration and a limited product range compared to traditional water-based cosmetics can restrain market growth.

Waterless liquid cosmetic formulations

The simplest waterless liquid formulations are solutions. In waterless (i.e., anhydrous) solutions, ingredients other than water are used as vehicles. The vehicle can be an organic solvent, which is the case for different make up products such as nail polish and nail polish remover. In cosmetic oils and serums, the solvent is an oil or mixture of oils. A few years ago, cosmetic oils were present on the market in very small amounts as bath products or body care oils for dry skin or for massage. Today, due to the waterless wave on the one hand, and the general demand for natural ingredients (plant oils) on the other, cosmetic oils and serums are the hottest trends in facial care products. Although both oils and oil-based serums are solutions from the point of view of formulation, they are considered to be two different product types on the market.

Oil usually refers to a simple blend of oils used primarily for skin care (to moisturize, soften and smooth the skin) and contains naturally occurring ingredients of oils as active substances. Since oil serums are usually intended for a specific skin condition, skin type and effect (anti-aging, antioxidant, anti-pollution, calming, protective, nourishing, firming, etc.), they are enhanced with cosmetic actives like plant extracts, or specific active ingredients such as vitamins or lipids, to meet the specific needs of the skin condition and/or type. In addition, this type of formulation could be used as carrier for the application of physiological lipids which contribute to skin barrier repair (38). In general, serums are presented as more effective products due to the high concentration of actives; in addition to oil-based serums, there are gel-based serums and numerous water-based serums, which are often concentrated emulsions with a small amount of water (39). For oils as anhydrous formulations, pH value has no significance, which can be considered an advantage both from the aspect of formulating the product and from the aspect of application and effect on the pH value of the skin (40).

Cosmetic oils and serums which are formulated as solutions can be defined as a mixture of two or more components forming a single phase that is homogeneous down to the molecular level, so they are thermodynamically stable and relatively easy to formulate (41). If the formulation contains solid lipid(s), heating is required for production of the homogeneous mixture. If this is not the case, no heat energy is required to produce the oil vehicle.

In the production of oil/oil-based serums, the heating step can be completely eliminated if all ingredients are liquid, radically reducing the amount of energy consumption and consequently reducing the product’s carbon-footprint and overall environmental impact (42).

The main concern with waterless liquid cosmetic formulations is ingredient selection. Key considerations include (43):

- The solubility in solvent/vehicle and/or miscibility of various liquid ingredients;
- The stability of the ingredients: certain oils are particularly sensitive to oxidation (44). Ingredients should be selected based on their stability and compatibility with other ingredients in the formulation;
- The function of the ingredients: careful selection of ingredients based on their specific functional properties can help ensure that the final product achieves the desired cosmetic effect;
- The safety of the ingredients: special attention should be paid to plant essential oils and extracts which are a source of potential allergens (45);
- The sensory characteristics of the ingredients (46): the spreadability, slipperiness and richness (as a textural attribute) of the ingredients in liquid waterless cosmetics have a crucial role in ensuring that the final product has a desirable texture and is easy to apply – most importantly, it is necessary to avoid products slipping through the fingers during application.

Table 1 provides examples of ingredient lists of liquid waterless cosmetic products.

Table I Examples of liquid cosmetic products' ingredient lists – for different categories of waterless cosmetic products

Tabela I Primeri lista sastojaka tečnih kozmetičkih proizvoda – za različite kategorije bezvodnih kozmetičkih proizvoda

Product (Manufacturer)*	Ingredients
Renew Retinol Oil (NakedPoppy)	Squalene, Rosa Rubiginosa Seed Oil, Argania Spinosa Kernel Oil, Caprylic/Capric Triglyceride, Retinol, Bakuchiol, Bisabolol, Stearyl Glycyrrhetinate, Phospholipids, Citrus Aurantium Bergamia (Bergamot) Fruit Oil, Zingiber Officinale (Ginger) Root Oil, Tocopherol, Beta-Sitosterol
French Cleansing Oil (Oden)	Papaver somniferum seed oil, Helianthus annuus seed oil, Polyglyceryl-4 oleate, Bellis perennis flower extract, Fragrance, Tocopherol
Face sunscreen lotion "Dry Oils" SPF 50 (Wooden spoon)	Caprylic/Capric Triglyceride, Zinc Oxide, Coco-Caprylate/Caprate, Cera Alba (Beeswax), Helianthus Annuus (Sunflower) Seed Oil, Cartjamus tinctorius (Safflower) seed oil, Rubus idaeus (Raspberry) seed oil, Parfum, Tocopherol (Vitamin E), Citral, Geraniol, Limonene
Cleansing Oil-to-Milk (L'occitane)	Helianthus Annuus (Sunflower) Seed Oil, PEG-40 Sorbitan Peroleate, Isopropyl Isostearate, Caprylic/Capric Triglyceride, Coco-Caprylate/Caprate, Parfum/Fragrance, Helichrysum Italicum Extract, Calendula Officinalis Flower Extract, Prunus Armeniaca (Apricot) Kernel Oil, Hippophae Rhamnoides Fruit Oil, Tocopherol

Prevent Anti-Aging Face Oil (Naked and Thriving)	Simmondsia chinensis (Jojoba) Seed Oil, Prunus amygdalus dulcis (Sweet Almond) Oil, Prunus armeniaca (Apricot) Kernel Oil, Rosa canina (Rosehip) Fruit Oil, Moringa oleifera (Moringa) Seed Oil, Daucus carota sativa (Carrot) Seed Oil, Tocopherol, Oryza sativa (Rice) Bran Extract, Rosmarinus officinalis (Rosemary) Leaf Extract, Helianthus anuus (Sunflower) Extract, Cymbopogon flexuosus (Lemongrass) Oil
Balmy Gloss Tinted Lip Oil (Naturelle)	Hydrogenated Polyisobutene, Diisostearyl Malate, Caprylic/Capric Triglyceride, Ethylene/Propylene/Styrene Copolymer, Butylene/Ethylene/ Styrene Copolymer, Limnanthes Alba (Meadowfoam) Seed Oil, Jojoba Esters, Ethylhexyl Palmitate, Tocopherol, Helianthus Annuus (Sunflower) Seed Oil, Butyrospermum Parkii (Shea) Butter Extract, Tetrahexyldecyl Ascorbate, Pentaerythrityl Tetra-Di-T-Butyl Hydroxyhydrocinnamate, Citrus Aurantium Dulcis (Orange) Peel Extract, Citrus Tangerina (Tangerine) Peel Extract, Silica Dimethyl Silylate, Salicornia Herbacea Extract, Citrus Grandis (Grapefruit) Peel Extract, Citrus Junos Peel Extract, Butylene Glycol, Caprylyl Glycol, Phenoxyethanol, Citrus Clementina Fruit Extract, Hedychium Spicatum Extract, Sodium Hyaluronate, Vanilla Planifolia Fruit Extract, Zingiber Officinale (Ginger) Root Extract, Hexylene Glycol, Limonene. May Contain/Peut Contenir (±): CI 77891 (Titanium Dioxide), CI 77491, CI 77492, CI 77499 (Iron Oxides), CI 15850 (Red 7 Lake), CI 19140 (Yellow 5 Lake), CI 73360 (Red 30 Lake)
L'Huile Original Hair Oil (Kerastase)	Cyclopentasiloxane, Dimethiconol, Zea Mays (Corn) Germ Oil, Argania Spinosa Oil, Argania Spinosa Kernel Oil, Sclerocarya / Birrea Seed Oil, Camellia Oleifera Seed Oil, Caprylic/Capric Triglyceride, Linalool / Pentaclethra Macroloba Seed Oil, Phyllanthus Emblica Fruit Extract, Alpha-Isomethyl Ionone, Limonene, Coumarin, Benzyl Alcohol, Tocopherol, Parfum / Fragrance.

* All ingredient lists are available on retail and/or manufacturer websites

This brief overview of the different types of products indicates the dominant presence of natural ingredients (plant oils and extracts) as constituents of cosmetic formulations – cosmetic vehicles on the one hand, and cosmetic actives which contribute to cosmetic effects of the product on the other. Moreover, in regard to the specific nature of the product and its intended purpose, different functional ingredients are present (e.g., cleansing agents, conditioners, isolated cosmetic actives, colorants). Tocopherol is the main antioxidant in these formulations, responsible for the stability of natural ingredients. The presence of potential allergens sourced from plant extracts is also indicated in ingredient lists, providing necessary information for consumers with regard to their safety.

Waterless semi-solid cosmetic formulations

The only water-free (anhydrous) semi-solid formulations are ointments (hydrophobic). Ointments are the oldest cosmetic formulations that are one-phase

systems – mixtures of one or more lipophilic substances which may differ in consistency (47). They are thick and greasy and in order to be applied on the skin they have to be intensively rubbed. For this reason, semi-solid formulations containing both lipids and water, i.e., emulsions, have replaced ointments because of their more appealing sensory characteristics. Today's advances in chemical technology have enabled the synthesis and design of various multifunctional lipid molecules – emollients whose variability in terms of polarity is continuously increasing (48). Different emollients can be combined in cosmetic ointments to achieve the appropriate texture, spreadability and consistency, which are important factors in enhancing their acceptability (49). In addition to preserving water resources, there are several other advantages of ointments that are important for different aspects of sustainable development, human health, and environment safety:

- The formulation of single-phase systems like ointments does not require emulsifiers – ingredients necessary for formation and stabilization of emulsion semi-solid systems. Surface active agents – surfactants – perform a wide range of functions in cosmetics and emulsifying is only one of them (50). Regardless of the overall safety of surfactants used in cosmetics, the enormous usage of these chemicals in almost every life aspect, including different industries, together with commissions related to the production/synthesis of surfactants, and issues on their biodegradability and biocompatibility, creates growing concerns (51). From this point of view, ointments contribute to the green movement as a surfactant-free cosmetic formulation.
- Similar to solutions, the heating step can be completely eliminated in the production of ointments if all ingredients are liquid and/or semi-solid. In cases where heating is necessary for the melting of solid lipid ingredients, the energy input is still much lower compared to emulsions because the emulsification and homogenization processes are not required in ointment production (52).
- A very important feature of all water-free products is that these products are generally free of preservatives. In anhydrous conditions, microorganisms do not grow and microbiological stability is not an issue for ointment stability; hence, preservative systems are not a necessary component of ointment formulation (guidelines on Annex I to Regulation (EC) No 1223/2009 of the European Parliament and of the Council on cosmetic products). In cases where product use involves contact with water (e.g., cleansing products) preservatives could be added to prevent microbiological contamination during usage. Preservatives used in cosmetic products are under regulatory authority (e.g., Annex IV of Cosmetic Directive Regulation (EC) No 1223/2009) (23). Nevertheless, considerable questions about preservatives safety exist, and consumers have great demands regarding the absence of preservatives (31). Therefore, ointments could be an appropriate solution which avoids preservative-related issues.

In addition to ointments, as water-free cosmetic formulations, concentrated cosmetic emulsions are becoming increasingly popular in the cosmetic industry. These concentrated products basically contain water, but in a much smaller proportion. As mentioned earlier, the entire waterless movement began with concentrated emulsions, and their popularity is based on highly concentrated active ingredients. Personal care products are designed to be mixed with a suitable medium, such as water or a moisturizer, before use, in order to produce a final formulation with a suitable (lower) concentration of active ingredients.

A general strategy for sustainable development in the manufacturing of cosmetic emulsions is the cold emulsification process (15). This process is a method of preparing emulsions without heating and therefore without cooling, enabling a large reduction in energy consumption and decrease in the carbon footprint of the product's life cycle (42). Another advantage of the cold emulsification process includes preservation of temperature-sensitive cosmetic active ingredients such as vitamins, enzymes, and probiotics. For cold processing, all ingredients must be in soluble, liquid, or semi-solid form, and the emulsifier used has to be efficient in the low temperature range.

The advantages of concentrated emulsions could be summarized as follows:

- concentrated and therefore more effective,
- used in a smaller amount and
- packed in smaller packages.

Although it does not seem that way, concentrated products are more economical and cost-effective, since they are consumed at a much slower rate (19). In this way, the shopping frequency of the consumer/buyer is decreased, which is a financial advantage for the consumer. The cosmetic company also benefits from lower transportation and distribution costs. Finally, this is also very important in terms of sustainability, as transportation and distribution are important parts of the carbon footprint in the life cycle of products.

Waterless solid cosmetic formulations

Solid cosmetic waterless formulations are water-free, and in terms of water sustainability and decrease of the water footprint in the product's life cycle they are the most important. These products include sticks, bars, powders and compressed powders (tablets).

Cosmetic sticks and bars are solid products that are used for skincare, haircare, cleansing and makeup (19). Some common types of cosmetic bars include soap bars, which are used for skin cleansing, and shampoo bars, which are used for hair cleansing. Other types of cosmetic sticks and bars include deodorant and antiperspirant sticks, body balms - butters, and scrub bars on the one hand, and solid makeup products on the other.

Cosmetic bars are mainly used as soap bars for personal hygiene and cleaning purposes. Although soap bars could be considered to be the oldest cosmetic product, known since prehistoric times and continuously present on the market, in the 20th century they were strongly suppressed by liquid products (53). In recent year, however, cosmetic bars have gained popularity as a more environmentally friendly and sustainable

alternative to traditional liquid-based products. They often come in minimal or plastic-free packaging and can last longer than their liquid counterparts.

Some common types of skincare bars include (53):

- Facial cleansing bars that are specifically formulated for cleansing the face. They can be made with a range of ingredients, including gentle surfactants, natural oils, and plant extracts. Some facial cleansing bars may also contain exfoliating ingredients to help remove dead skin cells and unclog pores.
- Body and face scrub bars which are designed to exfoliate the skin. They may contain ingredients such as sugar, salt, different solid lipid or mineral particles or coffee grounds, as well as moisturizing oils and butters to help hydrate and soften the skin.

Hair cleansing bars are solid bars of shampoo that are used to clean the hair (54). They are a more sustainable and environmentally friendly alternative to traditional liquid shampoos, because they usually come in minimal packaging and do not require plastic bottles. Moreover, due to the great efforts made in the direction of more eco-sustainable formulations, new ingredients and formulation technologies are used in the formulation of solid hair cleansing products (55).

Hair cleansing bars are formulated with a variety of ingredients, including essential cleansing bases containing mixtures of different surfactants, and nowadays very popular natural oils, and plant extracts. The key challenge has become replacing traditional surfactants with new eco-friendly surfactants or biosurfactants, which must provide not only the same efficacy (cleaning performance), but also the expected cosmetic performance, which for this type of product is mainly focused on good foaming ability (51, 56). In general, innovative fast-rinse technology and non-rinse formulations which require less or no water for use are being developed for cleansing products (57).

Although these products offer numerous opportunities to achieve sustainability goals in the cosmetic industry, their main advantages in terms of reducing the water footprint throughout the life cycle of products are that:

- The products are completely waterless;
- Fast rinse-off and non-rinse formulations save the amount of water used.

A particular challenge arising from the effort of the cosmetic industry to develop cosmetics that meet sustainability goals became finding the way to inform and educate consumers of the different and/or altered application of newly developed formulations. Furthermore, cosmetics manufacturers must make additional efforts to raise customer awareness regarding the expected cosmetic performances, especially sensorial expectations, which sometimes have to be lowered for a greater good – sustainable living on Earth, and these challenges are quite complex (15, 58-59). In general, cosmetic companies need to use multiple channels to communicate their sustainability message and efforts to consumers. The most commonly used channels are cosmetic claims. Table 2 presents examples of cosmetic claims that address different aspects of sustainability goals used in product marketing.

Table II Cosmetic claims addressing different aspects of sustainability goals

Tabela II Kozmetičke tvrdnje koje adresiraju različite aspekte ciljeva održivosti

Product (Manufacturer)	Claims
The Bawdy Wash (Bawdy)	Sustainable and non-toxic, this powder-to-foam wash leaves your skin revitalized—and is safe for marine life too—because what goes on your body eventually goes down the drain.
Dream team mini, Clean slate (Alleyoop)	Jar made of 50% PCR material. Instead of paying for a product that's typically 60% water, our waterless formula packs the ultimate punch in terms of efficacy and value. Conveniently packed for travel.
The Clean Deo (Beautycounter)	Comes in a refillable case. Approximately 90% of the plastic in this product is composed of post-consumer recycled (PCR) resin.
Ganni x Submission Beauty Glitter (Ganni)	We've joined up with responsible luxury pioneers Submission Beauty on our first ever, limited edition capsule of zero-plastic glitter. With none of the plastic but all of the shine, our three popping shades of pink, gold and silver are not only safe for your face and body, but also softer on the skin. The Glitter is made from natural and plant-derived materials. It is zero-plastic and made with cellulose from eucalyptus trees, which feels softer on the skin than conventional glitter and creates a unique iridescent effect.
Eau de parfum Vigilante (St. Rose)	GOOD FOR THE EARTH CLEAN & CONSCIOUS, FROM SEED TO BOTTLE. SOURCING AT ORIGIN ECO-LUXE DESIGN SMALL CARBON FOOTPRINT
Plum Plump Refillable Hyaluronic Acid Moisturizer (Glow Recipe)	Clean + Planet Positive seal (brands meeting standards for climate commitments, sustainable sourcing, responsible packaging, and environmental giving)
Daily Regenerative Gel Cleanser (Circumference)	Key bioactive ingredients come from our Waste-Not Sourcing Initiative, in which we partner with cult favorite Brightland Olive Oil to upcycle their organic byproducts (Olive Leaf) into luxe, slow-extracted botanicals. All of the skin-supportive nutrients. None of the waste.
Water-Lock Moisturizer Refill Pod (Tata Harper)	Run out. Refill. Reuse. This recyclable refill pod locks into your refillable Water-Lock Moisturizer jar.
Roll over image to zoom in	ALL NATURAL INGREDIENTS, If you are looking for a product that is safer, healthier, and more environmentally friendly, look no further.

Viori Shampoo Bar (Citrus Yao)	SOCIALLY RESPONSIBLE- Want to feel good about the products you are purchasing and the impact you are having on the world? Our all natural, sulfate-free, and eco-friendly shampoo bars are ethically and sustainably sourced, with 5% of profits donated back to the Red Yao Tribe, from which our rice is sourced.
N°1 DE CHANEL REVITALIZING CREAM (Chanel)	The N°1 DE CHANEL line seeks to minimize its environmental impact with sustainably developed formulas that contain up to 97% naturally derived ingredients. Each product is housed in environmentally sound packaging for a reduced carbon footprint.
Tulum - natural deodorant (Evolvetogether)	Doing good; Vegan, cruelty free; Biodegradable paper exterior made from responsibly-harvested FSC-certified paper to minimize waste; Packaging: 100% biodegradable and reusable pouch printed with soy ink; Made in the USA in a socially and environmentally responsible factory.
Creme para o corpo Body cream (Violet grey)	With no added water and no filler ingredients, this cream penetrates quickly and acts as a powerful treatment for skin while the signature, natural scent of Breu Branco (a Brazilian resin) calms the mind. Because this cream contains no added water you may find you require less product to feel hydrated.
Hand Soap Duos (Blueland)	We've eliminated the single-use plastic waste of traditional hand soaps by creating one bottle made to last forever. Just fill with water, drop in a tablet and voila!
All Natural Conditioner Bar Waterless Edition (Stop the Water While Using Me!)	Application: Simply rub the rich conditioner over the hair after shampooing, spread evenly through the lengths and tips and then rinse. To increase the effectiveness, allow to dry well after use. Water is a valuable resource that needs to be preserved instead of being wasted. Making small changes can contribute to water preservation, like spending time in the bathroom. STOP THE WATER WHILE USING ME! encourages people to do just that - whether at home, in restaurants or hotels, simply everywhere!

* All claims are available on retail and/or manufacturer websites

Cosmetic claims are any texts, images, symbols, etc. that in an explicit or implicit way imply the product's effects, benefits, or features (23). These claims are typically found on product labeling, in advertising, or in marketing materials, and are intended to attract consumers by highlighting specific qualities or outcomes associated with the use of the cosmetic product. One of their most important purposes is enabling the consumers to make informed purchasing decisions based upon credible references (60). Based on these claims, consumers make purchasing decisions, and if the claims are related to sustainability issues, like the ones presented in Table 2, then consumers contribute to more sustainable consumption with their purchases.

Cosmetic powders are one of the oldest make-up cosmetic products, used since ancient times, and are usually sold as flow powders or compact (compressed) powders or tablets (61). Make up powders – flow and compressed – are used to enhance the appearance of the skin and are available in a wide range of colours and textures. They can

be used for various purposes, such as setting makeup, adding colour and contouring, absorbing excess oil, and mattifying the skin. Powders enhance the appearance of the skin using camouflage effects for complexion imperfections, oil control and/or a matte finish, and providing tactile smoothness to the skin. Together with semi-solid products, powders are considered to be the most important elements of the cosmetic camouflage technique, which has been found to improve well-being, psychological experiences, and self-rated attractiveness with make-up, as well as increasing self-esteem and facial attractiveness, therefore enhancing the overall quality of life among patients with different skin conditions (62).

Modern face powders are completely water-free mixtures of different constituents which impact the following essential properties (63):

- Covering power – the ability to conceal skin imperfections and defects (colour variety, skin shine, enlarged pores, minor blemishes and spots). Covering agents in powders are usually: titanium dioxide, zinc oxide, kaolin and magnesium oxide.
- 'Long-lasting' formulation, which enables good adherence/adhesiveness of the product to the skin (avoids repeated application), prevents the product from being rubbed off onto clothing, and contributes to smooth application. The lack of adhesiveness was a disadvantage of earlier powder formulations, while current ingredients (such as: zinc and magnesium stearate, magnesium and calcium salts of myristic acid, stearates of lithium and calcium, dimethicone, talc, cocoa seed butter, zinc oxide, cetyl alcohol, stearyl alcohol, glyceryl monostearate, petrolatum, lanolin or similar fats) are used as adhesive agents.
- Slip – good slipping properties are related to good flow properties and they enable the easy spreading of the powder over the skin without dragging by the applicator (puff or brush) during the application. However, these properties are very important for the manufacturing process. Ingredients that are used to give a powder an adequate slip are kaolin, stearates and starch, talc (magnesium silicate), aluminium hydrosilicate, zinc stearate, magnesium stearate, zinc undecanoate, magnesium undecanoate, tapioca starch etc.
- Absorbency – by absorbing the skin secretions (perspiration and oiliness), powders eliminate shine in shiny skin. Ingredients with high absorptive capacity, like kaolin, starch, microcrystalline cellulose, magnesium and calcium carbonate, are used as absorbents in the formulation of powders.
- Bloom – the peach-like finish on the skin can be achieved by the addition of chalk, rice starch, prepared starch and silk powder to the formulation.

In the dynamic landscape of the cosmetics industry, where innovation is paramount and consumer demands continually evolve, solid and powder cosmetics emerge as versatile and indispensable assets. From the ancient civilizations' rudimentary powders, these cosmetic forms have traversed epochs, adapting to cultural shifts, technological

advancements, and sustainability imperatives. Technological advancements in powder and solid particle research have indeed been crucial for enhancing cosmetics powder formulations. The most notable improvements are related to nano- and microencapsulation technologies, surface modification for improved functionality, and advanced characterization techniques. Nanotechnology has enabled the production of nanoparticles with enhanced properties, such as improved stability, bioavailability, and skin penetration, making them valuable in cosmetic formulations (64-67). Encapsulation techniques, such as liposomes, phytosomes, microspheres, and solid lipid nanoparticles, have been employed to protect active ingredients, control release, and enhance stability in cosmetic formulations (68-71). Surface modification techniques, including coating and functionalization, have been utilized to tailor the physicochemical properties of powder and solid particles, enhancing their functionality, compatibility, dispersibility, and performance in topical formulations (72-74). The application of advanced analytical techniques, such as electron microscopy, spectroscopy, and rheology, enables a comprehensive understanding of powder and solid particle characteristics, facilitating the optimization of cosmetic formulations (75-77).

Finally, one of the latest trends in the development of waterless products are compressed powders or tablets, which are mainly used for cleaning not only the skin, but also the oral cavity and teeth. Usually, solid products in this category must be activated with water when used. Since water is considered necessary for the application of these products, the overall water footprint of the mentioned products is reduced. Another advantage of compressed and flow powdered products from a sustainability point of view is the reduction in packaging (19). Instead of plastic bottles used for the packaging of rinse-off products, paper/cardboard or no packaging at all are used for solid cleansing products (78).

Solid and powder cosmetics hold a pivotal role in the beauty rituals of individuals worldwide. Beyond their aesthetic appeal, these formulations serve as agents of self-expression, confidence enhancement, and self-care. They offer convenient solutions for various cosmetic needs, from complexion correction to enhancing features, all the while catering to diverse skin types and preferences.

Furthermore, solid and powder cosmetics embody a paradigm of sustainability and efficiency. Compared to their liquid counterparts, they often require fewer preservatives and packaging materials, aligning with the growing eco-conscious consumer ethos. Their portability and extended shelf life not only reduce environmental footprints, but also resonate with the demands of the modern, on-the-go lifestyle. Moreover, the convergence of beauty and wellness opens new avenues for product development within the realm of solid and powder cosmetics. Incorporating skincare benefits, sun protection properties, or aromatherapeutic elements into these formulations not only enhances their efficacy, but also resonates with the holistic approach to beauty embraced by contemporary consumers.

Waterless cosmetic product benefits

Waterless cosmetic products offer several benefits, including:

- Less or no preservatives – the benefits of preservative-free formulations for overall consumer and environment safety have already been discussed.
- Longer shelf life and better stability – because these products do not contain water, there is less risk of bacterial growth, which means they can last longer without preservatives. Certain substances are more stable in the absence of water.
- More concentrated – a smaller amount of product is used to achieve the same results, which can lead to cost savings in the long run.
- Less packaging and transportation required, which means a lower overall environmental impact, especially a smaller carbon footprint.
- Travel-friendly – because waterless cosmetic products are often more compact and lighter than their water-based counterparts, they are ideal for travel.

Challenges in the formulation of waterless cosmetic product

Although each cosmetic formulation has its own challenges in terms of ingredient selection, compatibility, safety and efficacy, the general challenge for any new waterless cosmetic formulation is to achieve the same performance and meet the consumers' expectations regarding sensory characteristics of the product based on their experience with traditional cosmetics containing water. This is a problem that formulators have to overcome, but at the same time manufacturers of cosmetic ingredients have to be prepared to meet the formulator's requirements. Solid cosmetics should have the same skin feel as cosmetic with water, and this can be achieved by creating non-greasy and non-tacky textures, as this is one of consumers' main concerns. Although sensory characteristics can be adjusted with the selection of proper ingredients, waterless products may have certain inevitable shortcomings regarding desired sensory performances, which must be clearly presented to the consumer (79). As for ingredients, a particular focus is on the next generation of texture modifiers. In addition to heavy product texture, waterless products also present challenges related to the oxidative stability of lipid-based formulations. Moreover, the substitution of water with other ingredients comes at a higher cost. On the other hand, waterless products are less expensive in concentrated form, which consumers should be informed about along with the environmental benefits. Finally, all these aspects must be brought to the attention of consumers, and the cosmetic industry has to find the ways to achieve this.

Conclusion

This article highlights the main advantages of waterless cosmetics in terms of water sustainability. Additionally, all other aspects of waterless cosmetics that can have a positive impact on the environment are presented. Although waterless cosmetics cannot solve water scarcity as such, the fact is that the presence of these products on the market,

along with numerous environmental claims, will raise water-consciousness, along with underscoring our responsibility to preserve our planet and life on Earth.

Public data demonstrate that life on Earth as we know might not exist within a few decades, with parts of the world having no access to drinking water, undergoing climate change, etc. Industry promotes sustainable development as the solution to these problems. Trying to use waterless beauty products could be considered as the cosmetic industry and consumers' contribution to environmental protection. However, this is not really an act of sacrifice, since waterless cosmetics can provide the full range of cosmetic product effects. Overall, waterless cosmetic products are a great option for anyone looking for a more natural, eco-friendly, and efficient approach to their skincare and beauty routine.

Acknowledgement

This research was funded by the Ministry of Science, Technological Development and Innovation, Republic of Serbia through Grant Agreement with the University of Belgrade – Faculty of Pharmacy No: 451-03-47/2023-01/ 200161.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contributions

Milica Lukić: Conceptualization; Formal analysis; Investigation; Visualization; Roles/Writing - original draft; and Writing - review & editing.

Danina Krajišnik: Supervision; Roles/Writing - original draft.

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Izazovi i napredak u razvoju formulacija bezvodnih kozmetičkih proizvoda – podizanje svesti o održivosti vode

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Kratak sadržaj

Osnovna strategija za upravljanje ograničenim svetskim vodnim resursima je očuvanje vode. Životni ciklus kozmetičkih proizvoda, koji se u nemerljivim količinama koriste u svakodnevnom životu, uključuje značajnu potrošnju vode. Voda ne samo da je čest sastojak kozmetičkih proizvoda, već se i koristi u svim fazama procesa njihove proizvodnje. S tim u vezi, danas se razvijaju brojne strategije za smanjenje potrošnje vode u različitim fazama životnog ciklusa kozmetičkih proizvoda, te se ovaj rad fokusira na napore da se minimizira upotreba vode u razvoju formulacije i izazove koji se pri tome pojavljuju. Kozmetički proizvodi bez vode su trend koji je počeo sa manje motivacije za održivost, ali je u kombinaciji sa globalnom svešću o značaju očuvanja životne sredine postao atraktivna formulaciona strategija za održivost vode. Kozmetičke formulacije bez vode smanjuju direktan otisak vode tako što ne koriste vodu kao glavni sastojak u formulacijama. Ipak, dizajn bezvodne kozmetike je veliki izazov. Ovaj rad sumira tendencije, principe i ključna razmatranja formulacije, kao i prednosti kozmetičkih proizvoda bez vode. Njime se ukazuje na značaj smanjenja vodenog i ugljeničnog otiska kozmetičkih proizvoda, i posledično njihov doprinos kvalitetu života i održivog razvoja.

Ključne reči: topikalne formulacije, dizajn kozmetičkih proizvoda, bezvodni proizvodi, održivost vode