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Strategy for the development of a new stick formula without microplastics

Laura Frigerio [a,b], Luigi Padovano [a], Simone Conti [a], Miryam Chiara Malacarne [b], Enrico Caruso [b,*]

[a] *Brasca Industrial s.r.l, Via Nerviano 31, 20045, Lainate, MI, Italy*
[b] *Department of Biotechnology and Life Sciences (DBSV). University of Insubria, Via J.H. Dunant 3, 21100, Varese, VA, Italy*

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ABSTRACT

Plastic is a synthetic, malleable, and durable material that has been used for various applications since its invention in the late 19th century. During its very long-time degradation process, mechanical and/or photochemical processes fragment plastic into increasingly smaller fragments called microplastics (MPs). In the cosmetic field, MPs are directly added to many products for various functions, including to exploit their exfoliating and structuring power. Unfortunately, it has been realized that MPs are not retained in purification plants and therefore end up in the aquatic environment causing a high problem of environmental pollution. Polyethene (PE) is the most widely used MP in cosmetics due to its use as a structuring agent, to provide consistency to formulations and as a key ingredient in lipsticks and mascaras. Given the limitations imposed by regulations and the growing demand from consumers for chemical-free and eco-friendly products, the common synthetic and petroleum-based waxes used in lipstick formulations, such as PE, must necessarily be replaced by natural waxes of plant origin. In this paper we report the development of a chemical-free and eco-friendly cosmetic stick. To achieve the goal, it was necessary to study the compatibility of the ABWAX® Revowax, natural alternative to PE, with oils and colours to predict the behaviour of these structuring waxes in more complex systems. Through a systematic comparative study, the two waxes showed similar thermal characteristics and showed similar penetration curves, presenting overall comparable performance in the MP-free finished product. We can therefore consider ABWAX® Revowax natural wax a valid alternative to PE.

1. Introduction

Plastic production has been increasing dramatically since the 50s, to the point that its annual global production reached approximately 300 million tons in 2022 (EuropePlastic, 2022; Geyer et al., 2017). Plastic is the longest lasting synthetic product as its complete degradation takes hundreds of years (Moharir and Kumar, 2019; Padervand et al., 2020; Verma et al., 2016). During this time, mechanical and/or photochemical processes fragment plastic and introduce harmful particles into the environment. Based on their size, these particles are called micro or nanoplastics (microplastics <5 mm or nanoplastics <1 μm) (Issac and Kandasubramanian, 2021). Under reasonably foreseeable conditions of use, it is estimated that MPs intentionally released into the environment are more than 42,000 tonnes per year. As data show, today we are facing a real planetary crisis linked to environmental MPs pollution, espe-

Abbreviations: DP, Drop point; DSC, Differential scanning calorimetry; ECHA, European Chemicals Agency; EU, European union; MP, Microplastic; PE, Polyethylene; REACH, Registration, Evaluation, Authorisation and Restriction of Chemicals.

* Corresponding author.
E-mail address: enrico.caruso@uninsubria.it (E. Caruso).

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cially water pollution. In fact, many "rinse-off" products that contain plastic obviously end up in domestic wastewater streams (Ivar do Sul and Costa, 2014; Ju et al., 2021; Nikiema et al., 2020). Research has shown that multiple sources MPs, in wastewater streams are retained in sewage sludge while the remainder are emitted into surface waters via treated wastewater effluent (Kalcikova, et al., 2017). Some of these effluents are discharged directly into the sea while the others enter river systems, which are known to carry suspended particulates with the current out to sea (Fendall and Sewell, 2009; Thompson et al., 2004). A lot of MPs are originated from cosmetics and cleaning products released into household wastewater (Akbay, et al., 2022, Koyilath Nandakumar et al., 2022; Mahon et al., 2017). In most cases, MPs are found in cosmetic products as microbeads added to exfoliate skin or teeth surface (Bhattacharya, 2016; Guerranti et al., 2019). Depending on polymer type, composition, size, and shape, plastic ingredients are being added into formulations with a vast number of functions (e.g. bulking agents, viscosity controlling, film formation, sorbent of delivering of active ingredients) (Ju, et al., 2021) so plastic ingredients are part of a wide variety of formulations (Lochhead, 2017; Patil and Ferritto, 2013; Sakamoto et al., 2017). Unfortunately, wastewater treatment plants were not designed to degrade plastic particles or totally retain them in the sludge fraction. This causes a serious pollution problem especially in the aquatic compartment (Leslie, 2014; Zhou et al., 2023).

This problem has been addressed by both the scientific community and individual governments. The scientific community has been interested in finding more effective MP degradation systems and this has led to numerous studies on the degradation of MPs, of different origins, by bacterial strains (Chandra, et al., 2020; Pathak and Navneet, 2023). At the same time, local governments first worked to limit and then definitively ban the use of MPs in various sectors including cosmetics (Tang, et al., 2021). As a result, in March 2019, the European Chemicals Agency (ECHA) provided clear definitions of different polymers and their applications, while proposing a global ban on specific products containing MPs, alone or in mixtures (Anderson, et al., 2016). This step forward was made up to effectively reduce emissions across the European Union (EU) (Anagnosti, et al., 2021; Kentin, 2018). ECHA proposed an immediate ban on plastics microspheres, ranging in size from 1 nm to 5 mm, in rinse-off cosmetics for cleansing and exfoliation (Zitko and Hanlon, 1991). The agency also imposed a restriction on the use of MPs, other than microbeads, added to cosmetics within the next 4 and 6 years for rinse-off and leave-on cosmetics, respectively, after the implementation of the new ECHA regulations. Transitional time was foreseen to allow cosmetic industries to reformulate products (ECHA, 2020).

In cosmetic industry, MPs are added as microspheres (MPs) (Cheung and Fok, 2016; Isobe, 2016) to improve cleansing and exfoliating properties of cosmetics (Napper, et al., 2015). Among the main constituents of MPs, 93% is represented by polyethylene (PE) (Gouin, et al., 2011; Nawalage and Bellanthudawa, 2022). PE wax is widely recognized as an excellent structuring agent, to provide formulations texture, and a key ingredient in lipsticks and mascaras (Loretz, et al., 2008). Currently, the most used PE agents differ only in molecular weight (MW) which provides them different properties and uses (Miyazaki and Marangoni, 2014; Shibata et al., 2003).

Given the limitations imposed by regulations and the growing consumers demand for natural products, common synthetic and petroleum-based waxes used in lipstick formulations, such as PE, must necessarily be replaced by natural waxes (de Clermont-Gallerande, et al., 2022; Lahoti, 2018). Nowadays, among the different natural raw materials, the choice falls on those of vegetal origin able of meeting the vegan consumers demand for eco-sustainable products.

The aim of this paper is the development of an eco-friendly cosmetic stick product. The strategy used to formulate the stick is based on the characterization of ABWAX® Revowax, a natural alternative to PE, patented and already present on the market. To achieve the objective, it was necessary to study the compatibility of the raw materials with the oils and colours most used in the cosmetic world to predict the behaviour of these structuring waxes in more complex systems. Through a systematic comparative study, the formulation of the finished MPs-free product was obtained.

2. Experimental section

2.1. Materials

Table 1 shows all the materials used with their relative function, chemical class and polarity.

2.2. Procedure

2.2.1. Thermal analysis

The two raw materials, ABWAX® Revowax and PE, were characterised by their physical appearance (colour, smell, and shape) and by thermal analysis, differential scan calorimetry (DSC) and drop point (DP) which provides more detailed information on their thermal properties. DSC was performed using STARe System DSC 3 while DP used Dropping Point System DP70 both provided by Mettler Toledo.

2.2.2. Oil-wax compatibility study

The experimental procedure began with preparing wax-oil synergies realized at decreasing amounts of wax (20%, 15% and 10%). The waxes were heated to melting temperature under agitation together with each oil tested (Table 1), then slowly cooled to 25 °C. Subsequently the samples were analysed using the manual penetrometer 650/SEM748 (Montepaone s.r.l.) to verify the resistance to penetration and, at the same time, to evaluate the compactness and consistency of these matrices. These samples were also used for a DP analysis.

Table 1
Structuring ingredients and oils used in tests.

	Trade name	INCI	NOI (ISO16128)	Functions	Chemical class	Polarity
Structuring ingredients	Polyethylene	Polyethylene	0	Polymer		
	ABWAX® Revowax	Helianthus Annuss Seed Cera, Hydrogenated Castor Oil	1	Wax		
Oils	Squalene	Squalane	0	Emollient	Hydrocarbon	Apolar
	Vaseline	Petrolatum	0	Emollient	Hydrocarbon	Apolar
	Octyldodecanol	Octyldodecanol	1	Emollient	Alcohol	Polar
	Beausens® air	Ethylhexyl pelargonate	0.6	Emollient	Monoester	Polar
	Oilfeel® skin	Triolein, Glyceryl Dioleate	1	Emollient	Diester	Polar
	EMotion® light	C8–C12 Acid tryglyceride	1	Emollient	Triester	Polar
	MCT	Caprylic/Capric Triglyceride	1	Emollient	Triester	Polar
	Castor oil	Ricinus communis seed oil	1	Emollient	Natural oil	Polar
	Squalene	Squalane	0	Emollient	Hydrocarbons	Apolar
	Vaseline	Petrolatum	0	Emollient	Hydrocarbons	Apolar
Ingredients of finished products	Hailucent ISDA	Polyglyceryl-2 Isostearate/Dimer Dilinoleate Copolymer		Emollient		
	Red7 + Tripelargonin	CI 15850		Coated Pigment		
	Celus BI® Feel-10	Zea Mays Starch, Polyvinyl Alcohol, Glycerine		Texturizer		

2.2.3. Production method for the formation of a stick

The oil-wax synergy prepared for penetration analysis was heated until completely melted; when it reached the temperature of 85 °C, it was poured into a metal mould for lip balms that was previously lubricated with a food grade silicon spray to facilitate the detachment of the stick, and heated at 85 °C, to avoid thermal shock. The sample was left a room temperature (RT) for 15 min and then at −18 °C for 15 min until complete solidification. Once the poured mass thickened enough to allow handling, the segments in the mould were disassembled so that the product could be inserted into the appropriate packaging. Pre-heating and a slow cooling step are extremely important for a successful formulation process: slow cooling generates a structure with large lattices, while fast cooling produces a finely cross-linked lattice which significantly affects the hardness of the oil-wax system (Shimizu, et al., 2021). The obtained sticks were subjected to sensory evaluations to obtain a better understanding of the performance and consumers' perception of the product. In the following study, a descriptive quantitative analysis (QDA) was carried out to define each of the parameters examined (Biraghi, et al., 2016). The test involved a group of 25 expert panellists specialized in quantifying the intensity of sensory perceptions in a reproducible way. The panellists were asked to give a score, ranging from 1 to 10, about the stick smoothness and spreadability. The results were then used to observe the difference between creamy and control sticks. Spreadability results were classified as low, medium, and high. The obtained sticks were monitored over time, at 1, 3 and 6 months at 25 °C and 40 °C.

2.2.4. Compatibility with pigments and coated lakes

Oil-wax synergies that showed the best results in terms of stability and thermal properties were chosen in this part of study to evaluate the compatibility with pigments and coated lakes.

The new samples were produced using 18% wax, 67% oil and 15% coated lakes as these percentages are standard quantities used in cosmetic finished products.

The three ingredients were weighed and heated up to 90–95 °C under stirring; once the temperature was reached, the sample was homogenized for 30 s at 10000 rpm with a dispersion homogenizer (OV5 homogenizer, Velp Scientifica) to break up pigments' agglomerates. The same sample was later heated up to 85 °C, and poured into a metal mould for lipsticks. The preparation of the lipstick continued following all the steps described in paragraph 2.2.3.

The lipsticks were subjected to sensory evaluations as reported in paragraph 2.2.3. The participants were asked to evaluate the texture, spreadability, texture richness and finish. The lipsticks stability was monitored up to 6 months at 25 °C and 40 °C.

2.2.5. Development of finished products

The production method is the same as the one described in paragraph 2.2.4. The only difference is that the holes of the stylo mould have smaller diameters. DP analysis and sensory evaluation were performed, and the lipsticks stability was monitored up to 6 months at 25 °C and 40 °C.

3. Results and discussion

3.1. Thermal analysis

The characterization began with the study of the thermal analysis of the raw materials, as it is the main parameter that is used to classify natural and synthetic waxes (Table 2). The DSC analysis was carried out as we aimed to evaluate all the comparative transitions between ABWAX® Revowax and PE, while the DP analysis was performed to allow us to classify the waxes as high-melting and structuring waxes or low-melting waxes, with the latter ones enabling better smoothness and a more significant colour release (Bryce, 1993; Iwata and Shimada, 2013; Mawazi et al., 2022).

Table 2
Physical-chemical characteristics of ABWAX® Revowax and PE.

Parameter	Requirement		Methods
	ABWAX® Revowax	PE	
Composition	Helianthus annuus seed cera, Hydrogenated castor oil	PE	–
Appearance	Waxy solid in pearls	Small spherical particle	IO 07-06A
Colour	White to pale yellow	White	IO 07-06A
Odor	Characteristic	Characteristic	IO 07-06A
Melting point[a]	74–81 °C	74–81 °C	DSC
Drop point[b]	81–87 °C	81–87 °C	Ph.Eur.2.2.17 (Method B)

[a] The melting point was derived from the thermic profile of the DSC.
[b] The DP analysis was performed 5 times to define a range of temperatures.

Delving into the thermal analysis of ABWAX® Revowax and PE has uncovered details regarding their crystallization and melting behaviours, as showcased in the visually informative cooling and heating curves presented in Fig. 1.

The cooling curves in the upper portion of the thermic profile of the ABWAX® Revowax appears to go up rapidly and reaches a higher peak compared to the PE curve. However, from the ends of the two curves we can notice that the major distribution of the PE has a crystallization temperature comparable to the ABWAX® Revowax. During samples heating, bottom part of the graph, a more defined peak is observed for ABWAX® Revowax and a less homogenous curve for PE (Alejandro Pineda Beltrán and García, 2023; Kumar et al., 2007).

The waxes have similar thermal characteristics: the same DP temperature ranging between 81 and 87 °C (Table 2), and the same melting temperature ranging between 74 and 81 °C (Table 2). The same DP temperature of the waxes suggests that the sticks produced with these two waxes will have a similar DP and comparable performance behaviour (Esposito and Kirilov, 2021; Pan and Germann, 2019). The melting temperature of ABWAX® Revowax and PE was taken from the DSC graph shown in Fig. 1.

The differences in these curves not only highlight the unique thermal profiles of the two waxes but also hint at potential implications for their practical application in cosmetic formulations (de Clermont-Gallerande, et al., 2022) such as solid anhydrous formulations like lip balms, lipsticks and every type of colour cosmetic in stick or balm where the presence of high melting point waxes is fundamental to achieve a highly structured formula (Rigano and Montoli, 2021).

3.2. Oil-wax compatibility study

The next step was to carry out a preventive study on the hardness of the samples at different percentages to evaluate the structuring properties of the two waxes to understand how similar they were to each other. The peculiar characteristics of the oils within the waxes are melted can impact the mechanical strength of the formed crystalline lattice (Biraghi, et al., 2016; Biraghi et al., 2019).

Penetration values of oil-wax synergies realized at different ratios (80%, 85%, and 90%) provided information on the plasticity of the waxy crystalline lattice. A high value is an index of deep penetration in the sample, sign that the sample has retained more oil and is more deformable. This analysis is crucial because the hardness of the sample is closely related to the performance (Juma'at et al., 2021, Pan and Germann, 2019) The stiffer the stick, the less oil will be released and vice versa. In addition, there is a correlation between the hardness of the stick and the drop point, so, we expect higher drop point temperatures in samples with lower penetration values (stiffer sticks).

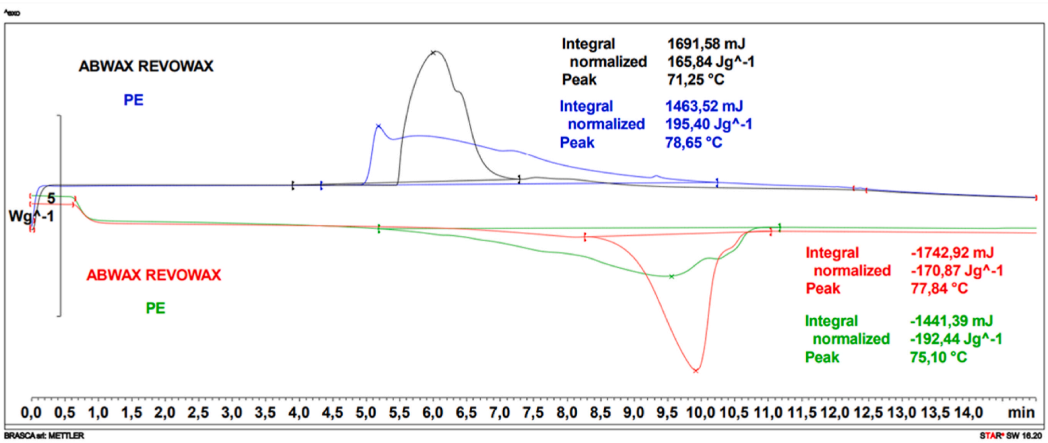

Fig. 1. DSC curve ABWAX® Revowax vs PE 400 Mw. Cooling and melting profile curves of ABWAX® Revowax (Cooling: black, Melting: green) and PE 400 MW (Cooling: blue, Melting: red). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

It is also possible to make predictions about the texture of the stick carrying out DP analysis (Kumar, et al., 2021). The higher the DP temperature, the more significant the gap with body temperature is, hence, the stick will not be smooth. Sticks with low DP temperature, close to body temperature, will produce a creamier application and release much more oil.

It was also conducted a panel test for a sensory analysis in terms of creaminess (scale from 1 to 10) and spreadability (low spreadability = 1–3; medium spreadability = 4–6; high spreadability = 7–10).

In this way, both a sensory analysis and an instrumental analysis of the performance between ABWAX® Revowax and the reference benchmarks were carried out.

Fig. 2A displays the penetration profile using Ethylhexyl pelargonate as the oil. Between 80% and 85% of oil, both waxes demonstrated comparable values. At 90% of oil, PE exhibited better structuring properties than ABWAX® Revowax, although the result was not rigid enough for stick formation. Creaminess ratings for 20% wax samples were 8, while those with 15% wax were 9. In terms of spreadability, 20% wax samples had medium spreadability (6 in both cases), while 15% wax samples had high spreadability (7 for ABWAX® Revowax and 9 for PE).

Fig. 2B shows penetration curves with Triolein, Glyceryl Dioleate as the oil, exhibiting similar performance. At 90% oil, stick formation was not achieved. Sensory analysis rated 20% wax samples as control sticks (3 for ABWAX® Revowax and 4 for PE) with low spreadability (3 in both cases), while 15% wax samples were creamy sticks (6 for ABWAX® Revowax and 7 for PE) with medium spreadability (4 for ABWAX® Revowax and 5 for PE).

Fig. 2C demonstrates similar performance of the two waxes at 20% in combination with 80% of C8-C12 Acid Triglyceride as the oil. At 85% oil, PE provided slightly more structure than ABWAX® Revowax, while at 90% oil, ABWAX® Revowax appeared to have more structuring properties. Both 20% and 15% wax sticks were classified similarly with spreadability ratings.

Fig. 2D depicts overlapping performance between 85% and 90% of oil with Caprylic/Capric triglyceride. At 80% oil, PE provided more structure than ABWAX® Revowax. Similar results were obtained with 20% and 15% wax concentrations, and the panel tests yielded identical ratings to those with C8-C12 Acid Triglyceride.

In Fig. 2E, the performance of the two waxes was very similar at all percentages tested, with all samples classified as control with low spreadability when combining Ricinus Communis (Castor Oil) seed oil and PE.

Fig. 2F shows very similar penetration values with Octyldodecanol, and both waxes formed sticks at concentrations up to 85% of oil. Creaminess and spreadability ratings were consistent across 20% and 15% wax samples.

The last two graphs (Fig. 2G and H) display the performance of the two waxes with Squalene or Petrolatum. Unlike other cases, ABWAX® Revowax and PE showed discordant performance. Sticks were obtained only in PE-Petrolatum synergies due to PE's non-polar nature. Squalene samples had high penetration values and did not form sticks, with the only two sticks obtained classified as control with varying spreadability ratings.

As observed, the waxes show different structuring behaviour depending on oil polarity and viscosity of the oil. Penetration increases with increasing polarity of the oil. The increase in polarity in oil-wax synergies leads to an increase in compactness by forming smaller crystalline structures (Imai, et al., 2001). The increase in polarity also seems to coincide with the formation of more compact structures (de Clermont-Gallerande, 2020).

In consequence, the desired stick hardness can be controlled by modifying the amount of wax and depends on a careful choice of oil based on the peculiar characteristics of polarity and viscosity (Shimizu, et al., 2021).

We obtained creamy sticks in synergies with fatty alcohols and low molecular weight esters at all the percentages tested. While with medium molecular weight esters, we obtained creamy sticks using lower wax concentrations and controlled sticks with high rates of wax. Using high molecular weight esters or hydrocarbons it was possible to have controlled sticks. Still, with these two chemical classes of oil, the phenomenon of syneresis has occurred with Ricinus Communis (Castor Oil) seed oil and on the other hand, hydrocarbon oils were only structured enough to have a stick using PE Furthermore, the results show that the recommended minimum percentage of wax is around 12–13% if it is used alone.

In addition, all the synergies in which ABWAX® Revowax was used at 10% we were always been able to get a stick. Still, when we proceeded to remove the stick from the mould, more than 50% of the samples broke or did not stick to the packaging, indicating that the sample was too creamy.

This, however, does not exclude that, in combination with other structuring factors, such as other waxes, butter or highly viscous esters, it can be used even at lower percentages (Rigano and Montoli, 2021).

3.3. Compatibility with pigments and coated lakes

As a continuation of this study, we introduced pigments an additional variable within binary systems. Furthermore, the addition was done only in the oil-wax synergies composed of polar oils because, in the previous research with non-polar oils, we encountered difficulty obtaining a stick. Moreover, the non-polar oils tested are of petrochemical origin that is in contrast with sustainability required in the cosmetic world today.

Since pure pigments are not soluble in any type of solvent but they may only be barely dispersible, this systematic formulation approach was focused on coated pigments that are characterized by a thin layer of oil on the surface that facilitates their dispersion within the lipstick oily phase speeding up the production process, thus saving time and energy (Pfaff, 2021; Rigano and Montoli, 2021).

Fig. 3 showed the results obtained from the compatibility study with pigments and coated lakes. In addition to assessing the degree of colour pay-off and coverage of the lipsticks (spreadability) achievable, the finish was also evaluated.

The texture scores were compared with the temperature obtained from DP analysis, and the lipsticks were classified as creamy or control. Texture richness provides an idea about the heaviness of the lipsticks when applied to the lips (Kasparaviciene, et al., 2016).

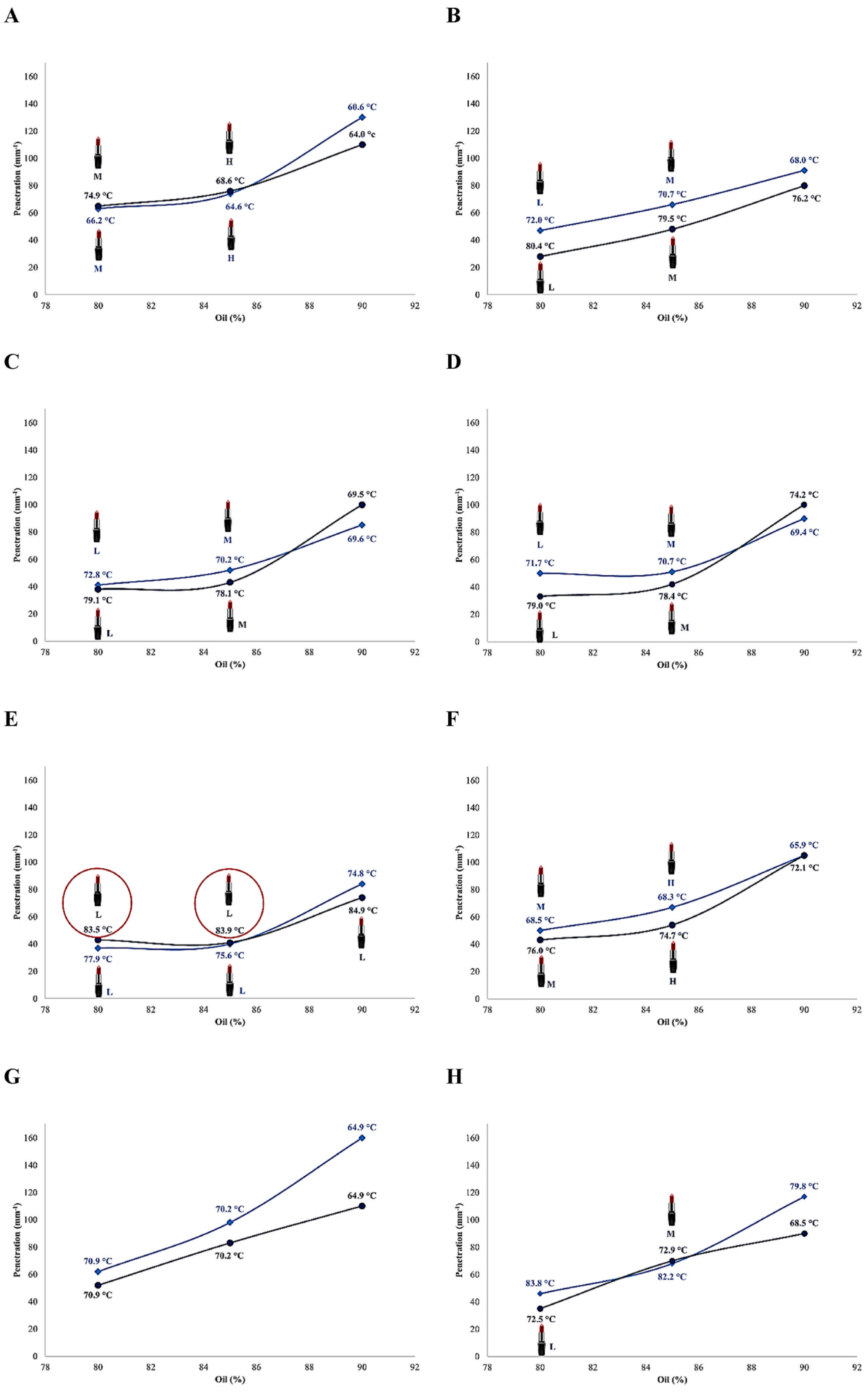

Fig. 2. Penetration curves of the samples at 3 different wax concentrations (20%, 15%, and 10%) with Ethylhexyl pelargonate (**A**), Triolein, Glyceryl Dioleate (**B**), C8-C12 Acid Triglyceride (**C**), Caprylic/Capric triglyceride (**D**), Ricinus Communis (Castor) seed oil (**E**), Octyldodecanol (**F**), Squalene (**G**), and Petrolatum (**H**) oil Blue:

Fig. 2. *(continued)*
ABWAX® Revowax, black: PE). For each sample, a stick image is added whether the stick was formed at the specified oil concentration and the value of spreadability is reported (L: low spreadability; M: medium spreadability; H: high spreadability). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

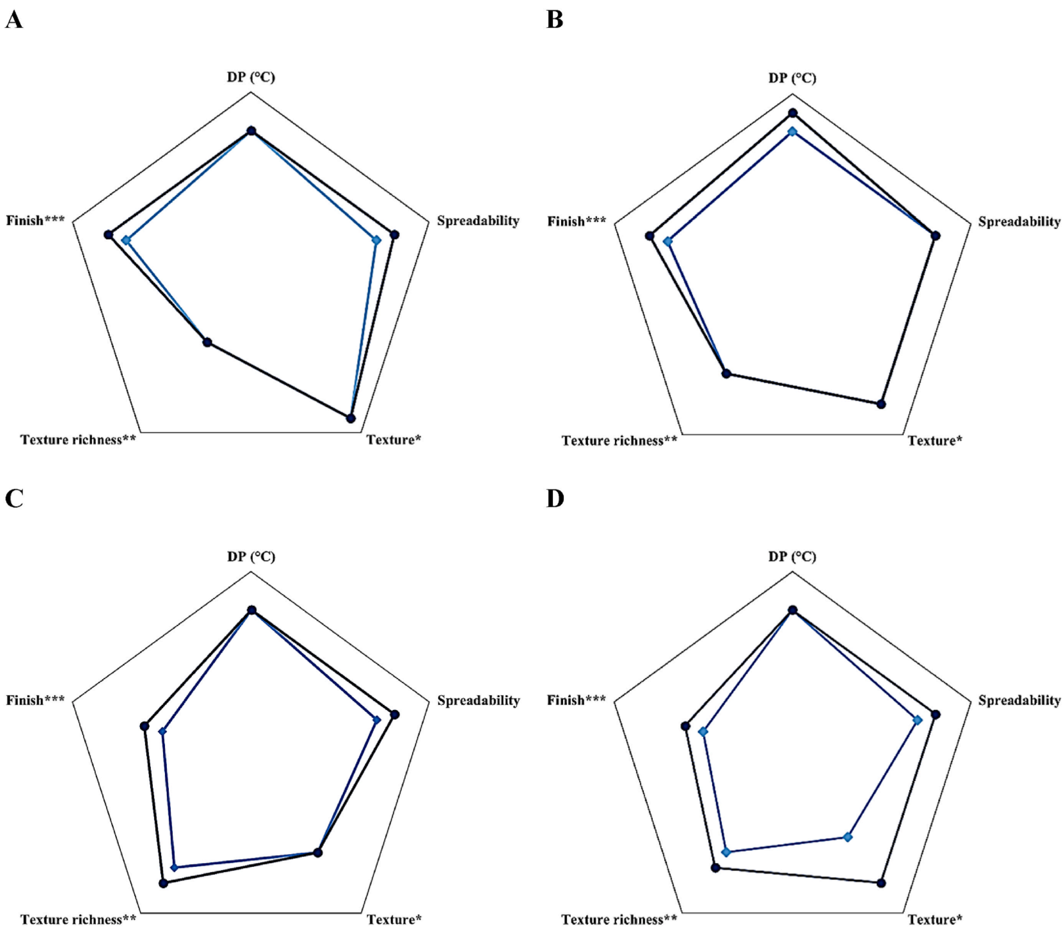

Fig. 3. Performance of 3-component lipsticks with Ethylhexyl Pelargonate (LMW ester) (**A**), Octyldodecanol (alcohol) (**B**), C8-C12 Acid triglyceride (MMW ester) (**C**), and Triolein, glyceryl Dioleate (MMW ester) (**D**) (Blue: ABWAX® Revowax, black: PE). *10: Creamy – 0: Control; ** 10: Rich – 0: Lightweight, *** 10: Glossy – 0: Matte. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

In this case 1 was attributed for lightweight lipsticks that left a thin layer and 10 to the very rich lipsticks leaving a thick layer on the lips.

Fig. 4 reports the behaviours of all 4 oils tested with the 2 waxes, the parameters tested were the same as those described in Fig. 3.

Less structured lipstick and a lower DP value were obtained with Ethylhexyl Pelargonate and Octyldodecanol since they are low molecular weight oils; lipsticks obtained using these combinations were creamy and provided good spreadability and a glossy finish. On the other hand, with higher molecular weight oils, C8-C12 Acid triglycerides and Triolein, Glyceryl dioleate, we obtained more structured sticks with a higher DP value, lower spreadability and a matte finish.

In all four cases tested (polar oils), ABWAX® Revowax showed very similar behaviour to PE, confirming the results obtained in the study of 2-component sticks. The best result, in terms of creaminess and glossiness was obtained using Octyldodecanol, while using C8-C12 Acid triglycerides, a matte and controlled stick was obtained.

The systemic formulation approach allowed us to critically evaluate ingredients performances and to find the optimal combination for the development of two lipstick bases: an innovative one without microplastics and a conventional one containing them.

3.4. Development of finished products

The goal of this part of the study was to develop a creamy lipstick that would apply smoothly on the lips with a good release of colour and a glossy finish. This was done to increase the number of variables that ultimately align this study closer to a finished cosmetic formulation.

Fig. 5 compares the finished stylo from Table 3 made with ABWAX® Revowax and the one made with PE.

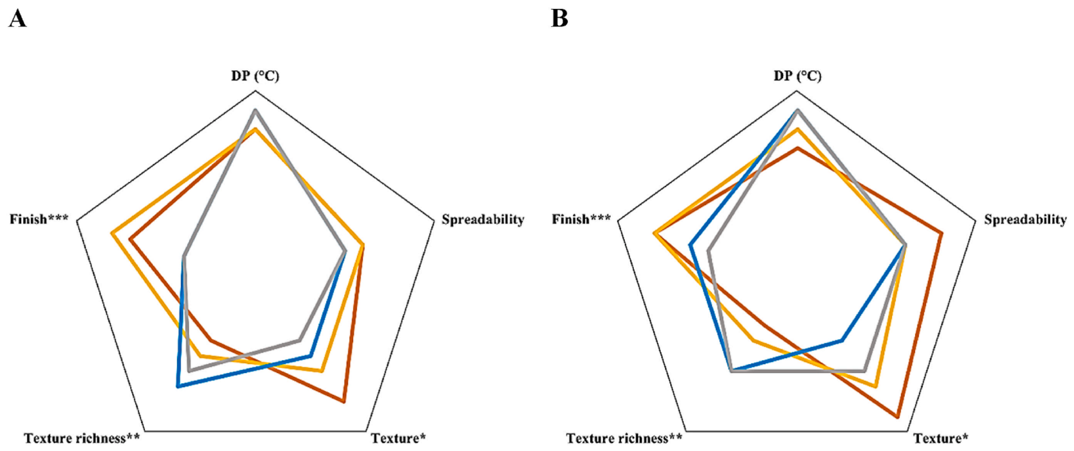

Fig. 4. Panel test results of ABWAX® Revowax (**A**) and PE (**B**) in combination with polar oils tested (Blue: C8-C12 Acid triglyceride; Orange: Ethylhexyl pelargonate; Grey: Triolein, Glyceryl Dioleate; Yellow: Octyldodecanol). * 10: Creamy – 0: Control; ** 10: Rich – 0: Lightweight, *** 10: Glossy – 0: Matte. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

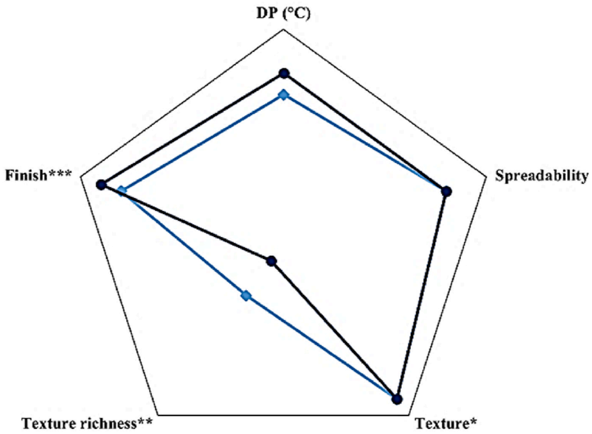

Fig. 5. Comparison between Table 3 stylo made with ABWAX® Revowax (Blue) or PE (Black). * 10: Creamy – 0: Control; ** 10: Rich – 0: Lightweight, *** 10: Glossy – 0: Matte. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 3
Percentages of all the ingredients used for each finished product.

INCI	%
ABWAX® Revowax/PE	10.80
Octyldodecanol	39.70
Polyglyceryl-2-Isostearate/Dimer Dilinoleate Copolymer	4.90
Ethylhexyl pelargonate	29.41
Zea Mays Starch, Polyvinyl Alcohol, Glycerine/Nylon	7.84
CI 15850	7.35

To achieve the desired texture, it was necessary to combine a low percentage of wax (both PE and ABWAX Revowax) with low molecular weight oil. Due to the formulative choices made, both lipsticks had low DP temperatures (ABWAX Revowax stylo 64–67 °C, while PE stylo 65–69 °C).

The performance of the two sticks is almost equal for all the parameters tested, except for the texture richness which is lower in PE stylo in comparison to ABWAX® Revowax stylo. Moreover, the synthetic one presents a slightly glossier finish. The finished products were then tested on the lips by 25 panellist who described the feeling during the application. According to most of the experts, the ABWAX® Revowax stylo felt more controlled during the application and therefore more comfortable, while the PE stylo was shinier and with a more significant colour release but too smooth on the lips and therefore difficult to apply.

In conclusion, in finished products made of just few ingredients, ABWAX Revowax can replace 1 to 1 PE without changing its performance, as shown in the panel test, also appearing to be more comfortable than the reference benchmark.

4. Conclusion

The study was conceived with the aim of understanding the thermal and compatibility characteristics of ABWAX® Revowax and PE, providing valuable guidance for cosmetic formulators seeking optimal product performance.

This investigation began with a methodical exploration essential for comprehending the behaviour of PE and its natural alternative, ABWAX® Revowax, in simple systems. The outcomes were then utilized to formulate a final product demonstrating comparable performance. Both raw materials were categorized as high-melting waxes, and subsequent assessments were conducted to understand their compatibility with other ingredients.

The combination of these waxes with low molecular weight oils yielded creamy sticks that are exceptionally smooth and exhibit significant colour release. Furthermore, the creaminess of the stick was found to be influenced by the percentage of wax utilized. Sticks with a higher wax percentage maintained a more structured form, while those with a lower wax percentage were less structured and, consequently, creamier during application.

Through these studies, the minimum wax usage percentage required for stick formation was determined for both waxes, falling within the range of 12–13%. These systematic findings were then applied to develop a finished product, namely the Stylo.

The strengths of this study lie not only in its novel findings but also in its comprehensive approach, integrating thermal analysis, sensory evaluation, and compatibility studies. This innovative approach offers a versatile model that can be applied in the development of a wide range of finished stick products. Importantly, it allows for the utilization of a sustainable and alternative wax to PE, exemplified by the successful use of ABWAX® Revowax.

CRediT authorship contribution statement

Laura Frigerio: Data curation, Methodology. **Luigi Padovano:** Writing – review & editing. **Simone Conti:** Conceptualization, Supervision. **Miryam Chiara Malacarne:** Writing – review & editing. **Enrico Caruso:** Conceptualization, Supervision, Validation.

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.

Data availability

No data was used for the research described in the article.

References

Akbay, H.E.G., Akarsu, C., Isik, Z., Belibagli, P., Dizge, N., 2022. Investigation of degradation potential of polyethylene microplastics in anaerobic digestion process using cosmetics industry wastewater. Biochem. Eng. J. 187, 108619.

Alejandro Pineda Beltrán, R., García, J., 2023. In: Ahmad, Usama, Juber, Akhtar (Eds.), In Cosmetic Products and Industry - New Advances and Applications. IntechOpen. Ch. (Chapter 5), Ch. 5.

Anagnosti, L., Varvaresou, A., Pavlou, P., Protopapa, E., Carayanni, V., 2021. Worldwide actions against plastic pollution from microbeads and microplastics in cosmetics focusing on European policies. Has the issue been handled effectively? Mar. Pollut. Bull. 162, 111883. https://doi.org/10.1016/j.marpolbul.2020.111883.

Anderson, A.G., Grose, J., Pahl, S., Thompson, R.C., Wyles, K.J., 2016. Microplastics in personal care products: Exploring perceptions of environmentalists, beauticians and students. Mar. Pollut. Bull. 113, 454–460. https://doi.org/10.1016/j.marpolbul.2016.10.048.

Bhattacharya, P., 2016. A review on the impacts of microplastic beads used in cosmetics. Acta Biomed. Sci. 3.

Biraghi, E., Quaggio, D., Abbà, P., 2016. Analisi sensoriale dei rossetti in stick. Kosmetica.

Biraghi, E., Abbà, P., Vitaloni, L., 2019. Funzionalità Delle Cere Naturali Nei Rossetti. Kosmetica.

Bryce, D.M., 1993. In: Butler, Hilda (Ed.), Poucher's Perfumes, Cosmetics and Soaps, vol. 3. Springer Netherlands, pp. 213–243. Ch. (Chapter 9).

Chandra, P., Enespa, Singh, D.P., 2020. In: Chowdhary, Pankaj, Raj, Abhay, Verma, Digvijay, Akhter, Yusuf (Eds.), Microorganisms for Sustainable Environment and Health. Elsevier, pp. 431–467.

Cheung, P.K., Fok, L., 2016. Evidence of microbeads from personal care product contaminating the sea. Mar. Pollut. Bull. 109, 582–585. https://doi.org/10.1016/j.marpolbul.2016.05.046.

de Clermont-Gallerande, H., 2020. Functional roles of lipids in make-up products. OCL 27, 33.

de Clermont-Gallerande, H., et al., 2022. Substitution of synthetic waxes by plant-based waxes in lipsticks. Ocl 29. https://doi.org/10.1051/ocl/2022010.

ECHA, 2020. Committee for risk assessment (RAC) committee for socio-economic analysis (SEAC). Opinion on an Annex XV Dossier Proprosing Restrictions on intentional-Added Microplastics. https://echa.europa.eu/documents/10162/a513b793-dd84-d83a-9c06-e7a11580f366.

Esposito, C.L., Kirilov, P., 2021. Preparation, characterization and evaluation of organogel-based lipstick formulations: application in cosmetics. Gels 7, 97. https://doi.org/10.3390/gels7030097.

EuropePlastic, 2022. Plastics—the facts 2022. An analysis of European latest plastics production, demand and waste data.

Fendall, L.S., Sewell, M.A., 2009. Contributing to marine pollution by washing your face: microplastics in facial cleansers. Mar. Pollut. Bull. 58, 1225–1228. https://doi.org/10.1016/j.marpolbul.2009.04.025.

Geyer, R., Jambeck, J.R., Law, K.L., 2017. Production, use, and fate of all plastics ever made. Sci. Adv. 3, e1700782. https://doi.org/10.1126/sciadv.1700782.

Gouin, T., Roche, N., Lohmann, R., Hodges, G., 2011. A thermodynamic approach for assessing the environmental exposure of chemicals absorbed to microplastic. Environ. Sci. Technol. 45, 1466–1472. https://doi.org/10.1021/es1032025.

Guerranti, C., Martellini, T., Perra, G., Scopetani, C., Cincinelli, A., 2019. Microplastics in cosmetics: environmental issues and needs for global bans. Environ. Toxicol. Pharmacol. 68, 75–79. https://doi.org/10.1016/j.etap.2019.03.007.

Imai, T., Nakamura, K., Shibata, M., 2001. Relationship between the hardness of an oil–wax gel and the surface structure of the wax crystals. Colloids Surf. A Physicochem. Eng. Asp. 194, 233–237.

Isobe, A., 2016. Percentage of microbeads in pelagic microplastics within Japanese coastal waters. Mar. Pollut. Bull. 110, 432–437. https://doi.org/10.1016/j.marpolbul.2016.06.030.

Issac, M.N., Kandasubramanian, B., 2021. Effect of microplastics in water and aquatic systems. Environ. Sci. Pollut. Res. Int. 28, 19544–19562. https://doi.org/10.1007/s11356-021-13184-2.

Ivar do Sul, J.A., Costa, M.F., 2014. The present and future of microplastic pollution in the marine environment. Environ. Pollut. 185, 352–364. https://doi.org/10.1016/j.envpol.2013.10.036.

Iwata, H., Shimada, K., 2013. In *Formulas, Ingredients And Production of Cosmetics* Ch, Springer Japan, pp. 21–86. (Chapter 2).

Ju, S., et al., 2021. Biodegradable chito-beads replacing non-biodegradable microplastics for cosmetics. Green Chem. 23, 6953–6965.

Juma'at, N., Rahmat, N.A., Hamidi, S.A., Adnan, N., 2021. The production and stability evaluation of natural lipstick. Multidisciplin. Appl. Res. Innovat. 2, 220–225. 220–225.

Kalcikova, G., Alic, B., Skalar, T., Bundschuh, M., Gotvajn, A.Z., 2017. Wastewater treatment plant effluents as source of cosmetic polyethylene microbeads to freshwater. Chemosphere 188, 25–31. https://doi.org/10.1016/j.chemosphere.2017.08.131.

Kasparaviciene, G., et al., 2016. Evaluation of beeswax influence on physical properties of lipstick using instrumental and sensory methods. Evid. Based Complement. Alternat. Med. 3816460. https://doi.org/10.1155/2016/3816460. 2016.

Kentin, E., 2018. Restricting microplastics in the European union: process and criteria under REACH. European Phys. J. Plus 133, 425. https://doi.org/10.1140/epjp/i2018-12228-2.

Koyilath Nandakumar, V., Palani, S.G., Raja Raja Varma, M., 2022. Interactions between microplastics and unit processes of wastewater treatment plants: a critical review. Water Sci. Technol. 85, 496–514. https://doi.org/10.2166/wst.2021.502.

Kumar, A., et al., 2021. Physico-chemical parameters apply for analysis of quality improvement of cosmetic product lipsticks. IJAEM 3, 439–442. https://doi.org/10.35629/5252-0307439442.

Kumar, S., Agrawal, K.M., Khan, H.U., Sikora, A., 2007. Study of phase transition in hard microcrystalline waxes and wax blends by differential scanning calorimetry. Petrol. Sci. Technol. 22, 337–345. https://doi.org/10.1081/lft-120024390.

Lahoti, A.M.s., 2018. Formulation and evaluation of lipstick containing sunflower wax. Int. J. Pharmaceut. Res. 10. https://doi.org/10.31838/ijpr/2018.10.03.060.

Leslie, H., 2014. Review of Microplastics in Cosmetics, vol. 476. IVM Institute for Environmental Studies, pp. 1–33.

Lochhead, R., 2017. Cosmetic Science and Technology: Theoretical Principles and Applications, Elsevier, pp. 171–221. Ch. 13.

Loretz, L.J., et al., 2008. Exposure data for cosmetic products: facial cleanser, hair conditioner, and eye shadow. Food Chem. Toxicol. 46, 1516–1524. https://doi.org/10.1016/j.fct.2007.12.011.

Mahon, A.M., et al., 2017. Microplastics in sewage sludge: effects of treatment. Environ. Sci. Technol. 51, 810–818. https://doi.org/10.1021/acs.est.6b04048.

Mawazi, S.M., Azreen Redzal, N.A.B., Othman, N., Alolayan, S.O., 2022. Lipsticks history, formulations, and production: a narrative review. Cosmetics 9, 25.

Miyazaki, Y., Marangoni, A.G., 2014. Structural-mechanical model of wax crystal networks—a mesoscale cellular solid approach. Mater. Res. Express 1, 025101. https://doi.org/10.1088/2053-1591/1/2/025101.

Moharir, R.V., Kumar, S., 2019. Challenges associated with plastic waste disposal and allied microbial routes for its effective degradation: a comprehensive review. J. Clean. Prod. 208, 65–76. https://doi.org/10.1016/j.jclepro.2018.10.059.

Napper, I.E., Bakir, A., Rowland, S.J., Thompson, R.C., 2015. Characterisation, quantity and sorptive properties of microplastics extracted from cosmetics. Mar. Pollut. Bull. 99, 178–185. https://doi.org/10.1016/j.marpolbul.2015.07.029.

Nawalage, N.S.K., Bellanthudawa, B.K.A., 2022. Synthetic polymers in personal care and cosmetics products (PCCPs) as a source of microplastic (MP) pollution. Mar. Pollut. Bull. 182, 113927.

Nikiema, J., Mateo-Sagasta, J., Asiedu, Z., Saad, D., Lamizana, B., 2020. Water Pollution by Plastics and Microplastics: a Review of Technical Solutions from Source to Sea.

Padervand, M., Lichtfouse, E., Robert, D., Wang, C., 2020. Removal of microplastics from the environment. A review. Environ. Chem. Lett. 18, 807–828. https://doi.org/10.1007/s10311-020-00983-1.

Pan, S., Germann, N., 2019. Thermal and mechanical properties of industrial benchmark lipstick prototypes. Thermochim. Acta 679. https://doi.org/10.1016/j.tca.2019.178332.

Pathak, V.M., Navneet, 2023. Exploitation of bacterial strains for microplastics (LDPE) biodegradation. Chemosphere 316, 137845. https://doi.org/10.1016/j.chemosphere.2023.137845.

Patil, A., Ferritto, M.S., 2013. Polymers for personal care and cosmetics. In: ACS Symposium Series, vol. 1148. American Chemical Society, pp. 3–11. Ch. 1.

Pfaff, G., 2021. Iron oxide pigments. Phys. Sci. Rev. 6, 535–548. https://doi.org/10.1515/psr-2020-0179.

Rigano, L., Montoli, M., 2021. Strategy for the development of a new lipstick formula. Cosmetics 8, 105.

Sakamoto, K., Lochhead, R.Y., Maibach, H.I., Yamashita, Y., 2017. Cosmetic Science and Technology: Theoretical Principles and Applications. Elsevier.

Shibata, M., et al., 2003. Control of the hardness of the oil-wax gel by mixing of normal paraffin wax and the branched paraffin wax. J. - Jpn. Soc. Colour Material 76, 380–384. https://doi.org/10.4011/shikizai1937.76.380.

Shimizu, M.S., Nomura, Y., Bui, H.S., 2021. In: Mittal, K.L., Bui, H.S. (Eds.), In Surface Science and Adhesion in Cosmetics, vol. 1. pp. 35–71. Ch.

Tang, Y., et al., 2021. A review: research progress on microplastic pollutants in aquatic environments. Sci. Total Environ. 766, 142572. https://doi.org/10.1016/j.scitotenv.2020.142572.

Thompson, R.C., et al., 2004. Lost at sea: where is all the plastic? Science 304, 838. https://doi.org/10.1126/science.1094559.

Verma, R., Vinoda, K.S., Papireddy, M., Gowda, A.N.S., 2016. Toxic pollutants from plastic waste- A review. Proc. Environ. Sci. 35, 701–708. https://doi.org/10.1016/j.proenv.2016.07.069.

Zhou, Y., et al., 2023. Current research trends on cosmetic microplastic pollution and its impacts on the ecosystem: a review. Environ. Pollut. 320, 121106. https://doi.org/10.1016/j.envpol.2023.121106.

Zitko, V., Hanlon, M., 1991. Another source of pollution by plastics: skin cleaners with plastic scrubbers. Mar. Pollut. Bull. 22, 41–42. https://doi.org/10.1016/0025-326x(91)90444-w.