



UNIVERSITÀ DEGLI STUDI DI MILANO
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Master's Degree in
Cosmetic Industrial Science

**SYSTEMATIC COMPARATIVE STUDY AND
APPLICATION OF THREE NATURAL O/W
EMULSIFIERS IN FINISHED PRODUCTS**

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*Ai miei genitori,
fondamenta di ciò che sono,
la mia casa ovunque io sia.*

*A mio fratello Nicola,
il legame che non ho scelto,
ma che sceglierei in ogni vita.*

*Quando ti metterai in viaggio per Itaca
devi augurarti che la strada sia lunga
fertile in avventure e in esperienze.*

*I Lestrigoni o i Ciclopi
o la furia di Nettuno non temere:
non sarà questo il genere di incontri
se il pensiero resta alto e un sentimento
fermo guida il tuo spirito e il tuo corpo.
In Ciclopi o Lestrigoni no certo,
né nell'irato Nettuno incapperai
se non li porti dentro
se l'anima non te li mette contro.*

*Devi augurarti che la strada sia lunga,
che i mattini d'estate siano tanti
quando nei porti – finalmente e con che gioia -
toccherai terra tu per la prima volta:
negli empori fenici indugia e acquista
madreperle coralli ebano e ambre,
tutta merce fina, e anche profumi
penetranti d'ogni sorta, più profumi
inebrianti che puoi,
va in molte città egizie
impara una quantità di cose dai dotti.*

*Sempre devi avere in mente Itaca –
Raggiungerla sia il tuo pensiero costante.
Soprattutto, però, non affrettare il viaggio;
fa che duri a lungo, per anni, e che da vecchio
metta piede sull'isola, tu, ricco
dei tesori accumulati per strada
senza aspettarti ricchezze da Itaca.
Itaca ti ha dato il bel viaggio,
senza di lei mai ti saresti messo
in viaggio: che cos'altro ti aspetti?*

*E se la trovi povera, non per questo Itaca ti avrà deluso.
Fatto ormai savio, con tutta la tua esperienza addosso
già tu avrai capito ciò che Itaca vuole significare.*

Konstantinos Kavafis Itaca (1911)

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SUMMARY

Cosmetic emulsions are thermodynamically unstable systems whose practical stability depends critically on emulsifier selection and overall formulation design. Growing consumer demand for ingredient transparency and sustainability, together with the K-beauty and skinification trends, has driven a shift toward natural-origin emulsifiers, whose technical performance must be systematically characterised to effectively replace conventional synthetic systems.

Three natural oil-in-water emulsifiers — Sorbitan Laurate/Polyglyceryl-4 Laurate/Dilauryl Citrate (ester-based system), C14-22 Alcohols/C12-20 Alkyl Glucoside (lamellar liquid-crystal system), and Sodium Starch Octenylsuccinate (Pickering-type system) — were systematically compared to use the resulting dataset as the technical basis for the development of three finished cosmetic prototypes. The work was carried out at LabAnalysis Life Science.

For each emulsifier, a common experimental scheme was applied across seven series investigating the effect of co-stabilisers, oil phase concentration and composition, emulsifier concentration, rheology-modifying polymers, preparation method, and inorganic pigment incorporation. All formulations were characterised through centrifuge stability testing, pH and viscosity measurements (t_0 and t_{24}), optical microscopy, and instrumental sensory evaluation.

The three systems revealed markedly distinct technical identities. The ester blend proved strongly dependent on co-stabilisers, performing optimally at 4% with a light, spreadable sensory profile suited to pigmented formulations. The alkyl glucoside system showed a strong intrinsic structuring capacity but sensitivity to processing method and incompatibility with pigments, making it best suited to rich, occlusive body-care formats. The modified starch displayed a particularly robust Pickering-type

stabilisation mechanism even without stabilisers, with fast skin absorption, but showed limitations in coloured systems.

Based on these findings, three finished products were developed — an Anti-Pollution BB Cream, an Anti-Age Body Cream, and a Milky Toner — each formulated with the emulsifier and stabilisation strategy most consistent with its intended sensory and functional profile. Final comparative characterisation confirmed pH stability and satisfactory short-term physical stability for all three products, validating the proposed methodology as a transferable framework for future comparative studies on natural emulsifiers.

CHAPTER 1 – INTRODUCTION

Emulsions are among the most widely studied and technologically significant disperse systems in both applied chemistry and consumer product science. In the cosmetic and personal care industry in particular, emulsions allow the production of all types of texture — from lightweight moisturisers and toners to rich body creams, BB creams and colour cosmetics. The ability to combine water-soluble and oil-soluble functional ingredients within a single, physically stable, sensory-pleasing vehicle is the central challenge that emulsion science seeks to address.

In recent years, the formulation landscape has been reshaped by several converging forces. Growing consumer concern for ingredient transparency and environmental sustainability has driven demand for natural and biodegradable emulsifier systems, leading to the rapid development of green emulsifier chemistries based on polysaccharide modification, alkyl polyglucoside synthesis, and polyol esterification. Simultaneously, the global influence of Korean beauty (K-beauty) trends and the broader phenomenon of skinification — the progressive integration of evidence-based active ingredient strategies into decorative cosmetics — has set new performance benchmarks for product texture, skin feel, and multifunctional efficacy. These converging pressures have made it increasingly difficult to develop formulations that are simultaneously stable, sensory-elegant, and free from synthetic emulsifiers.

The experimental work described in the following chapters investigates the comparative formulation performance of three natural oil-in-water (O/W) emulsifiers — Sorbitan Laurate/Polyglyceryl-4 Laurate/Dilauryl Citrate, C14-22 Alcohols/C12-20 Alkyl Glucoside, and Sodium Starch Octenylsuccinate — across seven systematically

designed experimental series. The results of this screening were subsequently used to develop three finished cosmetic prototypes.

1.1. Emulsion Thermodynamics and Stability

An emulsion is a thermodynamically unstable heterogeneous system consisting of at least two immiscible liquid phases, one dispersed as droplets of microscopic to submicroscopic dimensions within the other. In the cosmetic context, the two phases are invariably an aqueous continuous phase and an oily dispersed phase (O/W emulsion) or the converse, water-in-oil (W/O emulsion). The kinetic and thermodynamic properties of such systems are determined by the interfacial tension between the two phases, the nature and concentration of the emulsifying agents present at the interface, the physical properties of the dispersed and continuous phases, and the mechanical energy imparted during preparation.¹

From a thermodynamic standpoint, the creation of an emulsion requires work to be done against the interfacial tension γ at the oil–water interface. This work is expressed by the Gibbs free energy of emulsification:

$$\Delta G_{\text{emuls}} = \gamma \cdot \Delta A - T\Delta S_{\text{mix}}$$

where ΔA is the increase in interfacial area generated during emulsification, and $T\Delta S_{\text{mix}}$ is the entropy contribution arising from droplet distribution. Because γ is invariably positive for immiscible systems, and because the term $T\Delta S_{\text{mix}}$ is relatively small for the macroscopic droplet sizes encountered in conventional emulsions, ΔG_{emuls} is invariably positive: emulsions are thermodynamically unstable systems that will spontaneously evolve towards bulk phase separation if kinetically permitted to do so.²

The practical stability of an emulsion is therefore always kinetic rather than thermodynamic in nature — it depends on the height of the energy barriers that slow

the rate at which the system returns to its ground state of two separated bulk phases. Cosmetic emulsions are expected to remain stable for 12 to 36 months; achieving this requires a thorough understanding of the destabilisation mechanisms and the formulation strategies available to retard them. Breakdown of possible ways is schematized in Figure 1:

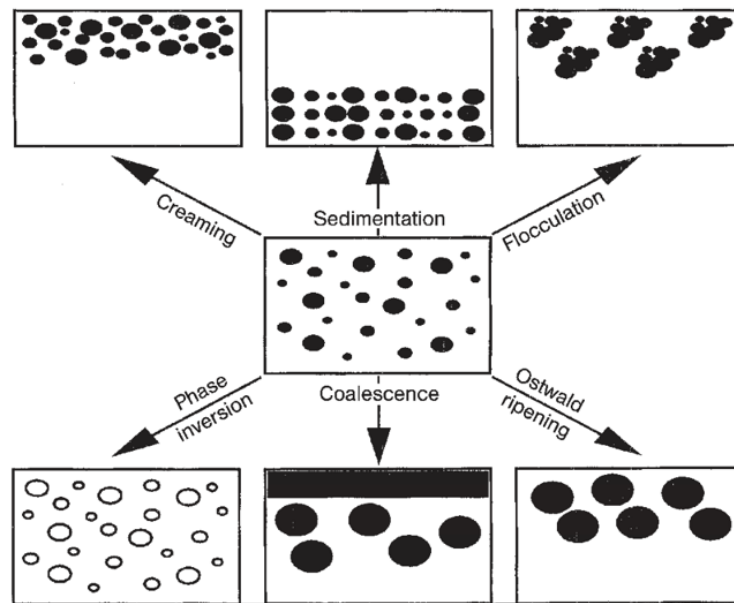


Figure 1: Schematic representation of the various breakdown processes in emulsions.

Creaming and sedimentation result from external forces, usually gravitational or centrifugal. When such forces exceed the thermal motion of the droplets (Brownian motion), a concentration gradient builds up in the system such that the larger droplets move more rapidly either to the top or to the bottom of the container, depending on their density. In the limiting cases, the droplets may form a close-packed array at the top or bottom of the system, with the remainder of the volume occupied by the continuous liquid phase.

Flocculation is the aggregation of droplets into larger units due to Van der Waals attractions when repulsive forces are insufficient to keep them apart.

Ostwald Ripening (Disproportionation) results from the finite mutual solubility of the liquid phases. Smaller droplets are more soluble and progressively disappear, while

their molecules diffuse and deposit onto larger droplets, shifting the droplet size distribution toward larger values.

Coalescence is the process of thinning and disruption of the liquid film between the droplets, with the result that fusion of two or more droplets occurs to form larger droplets. The limiting case for coalescence is the complete separation of the emulsion into two distinct liquid phases. The driving force for coalescence is the surface or film fluctuations; this results in a close approach of the droplets whereby the Van der Waals forces are strong and prevent their separation.

Phase Inversion is the process in which there is an exchange between the dispersed phase and the medium. For example, an O/W emulsion may, with time or a change of conditions, invert to a W/O emulsion. In many cases, phase inversion passes through a transition state whereby multiple emulsions are produced.

The role of emulsifying agents is to function primarily by adsorbing at the oil–water interface and reducing the interfacial tension γ . This reduction lowers the energy cost of creating new interfacial area during homogenisation, thereby facilitating droplet disruption, while simultaneously increasing the energy barrier to coalescence by creating a mechanically robust, viscoelastic interfacial film.¹

1.2. Types of Emulsions: O/W, W/O, and Pickering Systems

Emulsions are classified according to the identity of the dispersed and continuous phases. In oil-in-water (O/W) emulsions, oil droplets are dispersed within an aqueous continuous phase; in water-in-oil (W/O) emulsions, the inverse geometry applies, with water droplets dispersed in an oil continuous phase. Multiple emulsions (W/O/W or O/W/O) represent a third class in which droplets themselves contain smaller dispersed droplets, though these are of limited relevance to the present work.³

O/W emulsions are the dominant format in facial skincare and body care. Their aqueous continuous phase confers a light, non-greasy skin feel, facilitates the incorporation of water-soluble active ingredients, and provides efficient evaporative cooling on application. The dispersed oil phase acts as an emollient reservoir, delivering lipophilic actives and contributing to skin softness through partial occlusion following water evaporation.³

W/O emulsions present a continuous oily phase that provides a more occluding, protective skin feel, making them appropriate for applications in cold climates, dry skin conditions, or as sun-care vehicles. They require high-HLB (hydrophile-lipophile balance) emulsifiers, are generally more viscous than their O/W counterparts, and are more susceptible to microbial growth limitations due to the reduced water activity in the aqueous dispersed phase.³

The hydrophile–lipophile balance (HLB) system, introduced by Griffin in 1949, provides the primary empirical framework for predicting emulsifier suitability for O/W versus W/O applications. HLB values range from 0 to 20, with low values (1–6) indicating predominantly lipophilic character suitable for W/O emulsification, intermediate values (8–18) indicating predominantly hydrophilic character and suitability for O/W emulsification, and values above 16 indicating strong solubilising/micellar character. The HLB system, while empirically useful, does not capture the kinetics of adsorption, the rheological properties of the interfacial film, or the complex structural phenomena observed with lamellar-phase-forming emulsifiers such as alkyl polyglucosides.³

A fundamentally distinct class of emulsion is the Pickering emulsion, stabilised not by molecular surfactants but by solid colloidal particles that adsorb irreversibly at the oil–water interface. First described by Pickering in 1907 and elaborated by Binks and colleagues in the early 2000s, these systems achieve kinetic stability through a purely steric mechanism: once adsorbed, the desorption energy of a particle from the interface

is many orders of magnitude greater than the thermal energy kT , rendering the adsorption effectively irreversible.^{4,5}

1.3. Role of Emulsifiers and Natural Alternatives

Emulsifiers are amphiphilic molecules — characterised by the simultaneous presence of a hydrophilic (water-attracted) and a lipophilic (oil-attracted) structural domain — that adsorb spontaneously at the oil–water interface, reduce the interfacial tension, and form a protective film around dispersed droplets. In conventional cosmetic emulsions, the emulsifier system serves three interconnected functions: it reduces the energy input required to create the emulsion during manufacture; it stabilises the resulting droplet population against coalescence and Ostwald ripening; and it determines, through its structural properties at the interface, the macroscopic rheological and sensory characteristics of the finished emulsion.¹

Synthetic emulsifiers — historically represented by Polyoxyethylene Sorbitan Esters (Polysorbates), Polyethylene Glycol (PEG)-based fatty acid esters, and ethoxylated alcohols — have dominated cosmetic formulation for decades on account of their consistent performance, wide availability, and established regulatory status. However, increasing consumer and regulatory pressure for *green* and *clean* beauty formulations, combined with growing environmental concerns related to the biodegradation and ecotoxicological profiles of polyethoxylated compounds, has driven a substantial shift towards natural and naturally derived emulsifier systems.

Natural emulsifiers are broadly defined as those derived from renewable biological sources (plant, microbial, or animal origin) through processes that do not involve petrochemical feedstocks, and that are biodegradable and compatible with the principal green certification frameworks. The two most widely applied reference standards in

the European cosmetic ingredient market are COSMOS (Cosmetic Organic Standard) and ECOCERT, both of which define permissible source materials, manufacturing processes, and degree of chemical transformation. Under the COSMOS standard v3.0, emulsifiers must derive from certified organic agricultural ingredients or naturally occurring minerals, and all chemical transformations must fall within the approved list of permitted processes, which includes — among others — esterification with natural acids, glycosylation (Fischer reaction), and esterification with succinic anhydride derivatives.⁶

Polyol esters and sorbitan derivatives, such as **Sorbitan Laurate/Polyglyceryl-4 Laurate/Dilauryl Citrate**, represent another important class of natural-derived emulsifiers. These are produced by esterification of natural fatty acids (in this case, lauric acid derived from coconut or palm kernel oil) with polyhydroxylated molecules (sorbitol, polyglycerol) and citric acid, yielding HLB-differentiated blends with complementary interfacial activities. The citrate component confers an additional benefit through chelation of divalent metal ions, reducing the risk of oxidative rancidity in the oil phase.⁷

Among the most commercially significant categories of natural emulsifiers are the following. Alkyl polyglucosides (APGs), including the alkyl glucoside component of **C14-22 Alcohols/C12-20 Alkyl Glucoside**, are synthesised by Fischer glycosylation of fatty alcohols with glucose, producing a family of mild, biodegradable non-ionic surfactants. Their self-assembly into lamellar liquid-crystal structures at concentrations above the critical lamellar concentration, particularly when combined with co-emulsifying fatty alcohols of matching chain length, provides a dual mechanism of emulsion stabilisation: interfacial film reinforcement and continuous-phase viscoelastic network formation.⁷

Modified polysaccharide emulsifiers, exemplified by **Sodium Starch Octenylsuccinate**, are produced by esterification of starch (from maize, rice, or

tapioca) with octenylsuccinic anhydride, introducing hydrophobic substituents onto the hydrophilic polysaccharide backbone. The degree of substitution (DS), typically 0.02–0.05 per anhydroglucose unit, is carefully controlled to maintain water solubility while conferring sufficient interfacial activity for Pickering-type emulsification. The partially hydrophobised starch polymer chains adsorb at the oil–water interface in a manner analogous to colloidal particle adsorption, forming a thick, mechanically robust polymeric film that provides steric stabilisation independent of the chemical nature of the oil phase.⁷

The selection criteria for natural emulsifiers in cosmetic formulation extend beyond sustainability profile. Formulators must consider the emulsifier's HLB value and its suitability for the intended O/W or W/O emulsion type; its compatibility with the oil-phase functional group profile; its sensitivity to pH, electrolytes, and polyvalent ions; its processing requirements (hot process vs. cold process); and its organoleptic profile in the finished emulsion. The experimental work in this thesis specifically addresses several of these criteria through a systematic screening approach that varies oil-phase composition, emulsifier concentration, stabiliser combinations, preparation method, and pH, providing a structured comparative dataset for the three selected systems.

1.4. Market Trends: Skinification and K-Beauty

The past decade has seen two converging phenomena reshape product development priorities in the global cosmetics industry: the rise of *skinification* and the worldwide diffusion of *Korean beauty* (K-beauty) culture. Both trends have directly informed the product concepts developed in this thesis and, to some extent, the formulation parameters investigated during the experimental screening phase.

Skinification describes the progressive incorporation of evidence-based skincare actives into product categories that were historically purely decorative or functional. Rather than maintaining a clear distinction between colour cosmetics and skincare, or

between facial and body care, the skinification approach collapses those boundaries: the consumer expects a BB cream to deliver coverage and active efficacy simultaneously, and equally expects a body cream to go beyond basic emolliency and address specific skin concerns such as ageing, barrier deterioration, and uneven tone. From a formulation standpoint, this places considerable technical demands on the emulsifier system, which must stabilise not only the emulsion matrix but also the active ingredient payload over the product's shelf life. Two of the three products developed in Chapter 5 are a direct expression of this philosophy. The *Anti-Pollution BB Cream* is a pigmented O/W emulsion that combines inorganic colour coverage with a three-component anti-pollution active system targeting oxidative stress, circadian clock disruption, and inflammatory signalling — a skinified colour cosmetic in the fullest sense. The *Anti-Age Body Cream* extends the same logic to body care: built on a high-lipid alkyl glucoside emulsion platform, it incorporates Palmitoyl Tripeptide-38, Niacinamide, Sodium Hyaluronate, and Allantoin — actives that until recently would have been reserved for facial serums and creams — into a format designed for daily full-body application. The selection of emulsifiers for both products was driven in part by their ability to stabilise these increasingly complex active ingredient payloads while maintaining the sensory profiles appropriate to their respective application contexts.⁸

K-beauty, or Korean beauty, refers to the set of product concepts, formulation technologies, and consumer rituals that emerged from the South Korean cosmetics industry and gained global commercial relevance during the 2010s and 2020s. Among the most technically significant contributions of K-beauty to mainstream formulation practice is the milky toner — a hybrid format positioned between a conventional aqueous toner and a fluid emulsion, characterised by a low oil fraction, rapid absorption, and a lightweight, watery texture that leaves no residue on the skin. This format underpins the *Milky Toner* developed in this thesis, which uses Sodium Starch Octenylsuccinate at a reduced concentration of 2.5% to produce a low-viscosity, fast-absorbing emulsion with an oil phase of approximately 8%. Beyond the product format

itself, K-beauty has also influenced the sensory expectations against which cosmetic emulsions are evaluated globally: lightweight textures, rapid absorption, absence of white cast, and minimal residual feel are now standard performance benchmarks rather than premium differentiators. These expectations directly shaped the sensory evaluation attributes selected for this study — absorption rate, soaping effect, shine effect, and residual amount — and provided the interpretive framework against which the sensory fingerprints of the three emulsifier systems were assessed in Section 4.8.^{9,10}

1.5. Sensoriality as a Formulation Parameter

The sensory properties of a cosmetic emulsion — broadly encompassing its appearance, application behaviour, skin feel during and after application, and longevity on the skin — are not merely aesthetic attributes to be optimised post hoc once physicochemical stability has been confirmed. They are primary formulation design parameters that are as deterministic of product success as stability, safety, or microbiological compliance. Consumer acceptance studies consistently demonstrate that sensory performance during and immediately after the first application is the principal determinant of purchase intention and repeat purchase, often outweighing considerations of ingredient composition, brand equity, or packaging design.

The conceptualisation of sensory properties as quantifiable formulation parameters has been formalised through the development of sensory analysis as a scientific discipline distinct from but complementary to physicochemical characterisation. Sensory analysis methodologies range from trained panel descriptive analysis, in which expert panellists generate and quantify attribute intensities on calibrated scales, to consumer acceptance testing, in which naïve respondents rate preference or acceptance without analytical training, to instrumental texture profile analysis (TPA), in which rheological measurements are correlated with specific sensory percepts.¹¹

In the specific context of pigmented emulsions (BB creams, tinted moisturisers), additional sensory dimensions become relevant: blendability (the ease of achieving a seamless, undetectable application edge), colour homogeneity (the uniformity of pigment distribution across the skin surface), coverage (the extent to which skin imperfections are concealed), and mattifying effect (the degree to which the product reduces skin shine, typically through light scattering by inorganic pigments or powder particles). ¹²

CHAPTER 2 – THESIS

OBJECTIVE

2.1. The host company: LabAnalysis Life Science

Lab Analysis is an Italian contract laboratory specialised in analytical testing, product development, and regulatory support for multiple industrial sectors, including cosmetics, pharmaceuticals, environmental sciences, food products, and consumer goods. Founded in 1976 by university professors Luigino and Isella, the company initially focused on chemical analyses, quality-control testing, and consultancy services in the environmental and pharmaceutical fields. Today, the company operates through an extensive network of accredited laboratories and highly qualified specialists, providing analytical services characterised by reliability, precision, and strict adherence to internationally recognised quality standards.



Figure 2: LabAnalysis' Logo

Within the Group, Lab Analysis Life Science represents the division dedicated to the cosmetic and personal care sector. The company offers comprehensive support for cosmetic product quality assessment through chemical, microbiological, instrumental, and sensory analyses, complemented by formulation development and validation activities. Continuous investment in research and innovation, together with the acquisition of specialised laboratories such as Bionos in 2023, has strengthened the

company's expertise in in vivo and in vitro testing, efficacy evaluation, safety assessment, and cosmetic formulation.

The cosmetics industry is characterised by rapid innovation, evolving consumer expectations, and increasingly stringent regulatory requirements. In this context, Lab Analysis Life Science provides technical support across a wide range of cosmetic categories, including sunscreens, skincare, haircare, cleansing products, and decorative cosmetics. The company assists clients throughout the product development process, offering consultancy services, tailored testing protocols, claim substantiation studies, and manufacturing support. Its customer base includes cosmetic brands, private-label manufacturers, and raw material suppliers seeking scientific validation of ingredient performance and formulation efficacy.

2.2 Internship role and activities

The internship activities focused on the formulation and analytical development work that constituted the experimental basis of this thesis. The project involved the preparation of emulsion systems, their physicochemical and sensory characterization, and the subsequent development of finished cosmetic prototypes.

The study was based on the investigation of three natural emulsifier systems: Sorbitan Laurate / Polyglyceryl-4 Laurate / Dilauryl Citrate, C14-22 Alcohols / C12-20 Alkyl Glucoside, and Sodium Starch Octenylsuccinate. A systematic formulation approach was adopted, involving the preparation of multiple oil-in-water (O/W) emulsion variants in which key formulation parameters were modified, including emulsifier concentration, oil phase composition, stabilising agents, polymer type, preparation method, and pigment incorporation.

Following preparation, each formulation underwent a series of physicochemical evaluations. Preliminary stability was assessed through centrifugation testing to

identify potential phase separation phenomena. Measurements of pH and viscosity were performed immediately after production (t_0) and after twenty-four hours of storage (t_{24}). Optical microscopy was also employed to investigate the microstructure of the emulsions, including droplet size distribution and dispersion homogeneity.

In parallel, sensory characterisation was carried out to evaluate the application properties of the formulations. Parameters including pickup, consistency, spreadability, whitening effect during application (soaping effect), absorption rate, residual feel, and skin appearance after application were assessed using a numerical scoring system and evaluated by professional panels. This methodology enabled the comparison of sensory profiles among the different emulsifier systems and formulation variants.

2.3 Objective of the thesis

This thesis aims to carry out a systematic comparative study of three natural emulsifiers — Sorbitan Laurate / Polyglyceryl-4 Laurate / Dilauryl Citrate, C14-22 Alcohols / C12-20 Alkyl Glucoside, and Sodium Starch Octenylsuccinate — to characterise and compare their performance across a wide range of formulation conditions, and to use the results of this screening as the technical basis for the development of three finished cosmetic products.

For each of the three emulsifiers, the study was designed around a common experimental scheme. The first set of formulations evaluated the emulsifier at its standard use level in a mixed oil phase, both with and without the addition of co-stabilisers, to assess the contribution of stabilising agents to emulsion stability and sensory performance. A second set explored the effect of oil phase concentration, comparing formulations containing 10% and 30% oil phase (always with stabilisers). A third set replaced the mixed oil phase with single oils belonging to different functional groups, tested both without (series A) and with (series B) stabilisers, in order

to investigate how the chemical nature of the oil phase influences emulsion formation and stability for each emulsifier.

A fourth set of formulations examined the effect of emulsifier concentration itself, doubling or halving the standard use level (depending on the emulsifier) while keeping the oil phase constant, with and without stabilisers. A fifth set kept the emulsifier and oil phase at their standard levels but introduced three different rheology-modifying polymers, to assess compatibility between each emulsifier and alternative thickening systems. A sixth set compared two preparation methods — a traditional Lin method and a modified version of the same method — using the standard oil phase composition, to evaluate the influence of the preparation procedure on the resulting emulsion. Finally, a seventh set assessed the behaviour of each emulsifier in a pigmented system, incorporating 3.78% of inorganic pigments into the standard formulation.

All formulations obtained from these seven experimental blocks were characterised using the same set of chemical-physical and sensory parameters: centrifuge stability, pH and viscosity at t_0 and t_{24} , and optical microscopy.

The second and final objective of the thesis is to translate the results of this systematic screening into practical formulation outcomes by developing three finished cosmetic products: a BB Cream Anti-Pollution, a Milky Toner, and an Anti-Age Body Cream. Each of these products was formulated using one of the three emulsifiers studied, selected and combined with the stabilisation strategy that, based on the screening results, was considered most suitable for the sensory profile, stability requirements, and active ingredient compatibility demanded by that specific product. In this way, the thesis aims not only to provide a systematic, comparative characterisation of three natural emulsifiers across a broad set of formulation variables but also to demonstrate how the results of such a screening can directly inform and support the development of finished cosmetic formulations.

CHAPTER 3 – MATERIALS AND METHODS

A systematic experimental approach was adopted to investigate the performance of selected oil-in-water (O/W) emulsifying systems under controlled formulation conditions. The study involved preparing model emulsions, followed by their physicochemical and sensory characterisation to assess the influence of the emulsifiers on emulsion stability and texture. The materials employed, the experimental design, the formulation procedures, and the analytical methods used throughout the study are described in the following sections.

3.1. Materials

3.1.1. Emulsifying Systems

Three commercially available O/W emulsifiers belonging to different chemical classes were selected for evaluation. Ingredient nomenclature is reported according to the International Nomenclature of Cosmetic Ingredients (INCI) established by the Personal Care Products Council. Table 1 summarises the complete INCI compositions and concentration ranges investigated during the experimental programme.

Table 1: Emulsifying System Investigated

INCI Name	Type
Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate	O/W
C14-22 Alcohols, C12-20 Alkyl Glucoside	O/W
Sodium Starch Octenylsuccinate	O/W

Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate is a three-component non-ionic system combining HLB-differentiated laurate esters and glycosides, designed for

O/W emulsions with a natural origin profile. *C14-22 Alcohols*, *C12-20 Alkyl Glucoside* belong to the alkyl polyglucoside family combined with long-chain fatty alcohols. As a promoter of liquid crystals that biomimic the lipid bilayer of the cellular membrane, it helps stabilise the emulsion, provides a restructuring effect (reduction of transepidermal water loss - TEWL), and provides a moisturising effect. *Sodium Starch Octenylsuccinate* is a modified-starch-based Pickering-like emulsifier in which the hydrophilic polysaccharide backbone is partially esterified with octenylsuccinate groups, providing amphiphilic character and the ability to adsorb at the oil–water interface. 1 2

3.1.2. Oil Phase Ingredients

A standardised oil blend composed of three emollients in equal proportions was employed as the reference oil phase across all three emulsifier systems: Caprylic/Capric Triglyceride, Coco-Caprylate/Caprates and Hydrogenated Polydecene. In Series 3 (single-oil study), each oil was evaluated individually at 20% w/w to assess the impact of chemical functional groups on emulsification performance. Additional oils were included in the three final product formulations. Table 2 summarises all oil-phase ingredients with their respective chemical classes.

Table 2: Oil-phase ingredients and chemical classes

INCI Name	Chemical Class
Caprylic/Capric Triglyceride	Triglyceride (C8/C10)
Coco-Caprylate/Caprates	Ester (coconut-derived)
Hydrogenated Polydecene	Synthetic hydrocarbon
Diisopropyl Adipate	Diester (adipic acid)
Octyldodecanol	Branched fatty alcohol
C13-15 Alkane	Branched alkane
Butyrospermum Parkii Butter	Vegetable butter (stearic/oleic esters)
Hydrogenated Ethylhexyl Olivates, Hydrogenated Olive Oil Unsaponifiables	Olive-derived ester / wax fraction
Caprylic/Capric/Myristic/Stearic Triglyceride	Mixed triglyceride (C8–C18)

The five oils evaluated in Series 3 were chosen to represent structurally distinct functional groups: a triglyceride (C8/C10 ester), a fatty acid ester derived from coconut oil, a diester of adipic acid, a branched-chain fatty alcohol, and a synthetic hydrocarbon. This selection allows systematic comparison of interfacial compatibility between each emulsifier and oils of differing polarities, chain lengths and functional groups.

3.1.3. Rheology Modifiers and Co-emulsifiers

Two categories of stabilisers were investigated: *Cetearyl Alcohol*, a fatty alcohol co-emulsifier used to reinforce the interfacial film and contribute to viscosity, and three water-phase polymers tested in Series 5 as thickeners in the absence of Cetearyl Alcohol. The polymers represent three distinct chemical classes: *Xanthan Gum*, a high-molecular-weight heteropolysaccharide; a cellulose derivative, *Hydroxyethylcellulose*; and a synthetic crosslinked acrylic polymer, *Polyacrylate Crosspolymer-11*. A fourth acrylic copolymer (*Ammonium Acryloyldimethyltaurate/VP Copolymer*) was used exclusively in the BB Cream final product. Table 3 summarises all rheology-modifying ingredients.

Table 3: Rheology modifiers and co-emulsifiers

INCI Name	Type
Cetearyl Alcohol	Fatty alcohol (co-emulsifier)
Xanthan Gum	Polysaccharide (microbial)
Xanthan Gum Crosspolymer-2	Crosslinked polysaccharide
Polyacrylate Crosspolymer-11	Acrylic polymer (crosslinked)
Hydroxyethylcellulose	Cellulose derivative
Ammonium Acryloyldimethyltaurate/VP Copolymer	Acrylic copolymer

3.1.4. Inorganic Pigments

Series 7 evaluated the ability of each emulsifier to incorporate and stabilise inorganic pigments not surface-treated. The pigment blend was formulated to achieve a skin-tone

tint representative of a BB cream product for Caucasian skin. Table 4 details the pigment system.

Table 4: Inorganic pigment system

INCI Name (CI)	Pigment Type	Color
CI 77891 (Titanium Dioxide)	Inorganic (metal oxide)	White
CI 77492 (Iron Oxide Yellow)	Inorganic (iron oxide)	Yellow
CI 77499 (Iron Oxide Black), CI 77491 (Iron Oxide Red), CI 77492 (Iron Oxide Yellow)	Inorganic (blend of iron oxides)	Brown

3.1.5. Active Ingredients in Final Product Formulations

Three finished cosmetic formulations were developed as final applicative outputs: an Anti-Pollution BB Cream based on Sorbitan Laurate, Polyglyceryl-4 Laurate, and Dilauryl Citrate; a rich Body Cream based on C14-22 Alcohols and C12-20 Alkyl Glucoside; and a Milky Toner based on Sodium Starch Octenylsuccinate. Each product incorporates targeted active ingredients selected for compatibility with the emulsifier platform and the claimed skin benefit. Table 5 lists all actives with their INCI nomenclature, concentrations, and reported functions.

Table 5: Active ingredients in final product formulations

INCI Name	Product	Claimed Activity
Ectoin	BB Cream	Extreme moisturization, anti-pollution
Propanediol, Aqua, Lespedeza Capitata Leaf/Stem Extract	BB Cream	Anti-pollution, antioxidant
Aqua, Propanediol, Camellia Japonica Flower Extract	BB Cream	Antioxidant, skin brightening
Niacinamide	Body Cream	Brightening, pore-minimizing, barrier support
Sodium Hyaluronate	Body Cream; Milky Toner	Deep hydration, film-forming
Glycerin, Aqua, Hydroxypropyl Cyclodextrin, Palmitoyl Tripeptide-38	Body Cream	Anti-aging, matrix-stimulating peptide
Madecassoside, Asiaticoside, Centella Asiatica Leaf Extract	Milky Toner	Soothing, repair (CICA actives)
Maltodextrin, Lactobacillus Ferment, Aqua	Milky Toner	Microbiome balance, probiotic

Ceramide NP, Ceramide AP, Ceramide EOP, Phytosphingosine, Cholesterol, Behenic Acid (multi-lamellar complex)	Milky Toner	Barrier restoration, skin-identical lipids
Allantoin	Body Cream	Soothing, skin-softening

3.2. Experimental Design Overview

The systematic trials have been designed into seven different series, each designed to isolate the effect of a specific formulation variable on emulsion stability and rheology. Every series was replicated independently for each of the three emulsifiers. The three systems were not always perfectly parallel: Sodium Starch Octenylsuccinate required a higher baseline concentration (5% vs 2%) due to its lower interfacial efficiency, and the dose-variation series (Series 4) involved dose reduction (to 2.5%) rather than doubling.

Trial numbers are assigned separately to each emulsifying system. Thus, the same trial number identifies the corresponding formulation condition within each system and allows the three emulsifiers to be compared under a common experimental design. The sequences are not necessarily identical in every series because some conditions were adapted to the characteristics of each emulsifier; these differences are specified in Table 6 and in the relevant Results sections.

Table 6: Experimental design overview.

Exp. Level	Sorbitan Laurate / Polyglyceryl-4 Laurate / Dilauryl Citrate	C14-22 Alcohols / C12-20 Alkyl Glucoside	Sodium Starch Octenylsuccinate
Level 1	2% emulsifier + 20% mixed oil phase ± stabilizers	2% emulsifier + 20% mixed oil phase ± stabilizers	5% emulsifier + 20% mixed oil phase ± stabilizers
Level 2	2% emulsifier + 10% and 30% mixed oil phase + stabilizers	2% emulsifier + 10% and 30% mixed oil phase + stabilizers	5% emulsifier + 10% and 30% mixed oil phase + stabilizers
Level 3	2% emulsifier + 20% single oil (different functional groups), Series A = without stabilizers Series B = with stabilizers	2% emulsifier + 20% single oil (different functional groups), Series A = without stabilizers Series B = with stabilizers	5% emulsifier + 20% single oil (different functional groups), Series A = without stabilizers Series B = with stabilizers

Level 4	4% emulsifier + 20% oil phase ± stabilizers	4% emulsifier + 20% oil phase ± stabilizers	2.5% emulsifier + 20% oil phase ± stabilizers
Level 5	2% emulsifier + 20% mixed oil phase + three different polymers (without Cetearyl Alcohol)	2% emulsifier + 20% mixed oil phase + three different polymers (without Cetearyl Alcohol)	5% emulsifier + 20% mixed oil phase + three different polymers (without Cetearyl Alcohol)
Level 6	2% emulsifier + 20% mixed oil phase; modified emulsification vs. Lin method	2% emulsifier + 20% mixed oil phase; modified emulsification vs. Lin method	5% emulsifier + 20% mixed oil phase; modified emulsification vs. Lin method
Level 7	4% emulsifier + 20% mix oil phase + 3.78% inorganic pigments	4% emulsifier + 20% mix oil phase + 3.78% inorganic pigments	2.5% emulsifier + 20% mix oil phase + 3.78% inorganic pigments

Note: “Mixed oil phase” refers to Caprylic/Capric Triglyceride, Coco-Caprylate/Caprate and Hydrogenated Polydecene in equal proportions. Unless otherwise specified, the stabiliser combination consists of 0.15% Xanthan Gum and 1% Cetearyl Alcohol. Formulations indicated as “without stabilisers” do not contain either component.

3.3. Preparation Methods

3.3.1. General Preparation Protocol

All emulsions were prepared by a hot process unless otherwise stated. The standard procedure began with the preparation of Phase A (aqueous phase), in which water-soluble polymers were dispersed using a turbo-emulsifier at room temperature. The solution was then heated to approximately 40–45°C for Xanthan Gum or 70–75°C for Hydroxyethylcellulose. Water-soluble active ingredients and humectants were subsequently added, and the phase was brought to the emulsification temperature: 70–75°C for Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate and C14-22 Alcohols, C12-20 Alkyl Glucoside, and 60–65°C for Sodium Starch Octenylsuccinate.

In parallel, Phase B (oil phase) was prepared by combining and melting all oil components in a separate beaker at the corresponding emulsification temperature, until a homogeneous liquid phase was obtained. The oil phase was then added to the aqueous

phase under continuous mechanical agitation using a Silverson L4R homogeniser. Mixing was maintained for approximately 5 minutes until complete emulsification. The resulting emulsion was cooled under manual stirring to below 40°C, after which temperature-sensitive ingredients, such as preservatives, active ingredients and fragrances, were added. Finally, the pH was measured and, when necessary, adjusted using an 80% Lactic Acid solution.

Unlike the other emulsifiers, Sodium Starch Octenylsuccinate was dissolved in the aqueous phase before emulsification. Due to its modified starch structure, hydration is required before interfacial adsorption. A cold process, as suggested by the manufacturer, was also tested but did not produce stable emulsions.

3.3.2. Lin Emulsification and Modified Direct Method (Series 6)

Series 6 was specifically designed to assess the effect of the emulsification procedure on final emulsion structure. Two procedural variants were compared:

The first is the modified direct emulsification process: the oil phase is added gradually to the pre-formed aqueous gel network in a smaller amount of distilled water. This approach allows the emulsifier to hydrate and align at the interface progressively, favouring the development of a more organised lamellar or viscoelastic network. This method provides cooling water to be added at the end, reducing viscosity at the initial stages of processing, facilitating oil incorporation and droplet disruption under shear, while allowing the emulsion structure to reorganise progressively as dilution proceeds. This method avoids the transient W/O intermediate characteristic of phase inversion emulsification and may favour the formation of a more homogeneous and mechanically stable O/W system.

The second is the Lin method: the aqueous phase is added to the oil phase (water-in-oil inversion), with subsequent phase inversion under controlled shear as the water-to-

oil ratio increases. This approach promotes the formation of a transient W/O emulsion that inverts to O/W during water addition, potentially improving droplet fineness. In this variant, it was not possible to use polymers.

Since the modified starch is added to the aqueous phase, it would be pointless to try these changing methods on its emulsions.

3.4. Characterisation Methods

All emulsions were characterised at two time points: immediately after preparation (t_0) and after 24 hours (t_{24}). This two-point protocol captures both initial formulation quality and medium-term stability. The methods employed are described in the following subsections.

3.4.1. pH Measurement (t_0 and t_{24})

The pH of each sample was measured using a calibrated benchtop pH meter (SevenEasy™, Mettler Toledo) fitted with a glass combination electrode. The pH measurement has a dual purpose: it assesses the initial formulation pH (relevant to skin compatibility, target range 5.0–7.5 for facial and body products) and detects chemical instability over time, which may manifest as pH drift resulting from ester hydrolysis, fatty acid release, or ingredient degradation.

3.4.2. Viscosity Measurement (t_0 and t_{24})

The viscosity was measured using a Brookfield DV-I+ viscometer with a cylindrical spindle selection appropriate to the expected viscosity range. Measurements were recorded at three rotational speeds — 2.5, 5.0 and 10.0 rpm — to capture the shear-thinning behaviour characteristic of structured cosmetic emulsions. The spindle selected was noted for each trial to ensure comparability.

3.4.3. Centrifuge Stability Test

Accelerated stability was assessed by centrifugation using a Multifuge 1 S-R (Heraeus) benchtop centrifuge. Each sample (~5 g) was placed in a centrifuge tube and centrifuged at 7050 rpm (approximately 7000 G, with a rotor radius of 12.6 cm) for 30 minutes at 37 °C. This protocol is widely employed in cosmetic formulation screening as an accelerated surrogate for gravitational creaming and phase separation over time.

3.4.4. Optical Microscopy

The microstructure of each emulsion was observed using an optical brightfield microscope (Optika Microscopes, Italy) equipped with a digital camera. Samples were prepared by placing a small drop (~2–5 µL) of undiluted emulsion on a glass slide and covering it with a coverslip. Observations were performed using a HC 40×/0.65 (160/0.17 mm) objective lens, allowing the assessment of droplet morphology and spatial distribution within the emulsion.

3.4.5. Sensory Evaluation Protocol

A trained sensory panel of five evaluators performed descriptive texture assessment on selected formulations. Panellists were recruited from the laboratory team and received a brief orientation on the meaning and boundaries of each attribute before evaluation. Samples were provided in coded containers without reference to the emulsifier identity or trial number. Each product was evaluated under standardised conditions: ambient temperature (25°C), identical sample quantity (0.06 g), and uniform application on the inner forearm (5x5 cm). The analysis was performed on Trial 3 of the three emulsifiers, listed below. In this way, the evaluation was not conditioned by the presence of other ingredients that could have an impact on the sensoriality. The formulations corresponding to Trial 3 for the three emulsifying systems investigated are reported in Tables 7–9.

Table 7: Trial 3 of Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate Emulsifier

TRIAL 3 - Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate		
PHASE	INCI	%w/w
A	Aqua	76.59
	Xanthan Gum	0.15
A1	Preservatives	0.25
B	Caprylic/capric Triglyceride	6.67
	Coco-caprylate/Caprates	6.67
	Hydrogenated Polydecene	6.67
	Cetearyl Alcohol	1.00
	Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate	2.00
		100.00

Table 8: Trial 3 of C14-22 Alcohols, C12-20 Alkyl Glucoside

TRIAL 3 - C14-22 Alcohols, C12-20 Alkyl Glucoside		
PHASE	INCI	%w/w
A	Aqua	76.59
	Xanthan Gum	0.15
A1	Preservatives	0.25
B	Caprylic/capric Triglyceride	6.67
	Coco-caprylate/Caprates	6.67
	Hydrogenated Polydecene	6.67
	Cetearyl Alcohol	1.00
	C14-22 Alcohols, C12-20 Alkyl Glucoside	2.00
		100.00

Table 9: Trial 3 of Sodium Starch Octenylsuccinate

TRIAL 3 – Sodium Starch Octenylsuccinate		
PHASE	INCI	%w/w
A	Aqua	73.59
	Xanthan Gum	0.15
A1	Preservatives	0.25
A2	Sodium Starch Octenylsuccinate	5.00
B	Caprylic/capric Triglyceride	6.67
	Coco-caprylate/Caprates	6.67
	Hydrogenated Polydecene	6.67
	Cetearyl Alcohol	1.00
		100.00

Attributes were scored on a continuous 0–10 numerical scale, where 0 represents the complete absence of the attribute and 10 its maximum perceived intensity. Table 10 lists all attributes evaluated and their operational definitions.

Table 10: Sensory evaluation attributes and definitions

Attribute	Definition
Pickup	Ease of scooping / dispensing the product from the container
Thickness	Perceived viscosity/density of the product on application
Spreadability	Ease of spreading on skin surface
Soaping Effect	Tendency to form a white soapy film during rubbing
Absorption Rate	Speed at which the product is absorbed into the skin
Shine Effect	Level of gloss or sheen left on skin after application
Residual Amount	Perceived quantity of product remaining on skin surface after absorption

For the pigmented series (Series 7), four additional attributes were evaluated to capture make-up-relevant texture and coverage performance. Blendability was assessed by a specific rubbing motion across a defined skin area and scoring the ease of achieving a seamless finish without visible edges. Coverage was estimated visually at a fixed application amount on a standardised artificial skin patch with printed imperfections. The analysis was performed on Trial 22 for Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate and Trial 19 for the Sodium Starch Octenylsuccinate. The compositions of the two pigmented formulations selected for the sensory evaluation are reported in Tables 11 and 12.

Table 11: Trial 22 of Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate

TRIAL 22 - Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate		
PHASE	INCI	%w/w
A	Aqua	50.81
	Xanthan Gum	0.15
A1	Preservatives	0.25
B	Caprylic/capric Triglyceride	6.67
	Coco-caprylate/Caprates	6.67
	Hydrogenated Polydecene	6.67
	Cetearyl Alcohol	1.00
	Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate	4.00

B1	CI77891	2.50
	CI 77492	0.80
	CI 77499, CI 77491, CI 77492	0.48
C	Aqua	20.00
		100.00

Table 12: Trial 18 of Sodium Starch Octenylsuccinate

TRIAL 19 – Sodium Starch Octenylsuccinate		
PHASE	INCI	%w/w
A	Aqua	72.31
	Xanthan Gum	0.15
A1	Preservatives	0.25
A2	Sodium Starch Octenylsuccinate	2.50
B	Caprylic/capric Triglyceride	6.67
	Coco-caprylate/Caprate	6.67
	Hydrogenated Polydecene	6.67
	Cetearyl Alcohol	1.00
B1	CI77891	2.50
	CI 77492	0.80
	CI 77499, CI 77491, CI 77492	0.48
		100.00

Table 13 summarises the four extra parameters.

Table 13: Sensory evaluation attributes and definitions for coloured emulsions

Mattifying Effect	Capacity to reduce skin shine and minimize appearance of pores
Color Homogeneity	Uniformity of color distribution on the skin
Coverage	Degree of skin imperfection concealment achieved by the product
Blendability	Ease of blending / seamless skin integration without demarcation

Panel results are presented in Chapter 4 (Section 4.8) as individual attribute spider diagrams allowing direct inter-emulsifier comparison.

CHAPTER 4 – RESULTS AND CONCLUSION

The performance of the three emulsifying systems was investigated through a structured experimental programme comprising seven formulation series designed to assess the influence of key formulation and processing variables on emulsion stability and sensory properties. The variables examined included oil phase concentration, oil chemical composition, emulsifier concentration, rheology modifier type, emulsification procedure, and pigment incorporation.

Emulsion performance was evaluated by means of physicochemical characterisation and sensory analysis. Physical stability was assessed through centrifugation testing, optical microscopy, pH determination, and viscosity measurements performed at preparation (t_0) and after twenty-four hours (t_{24}). Sensory evaluation included the assessment of pick-up, thickness, spreadability, white cast, absorption rate, shine effect, and residual feel.

Results are presented according to the experimental design, allowing the effects of individual formulation variables to be examined while enabling direct comparison among the investigated emulsifying systems. Emphasis is placed on the identification of formulation conditions associated with improved physical stability and desirable sensory characteristics.

Based on the results obtained during the screening phase, two emulsifying systems were selected for further investigation in pigmented formulations containing inorganic pigments. Their suitability for colour cosmetic applications was evaluated through physicochemical characterisation and sensory assessment, including spreadability, mattifying effect, colour homogeneity, coverage, blendability, and residual amount.

The alkyl polyglucoside-based emulsifier (*C14-22 Alcohols / C12-20 Alkyl Glucoside*) was not included in this phase, as phase separation was observed within 24 hours of preparation.

4.1. Series 1 — 20% Mixed Oil Phase, with and without Stabilisers

This series establishes the baseline behaviour of each emulsifying system at the supplier-recommended concentration (2% or 5% w/w) combined with a 20% oil-phase mixture, comparing three formulation states: no co-stabiliser (Trial 1), *Cetearyl Alcohol* alone (Trial 2), and the binary combination of *Cetearyl Alcohol* with *Xanthan Gum* (Trial 3).

4.1.1. Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate

The results on the emulsions of Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate are summarized in Table 14.

Table 14: 2% Physicochemical results for Series 1 on Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate

Trial	Oil phase	Stabilisers	Centrifuge	pH t ₂₄	Spindle	Viscosity t ₀ (2.5rpm)	Viscosity t ₂₄ (2.5rpm)	Microscopy
1	Mix 20%	No	creaming +coalescence	6.7	S01	Not measurable	Not measurable	5 - 25 µm
2	Mix 20%	Cetearyl Alcohol 1%	creaming +coalescence	6.7	S01	Not measurable	Not measurable	10 - 40 µm
3	Mix 20%	Xanthan Gum 0.15% + Cetearyl Alcohol 1%	creaming	6.7	S01	812	916	2 - 15 µm

Note: “Mix 20%” indicates the total oil-phase concentration in the formulation. The oil phase contains Caprylic/Capric Triglyceride, Coco-Caprylate/Caprates and Hydrogenated Polydecene in equal proportions (approximately 6.7% each).

Without stabilisers (Trial 1), the system failed to develop measurable viscosity, and optical microscopy revealed a polydisperse droplet population (5–25 μm) with extensive coalescence under centrifugal stress. The incorporation of Cetearyl Alcohol alone (Trial 2) did not resolve the instability. Cetearyl Alcohol acts as a co-emulsifier whose C16–C18 saturated chain intercalates at the oil–water interface and reinforces the interfacial film, but the resulting structure remained insufficient to prevent phase separation, and droplet size increased further to 10–40 μm ¹⁴. Only the binary system of Xanthan Gum and Cetearyl Alcohol (Trial 3) produced a measurable viscosity (812 $\text{mPa}\cdot\text{s}$ at t_0 , rising to 916 $\text{mPa}\cdot\text{s}$ at t_{24}) and limited centrifuge outcome to creaming without coalescence, with droplet size narrowing to 2–15 μm . These results indicate that this emulsifying system at 2% requires a complete structural support network: the hydrocolloid builds the continuous-phase viscoelastic matrix while the fatty alcohol reinforces the interfacial layer. The microstructure of Trial 3 of Sorbitan Laurate is shown in Figure 3.

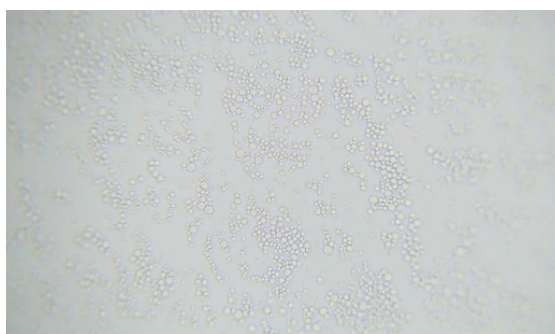


Figure 3: Microscopy picture of Trial 3 of Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate

4.1.2. C14-22 Alcohols / C12-20 Alkyl Glucoside

The results on the emulsions of C14-22 Alcohols / C12-20 Alkyl Glucoside are summarised in Table 15:

Table 15: Physicochemical results for Series 1 of C14-22 Alcohols / C12-20 Alkyl Glucoside

Trial	Oil Phase	Stabilisers	Centrifuge	pH t ₂₄	Spindle	Viscosity t ₀ (2.5rpm)	Viscosity t ₂₄ (2.5rpm)	Microscopy
1	Mix 20%	No	Creaming + coalescence	7.4	S01	1,704	1,904	5 – 40 µm
2	Mix 20%	Cetearyl Alcohol 1%	Creaming + coalescence	7.5	S02	10,280	11,880	5 – 40 µm
3	Mix 20%	Xanthan Gum 0.15% + Cetearyl Alcohol 1%	Creaming	7.5	S02	7,560	14,400	3 – 15 µm

Note: “Mix 20%” indicates the total oil-phase concentration in the formulation. The oil phase contains Caprylic/Capric Triglyceride, Coco-Caprylate/Caprate and Hydrogenated Polydecene in equal proportions (approximately 6.7% each).

The alkyl glucoside system displays a markedly different rheological profile. Even without co-stabilisers (Trial 1), viscosity at 2.5 rpm reached 1,704 mPa·s at t₀ and 1,904 mPa·s at t₂₄, reflecting the tendency of long-chain fatty alcohols in this blend to form lamellar gel-network structures in the continuous phase — a behaviour of alkyl glucoside–fatty alcohol combinations that organise into interdigitated bilayers immobilising water and building gel strength¹⁵. Despite this intrinsic structuring, centrifuge stability remained poor (creaming and coalescence), and droplet size was broad (5–40 µm), indicating that the lamellar network formed at 2% is not fully developed. Adding Cetearyl Alcohol (Trial 2) dramatically elevated viscosity to 10,280 mPa·s, confirming synergistic co-crystallisation between the emulsifier's own fatty alcohols and the added co-emulsifier; however, coalescence persisted. Full stabilisation required the ternary system with Xanthan Gum (Trial 3), which reduced droplet size to 3–15 µm and confined centrifuge behaviour to light creaming without coalescence, while viscosity showed a characteristic time-dependent increase (7,560 → 14,400 mPa·s) indicative of ongoing crystalline network maturation and the complete formation of the Xanthan Gum network. The microstructure of Trial 3 of C14-22 Alcohols / C12-20 Alkyl Glucoside is shown in Figure 4.

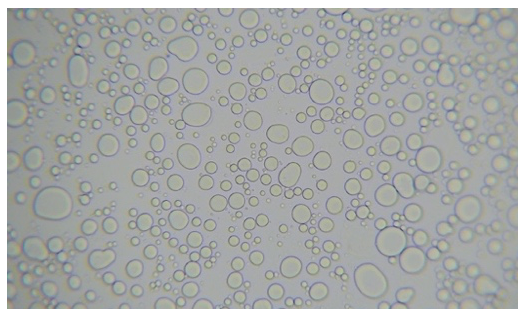


Figure 4: Microscopy picture of Trial 3 of C14-22 Alcohols / C12-20 Alkyl Glucoside

4.1.3. Sodium Starch Octenylsuccinate

The results on the emulsions of Sodium Starch Octenylsuccinate are summarised in Table 16:

Table 16: Physicochemical results for Series 1 of Sodium Starch Octenylsuccinate

Trial	Oil phase	Stabilisers	Centrifuge	pH t ₂₄	Spindle	Viscosity t ₀ (2.5rpm)	Viscosity t ₂₄ (2.5rpm)	Microscopy
1	Mix 20%	No	No phase separation	5.7	S03	83,200	104,000	2 – 20 µm
2	Mix 20%	Cetearyl Alcohol 1%	Creaming	5.8	S03	69,280	31,680	5 – 25 µm
3	Mix 20%	Xanthan Gum 0.15% + Cetearyl Alcohol 1%	No phase separation	5.8	S03	91,360	68,800	5 – 20 µm

Note: “Mix 20%” indicates the total oil-phase concentration in the formulation. The oil phase contains Caprylic/Capric Triglyceride, Coco-Caprylate/Caprate and Hydrogenated Polydecene in equal proportions (approximately 6.7% each).

The modified-starch emulsifier demonstrated behaviour profoundly different from the other two systems. At 5% w/w — the concentration required to obtain adequate emulsification — the unstabilised formulation (Trial 1) already showed perfect centrifuge stability and a viscosity of 83,200 mPa·s at t₀, rising to 104,000 mPa·s at t₂₄. This performance reflects the Pickering-like mechanism of starch-derived emulsifiers, in which polymer chains adsorb irreversibly at the oil–water interface and form a thick steric barrier against coalescence. Paradoxically, Cetearyl Alcohol (Trial 2) was

detrimental, reducing viscosity to 69,280 mPa·s at t_0 and declining to 31,680 mPa·s at t_{24} , with creaming appearing. This antagonistic effect may arise from competitive displacement of starch chains at the interface by the fatty alcohol, or from disruption of the polysaccharide network architecture. The binary stabiliser system (Trial 3) restored stability and elevated viscosity (91,360 mPa·s at t_0), suggesting that Xanthan Gum in the continuous phase compensates for interfacial perturbation caused by Cetearyl Alcohol. The appearance of the three samples after centrifugation is shown in Figure 5.

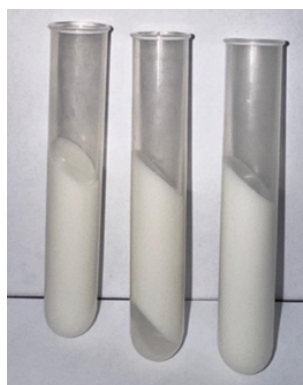


Figure 5: Appearance of the three emulsion samples formulated with Sodium Starch Octenylsuccinate after centrifugation. From left to right: Trial 1, Trial 2, and Trial 3.

4.2. Series 2 — Concentration Oil Phase Study

This series evaluated the effect of fatty-phase concentration on the rheological behaviour and physical stability of the emulsions. The stabiliser combination identified in Series 1 (Xanthan Gum and Cetearyl Alcohol) was kept constant, while the oil-phase content was varied from 10% to 30% and composed of a mixture of the three oils. These levels were selected to represent formulations with substantially different internal phase volumes, allowing assessment of emulsifier performance under increasing structural demands.

4.2.1. Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate

The physicochemical results obtained for Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate in Series 2 are presented in Table 17.

Table 17: Physicochemical results for Series 2 on Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate

Trial	Oil phase	Stabilisers	Centrifuge	pH t ₂₄	Spindle	Viscosity t ₀ (2.5rpm)	Viscosity t ₂₄ (2.5rpm)	Microscopy
4	Mix 10%	XG 0.15% + CA 1%	creaming	6.0	S01	592	972	2 - 10 μ m
5	Mix 30%	XG 0.15% + CA 1%	creaming +coalescence	6.3	S01	1,020	1,164	5 - 20 μ m

Note: “Mix 10%” and “Mix 30%” indicate the total oil-phase concentration in the formulation. The oil phase contains Caprylic/Capric Triglyceride, Coco-Caprylate/Caprate and Hydrogenated Polydecene in equal proportions (approximately 3.33% each in Mix 10% and 10% each in Mix 30%). XG = Xanthan Gum; CA = Cetearyl Alcohol.

At 10% oil (Trial 4), viscosity was 592 mPa·s at t₀ and increased to 972 mPa·s at t₂₄, with creaming as the sole centrifuge outcome and a fine droplet population (2–10 μ m). Increasing oil content to 30% (Trial 5) raised initial viscosity to 1,020 mPa·s, but centrifuge stability deteriorated with the reappearance of coalescence alongside creaming, and droplet size widened to 5–20 μ m. This indicates that the emulsifying capacity at 2% is exceeded below 30% oil; the available emulsifier cannot fully cover the augmented interfacial area generated by a 50% increase in dispersed-phase volume. The optimal oil-phase range for this emulsifier at 2% is therefore approximately 10–20%. The microscopic appearance of Trials 4 and 5 is compared in Figure 6.

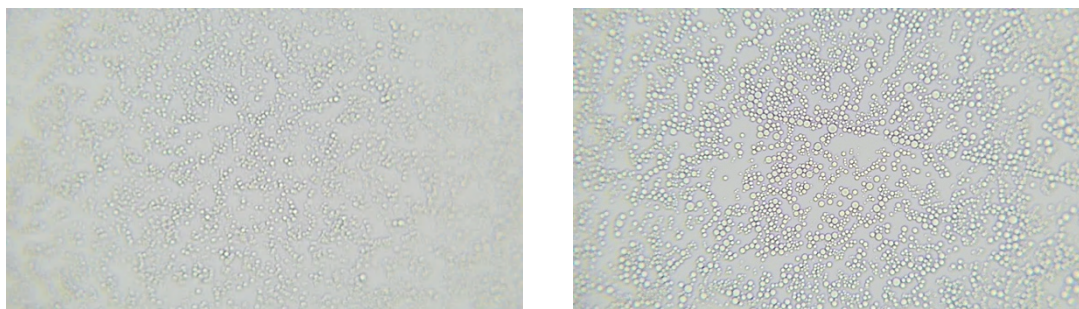


Figure 6: Microscopy picture of Trial 4 (on the left) and 5 (on the right) of Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate

4.2.2. C14-22 Alcohols / C12-20 Alkyl Glucoside

The physicochemical characterization of C14-22 Alcohols / C12-20 Alkyl Glucoside in Series 2 is reported in Table 18.

Table 18: Physicochemical results for Series 2 of C14-22 Alcohols / C12-20 Alkyl Glucoside

Trial	Oil phase	Stabilisers	Centrifuge	pH t ₂₄	Spindle	Viscosity t ₀ (2.5rpm)	Viscosity t ₂₄ (2.5rpm)	Microscopy
4	Mix 10%	XG 0.15% + CA 1%	Creaming > Trial 5	7.3	S01	992	7,520	2 – 30 µm
5	Mix 30%	XG 0.15% + CA 1%	Light creaming	7.2	S02	12,440	21,360	2 – 10 µm

Note: “Mix 10%” and “Mix 30%” indicate the total oil-phase concentration in the formulation. The oil phase contains Caprylic/Capric Triglyceride, Coco-Caprylate/Caprate and Hydrogenated Polydecene in equal proportions (approximately 3.33% each in Mix 10% and 10% each in Mix 30%). XG = Xanthan Gum; CA = Cetearyl Alcohol.

This system exhibited an inverse viscosity–oil-load relationship. At 10% oil (Trial 4), initial viscosity was low (992 mPa·s) but grew substantially by t₂₄ (7,520 mPa·s), pointing to delayed lamellar network formation. At 30% oil (Trial 5), viscosity was already high at t₀ (12,440 mPa·s) and increased further at t₂₄ (21,360 mPa·s), with only slight creaming. The ability to perform better at higher oil fractions is consistent with the known behaviour of alkyl glucoside–fatty alcohol systems: the fatty alcohols in both the emulsifier and the oil phase contribute to the lamellar gel network, and higher

oil-phase volume provides more co-structuring material. The microscopic appearance of Trials 4 and 5 is compared in Figure 7.

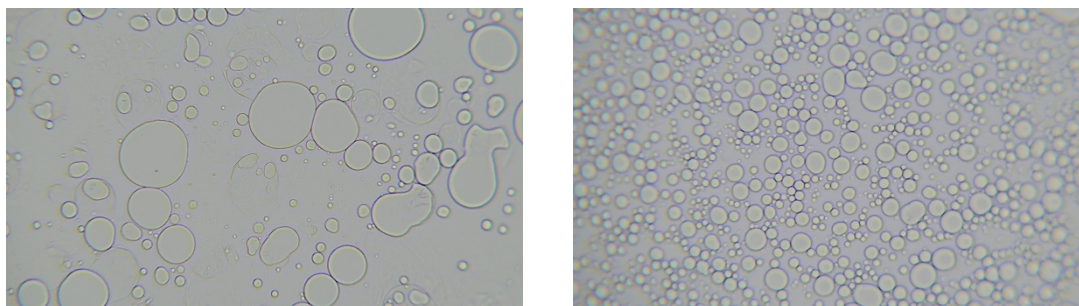


Figure 7: Microscopy picture of Trial 4 (on the left) and 5 (on the right) of C14-22 Alcohols / C12-20 Alkyl Glucoside

4.2.3. Sodium Starch Octenylsuccinate

The physicochemical results obtained for Sodium Starch Octenylsuccinate in Series 2 are presented in Table 19.

Table 19: Physicochemical results for Series 2 of Sodium Starch Octenylsuccinate

Trial	Oil phase	Stabilisers	Centrifuge	pH t ₂₄	Spindle	Viscosity t ₀ (2.5rpm)	Viscosity t ₂₄ (2.5rpm)	Microscopy
4	Mix 10%	XG 0.15% + CA 1%	No phase separation	5.7	S02	25,760	20,880	5 – 15 µm
5	Mix 30%	XG 0.15% + CA 1%	No phase separation	5.8	S04	185,000	216,000	5 – 20 µm

Note: “Mix 10%” and “Mix 30%” indicate the total oil-phase concentration in the formulation. The oil phase contains Caprylic/Capric Triglyceride, Coco-Caprylate/Caprate and Hydrogenated Polydecene in equal proportions (approximately 3.33% each in Mix 10% and 10% each in Mix 30%). XG = Xanthan Gum; CA = Cetearyl Alcohol.

The modified starch maintained excellent centrifuge stability across both oil fractions. At 10% oil (Trial 4), viscosity was 25,760 mPa·s at t₀ and declined slightly to 20,880 mPa·s at t₂₄. At 30% oil (Trial 5), viscosity reached 185,000 mPa·s at t₀ and climbed to 216,000 mPa·s at t₂₄ with perfect centrifuge performance. The very high viscosity at elevated oil loads represents a pasty consistency unsuitable for skin application,

suggesting that 30% oil exceeds the sensory optimum for this emulsifier even when stability is maintained. The microscopic appearance of Trials 4 and 5 is compared in Figure 8.

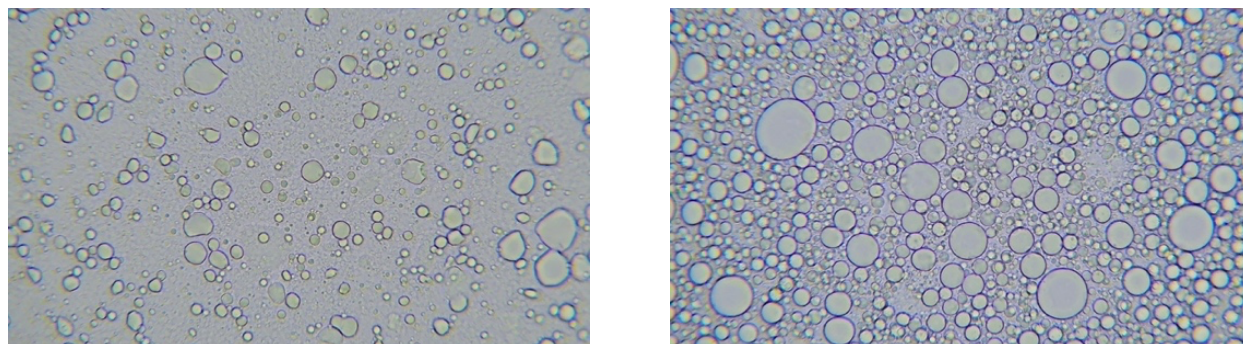


Figure 8: Microscopy picture of Trial 4 (on the left) and 5 (on the right) of Sodium Starch Octenylsuccinate

4.3. Series 3 — Functional Groups Study

Each emulsifier was tested with five individual oil ingredients representing distinct structural classes: a hydrogenated polyolefin (Hydrogenated Polydecene), a medium-chain ester (Coco-Caprylate/Caprate), a diester (Diisopropyl Adipate), a branched fatty alcohol (Octyldodecanol), and a medium-chain triglyceride (Caprylic/Capric Triglyceride). Sub-series A (no stabiliser) isolates pure emulsifier–oil compatibility; sub-series B (Xanthan Gum + Cetearyl Alcohol) reveals the additional contribution of the stabiliser package.

4.3.1. Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate

The physicochemical results of Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate in Series 3 are reported in Table 20.

Table 20: Physicochemical results for Series 3 on Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate

Trial	Oil phase (20%)	Stabilisers	Centrifuge	pH t ₂₄	Spindle	Viscosity t ₀ (2.5rpm)	Viscosity t ₂₄ (2.5rpm)	Micro
6A	Hydrogenated Polydecene	No	creaming +coalescence	5.8	S01	N.M.	N.M.	10 – 40 µm
7A	Coco-Caprylate/Caprate	No	creaming +coalescence	6.4	S01	N.M.	N.M.	10 - 30 µm
8A	Diisopropyl Adipate	No	creaming +coalescence	5.8	S01	N.M.	N.M.	10 - 40 µm
9A	Octyldodecanol	No	creaming +coalescence	6.6	S01	N.M.	N.M.	15 - 25 µm
10A	Caprylic/Capric Triglyceride	No	creaming +coalescence	6.4	S01	N.M.	N.M.	5 - 15 µm
6B	Hydrogenated Polydecene	XG 0.15% + CA 1%	creaming	5.8	S02	3,888	7,500	5 - 25 µm
7B	Coco-Caprylate/Caprate	XG 0.15% + CA 1%	creaming	6.3	S01	720	908	2 -10 µm
8B	Diisopropyl Adipate	XG 0.15% + CA 1%	creaming +coalescence	5.7	S01	512	684	5 - 15 µm
9B	Octyldodecanol	XG 0.15% + CA 1%	creaming	6.3	S01	480	752	5 - 20 µm
10B	Caprylic/Capric Triglyceride	XG 0.15% + CA 1%	creaming	6.3	S01	620	736	2 - 8 µm

Note: XG = Xanthan Gum; CA = Cetearyl Alcohol; N.M. = Not Measurable

In the absence of stabilisers (sub-series A), all five oils produced unstable emulsions with coalescence, confirming the structural dependence established in Series 1. Notable differences emerged among oil types. With the medium-chain triglyceride (Trial 10A), droplets were the finest (5–15 µm), probably due to structural compatibility between the laurate chains of the emulsifier and the C8/C10 ester groups of the triglyceride — both being saturated medium-chain lipids that facilitate tight interfacial packing. With Diisopropyl Adipate (Trial 8A), the emulsion showed a pH shift toward acidity (5.8), which may reflect partial ester hydrolysis at elevated temperature during preparation.

In the stabilised systems (sub-series B), the nature of the oil phase continued to influence emulsion performance despite the presence of Xanthan Gum and Cetearyl

Alcohol. Among all tested oils, Coco-Caprylate/Caprates (Trial 7B) provided the most favourable overall performance, combining a narrow droplet size distribution (2–10 μm) with the absence of coalescence and only limited creaming. Its superior behaviour was also consistent with observations from the corresponding unstabilised emulsion (Trial 7A), which exhibited the lowest degree of phase separation after one week compared with the other oils. This trend suggests a particularly good compatibility between Coco-Caprylate/Caprates and the emulsifier system. A visual comparison of the unstabilised emulsions after one week is shown below, where the reduced extent of phase separation in Trial 7A is clear. Their appearance after one week of storage is shown in Figure 9.

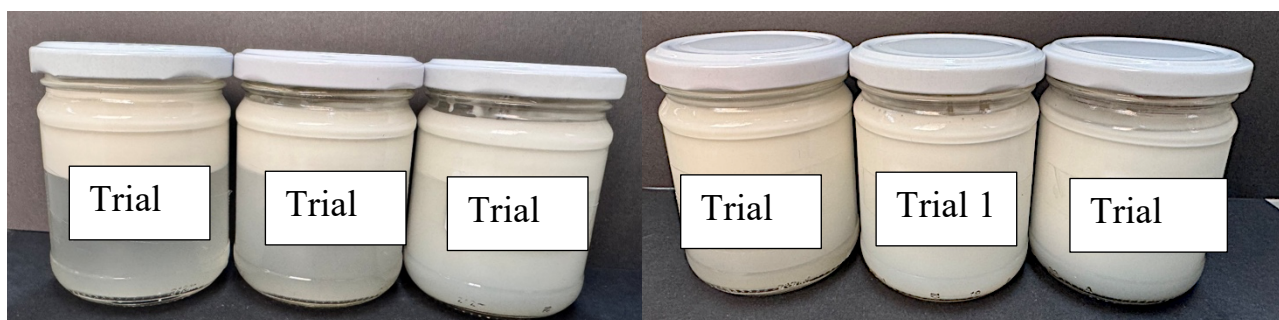


Figure 9: the trials of Series 3A after one week of storage, in order from the most unstable to the most stable

Octyldodecanol (Trial 9B) and Caprylic/Capric Triglyceride (Trial 10B) produced intermediate results, with creaming occurring in both cases but without significant droplet coalescence. Overall, the results indicate that oil chemistry played a decisive role in emulsion stability and that Coco-Caprylate/Caprates represented the most suitable emollient for this emulsifier system.

4.3.2. C14-22 Alcohols / C12-20 Alkyl Glucoside

Table 21 summarizes the physicochemical results of C14-22 Alcohols / C12-20 Alkyl Glucoside obtained for Series 3.

Table 21: Physicochemical results for Series 3 of C14-22 Alcohols / C12-20 Alkyl Glucoside

Trial	Oil phase (20%)	Centrifuge	Stabilisers	pH t ₂₄	Spindle	Viscosity t ₀ (2.5rpm)	Viscosity t ₂₄ (2.5rpm)	Micro
6A	Hydrogenated Polydecene	Creaming >50% + coalescence	No	7.7	S01	N.M.	N.M.	15 – 50 µm
7A	Coco-Caprylate/Caprates	Creaming	No	7.6	S01	N.M.	3,600	5 – 80 µm
8A	Diisopropyl Adipate	Creaming ~50%	No	5.4	S01	N.M.	296	5 – 12 µm
9A	Octyldodecanol	Creaming ~70%	No	7.3	S01	508	2,112	5 – 20 µm
10A	Caprylic/Capric Triglyceride	Separated	No	7.7	S01	N.M.	Separated	/
6B	Hydrogenated Polydecene	Creaming ~30%	XG 0.15% + CA 1%	7.6	S02	3,584	12,560	3 – 12 µm
7B	Coco-Caprylate/Caprates	Light Creaming	XG 0.15% + CA 1%	7.1	S02	7,392	10,800	2 – 8 µm
8B	Diisopropyl Adipate	Creaming ~20%	XG 0.15% + CA 1%	5.3	S02	1,968	7,080	5 – 12 µm
9B	Octyldodecanol	Light Creaming ~15%	XG 0.15% + CA 1%	7.2	S01	784	3,392	5 – 20 µm
10B	Caprylic/Capric Triglyceride	Light Creaming	XG 0.15% + CA 1%	7.6	S02	5,920	8,560	3 – 10 µm

Note: XG = Xanthan Gum; CA = Cetearyl Alcohol; N.M. = Not Measurable

Without stabilisers, all single-oil emulsions were unstable. The Caprylic/Capric Triglyceride (Trial 10A) completely separated at t₂₄; this is an unexpected outcome given that this oil is generally considered compatible with alkyl glucoside systems; the absence of co-structuring fatty alcohols in the oil phase may have prevented lamellar network formation.

With stabilisers (sub-series B), Coco-Caprylate/Caprates (Trial 7B) provided the best outcome — lowest creaming, fine droplets (2–8 µm), high viscosity — confirming this ester as the reference oil for this emulsifier class. Caprylic/Capric Triglyceride (Trial

10B) recovered substantially with stabilisers, demonstrating that co-structuring fatty alcohols from Cetearyl Alcohol can partially compensate for their absence in the oil phase.

4.3.3. Sodium Starch Octenylsuccinate

The main physicochemical parameters of Sodium Starch Octenylsuccinate evaluated for Series 3 are presented in Table 22.

Table 22: Physicochemical results for Series 3 of Sodium Starch Octenylsuccinate

Trial	Oil phase (20%)	Stabilisers	Centrifuge	pH t₂₄	Spindle	Viscosity t₀ (2.5rpm)	Viscosity t₂₄ (2.5rpm)	Micro
6A	Hydrogenated Polydecene	No	Slight creaming	5.7	S05	121,000	97,600	5 – 30 µm
7A	Coco-Caprylate/Caprate	No	No phase separation	5.6	S05	140,000	119,000	5 – 20 µm
8A	Diisopropyl Adipate	No	No phase separation	5.6	S05	131,000	118,000	5 – 20 µm
9A	Octyldodecanol	No	No phase separation	5.8	S05	177,000	171,000	5 – 25 µm
10A	Caprylic/Capric Triglyceride	No	No phase separation	5.7	S05	118,000	151,000	5 – 20 µm
6B	Hydrogenated Polydecene	XG 0.15% + CA 1%	No phase separation	5.7	S05	61,600	60,400	2 – 10 µm
7B	Coco-Caprylate/Caprate	XG 0.15% + CA 1%	No phase separation	5.3	S05	151,000	105,000	5 – 25 µm
8B	Diisopropyl Adipate	XG 0.15% + CA 1%	No phase separation	5.6	S05	150,000	138,000	5– 25 µm
9B	Octyldodecanol	XG 0.15% + CA 1%	No phase separation	5.7	S05	174,000	184,000	5 – 15 µm
10B	Caprylic/Capric Triglyceride	XG 0.15% + CA 1%	No phase separation	5.8	S05	162,000	141,000	2 – 15 µm

Note: XG = Xanthan Gum; CA = Cetearyl Alcohol.

The modified starch demonstrated broad oil-class compatibility even in sub-series A. Four out of five single-oil emulsions achieved perfect centrifuge stability without stabilisers, reflecting the emulsifier's robust Pickering-type adsorption mechanism independent of oil polarity or functional group. Only the hydrogenated polyolefin

(Trial 6A) produced slight creaming, attributed to the high molecular volume, linear structure and very low polarity of this mineral oil, which may reduce the probability of interfacial adsorption events.

Overall, these results indicate that Sodium Starch Octenylsuccinate is considerably less sensitive to oil-phase chemistry than the emulsifier systems evaluated in the previous series, providing robust stabilisation across hydrocarbons, esters, triglycerides and fatty alcohols without requiring additional stabilisers.

4.4. Series 4 —Emulsifier Concentration Study

For the ester blend and the alkyl glucoside system, emulsifier concentration was doubled from 2% to 4% to assess the effect of increased interfacial coverage. For the modified starch, the inverse experiment was conducted — concentration was halved from 5% to 2.5% — to determine the minimum effective level, as doubling to 10% would be texturally unacceptable. These contrasting experimental designs reflect the fundamentally different usage ranges of these systems.

4.4.1. Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate

Table 23 summarizes the physicochemical results of Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate obtained for Series 4.

Table 23: Physicochemical results for Series 4 on Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate

Trial	Oil phase	Stabilisers	Centrifuge	pH t₂₄	Spindle	Viscosity t₀ (2.5rpm)	Viscosity t₂₄ (2.5rpm)	Micro
11	Mix 20%	No	Separated	N.M.	S01	1,004	Separated	Separated
12	Mix 20%	XG 0.15% + CA 1%	creaming ~50%	6.1	S01	916	1,140	3 – 5 µm
13	Caprylic/ Capric Triglyceride	No	creaming +coalescence	6.1	S01	N.M.	N.M.	8 - 25 µm

14	Caprylic/ Capric Triglyceride	XG 0.15% + CA 1%	creaming ~50%	6.2	S01	728	928	2 - 5 μm
15	Mix 10%	No	creaming +coalescence	6.1	S01	N.M.	N.M.	2 - 10 μm
16	Mix 10%	XG 0.15% + CA 1%	slight creaming	6.1	S01	524	716	5 - 25 μm

Note: “Mix 10%” and “Mix 30%” indicate the total oil-phase concentration in the formulation. The oil phase contains Caprylic/Capric Triglyceride, Coco-Caprylate/Caprate and Hydrogenated Polydecene in equal proportions (approximately 3.33% each in Mix 10% and 10% each in Mix 30%). XG = Xanthan Gum; CA = Cetearyl Alcohol; N.M. = Not Measurable.

Following the results obtained in Series 1–3, additional experimental sets were designed to investigate the effect of emulsifier concentration on the performance of the Sorbitan Laurate / Polyglyceryl-4 Laurate / Dilauryl Citrate system. The first was the 20% mixed oil phase, which had served as the reference composition throughout the study. The second was the 10% mixed oil phase, as Series 2 had demonstrated improved stability at lower oil loads compared with the 20% and 30% systems. In addition, formulations based on Caprylic/Capric Triglyceride were included because this oil had previously generated the smallest droplet sizes and among the most promising stability profiles within Series 3.

The emulsifier concentration was increased from the supplier-recommended level of 2% to 4% w/w to evaluate whether enhanced interfacial coverage could improve emulsion stability. Increasing the emulsifier concentration is expected to promote more complete droplet surface coverage during homogenisation, thereby reducing droplet coalescence and improving resistance to phase separation.

The results indicate that increasing the emulsifier concentration substantially improved emulsion formation compared with the corresponding formulations prepared at 2%. In particular, formulations containing Xanthan Gum and Cetearyl Alcohol (Trials 12, 14 and 16) remained physically stable and showed reduced droplet sizes compared with the corresponding systems evaluated in Series 1.

Among the tested formulations, Trial 16 (10% mixed oil phase with co-stabilisers) exhibited the most favourable overall balance between viscosity, centrifuge stability and microscopic appearance, confirming the beneficial effect of reducing oil-phase content previously observed in Series 2. The Caprylic/Capric Triglyceride formulations also showed improved droplet size distribution relative to the mixed-oil systems, supporting the findings of Series 3 that this ester is particularly compatible with the emulsifier system. Nevertheless, some degree of creaming remained evident in all formulations, indicating that although increased emulsifier concentration improved kinetic stability, it was not sufficient to eliminate destabilisation phenomena.

4.4.2. C14-22 Alcohols / C12-20 Alkyl Glucoside

The main physicochemical parameters of C14-22 Alcohols / C12-20 Alkyl Glucoside evaluated for Series 4 are presented in Table 24.

Table 24: Physicochemical results for Series 4 of C14-22 Alcohols / C12-20 Alkyl Glucoside

Trial	Oil phase	Stabilisers	Centrifuge	pH t₂₄	Spindle	Viscosity t₀ (2.5rpm)	Viscosity t₂₄ (2.5rpm)	Micro
11	Mix 10%	No	Creaming ~50%	6.7	S01	N.M.	2,336	5 – 25 µm
12	Mix 10%	XG 0.15% + CA 1%	Acceptable	7.2	S02	3,952	4,800	3 – 12 µm
13	Mix 20%	No	Light creaming	6.8	S02	3,040	2,960	5 – 25 µm
14	Mix 20%	XG 0.15% + CA 1%	No phase separation	7.1	S04	17,280	26,480	2 – 10 µm
15	Mix 30%	No	Light creaming	7.2	S03	13,200	10,520	4 – 20 µm
16	Mix 30%	XG 0.15% + CA 1%	Slight sedimentation	7.1	S04	20,640	23,040	2 – 10 µm

Note: “Mix 10%” and “Mix 30%” indicate the total oil-phase concentration in the formulation. The oil phase contains Caprylic/Capric Triglyceride, Coco-Caprylate/Caprates and Hydrogenated Polydecene in equal proportions (approximately 3.33% each in Mix 10% and 10% each in Mix 30%). XG = Xanthan Gum; CA = Cetearyl Alcohol.

The mixed-oil system was selected for further investigation because previous experiments (Series 1 and Series 2) demonstrated superior performance compared with the individual oils evaluated in Series 3. Increasing the alkyl glucoside concentration to 4% produced a marked improvement in emulsion stability and rheological properties across all oil loads tested. The most successful formulation was Trial 14 (20% oil phase, Xanthan Gum and Cetearyl Alcohol), which exhibited perfect centrifuge stability, a narrow droplet size distribution (2–10 μm), and the highest viscosity values observed within the series, increasing from 17,280 $\text{mPa}\cdot\text{s}$ at t_0 to 26,480 $\text{mPa}\cdot\text{s}$ at t_{24} . Similarly, Trial 16 (30% oil phase, with stabilisers) maintained excellent viscosity (20,640–23,040 $\text{mPa}\cdot\text{s}$) and a fine droplet distribution, although slight sedimentation was observed after centrifugation.

In the absence of stabilisers, the effect of the increased emulsifier concentration remained evident. Trial 13 (20% oil phase) showed only slight creaming, while Trial 15 (30% oil phase) achieved substantially higher viscosity than comparable formulations prepared with lower emulsifier concentrations. These findings suggest that, at 4%, the emulsifier is contributing significantly to emulsion stability even without auxiliary rheology modifiers.

4.4.3. Sodium Starch Octenylsuccinate

The physicochemical results of Sodium Starch Octenylsuccinate in Series 4 are reported in Table 25.

Table 25: Physicochemical results for Series 4 of Sodium Starch Octenylsuccinate

Trial	Oil phase	Stabilisers	Centrifuge	pH t_{24}	Spindle	Viscosity t_0 (2.5rpm)	Viscosity t_{24} (2.5rpm)	Microscopy
11	Mix 10%	No	Slight creaming	5.8	S04	29,440	24,160	5 – 35 μm
12	Mix 10%	XG 0.15% + CA 1%	Slight creaming	6.1	S04	34,080	29,760	5 – 20 μm
13	Mix 20%	No	Creaming	6.4	S03	5,648	5,760	10 – 55 μm

14	Mix 20%	XG 0.15% + CA 1%	Slight creaming	6.2	S03	5,480	5,160	5 – 18 µm
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Note: “Mix 10%” and “Mix 30%” indicate the total oil-phase concentration in the formulation. The oil phase contains Caprylic/Capric Triglyceride, Coco-Caprylate/Caprate and Hydrogenated Polydecene in equal proportions (approximately 3.33% each in Mix 10% and 10% each in Mix 30%). XG = Xanthan Gum; CA = Cetearyl Alcohol.

The concentration of Sodium Starch Octenylsuccinate was reduced from 5% to 2.5% to investigate whether a lower emulsifier level could generate emulsions with a more homogeneous appearance and a less structured, more pleasant texture while maintaining acceptable stability. As no clear preference for a specific oil load had emerged in the previous experimental series, both 10% and 20% mixed-oil systems were evaluated.

Reducing the emulsifier concentration resulted in a general decrease in emulsion performance compared with the formulations prepared at 5%. At 10% oil phase, both Trial 11 and Trial 12 showed slight creaming after centrifugation, whereas the corresponding 5% formulation (Trial 4, Series 2) exhibited perfect stability. The droplet size distribution also broadened, particularly in the absence of stabilisers (5–35 µm), indicating less efficient interfacial coverage. The addition of Xanthan Gum and Cetearyl Alcohol improved droplet uniformity (5–20 µm) but was insufficient to fully restore the stability observed at the higher emulsifier concentration.

The effect was more pronounced at 20% oil phase. Trials 13 and 14 displayed evidence of creaming during centrifugation. As observed in previous series, the combination of Xanthan Gum and Cetearyl Alcohol improved droplet size distribution and centrifuge performance compared with the unstabilised system, although perfect stability was not achieved.

Overall, the results indicate that reducing Sodium Starch Octenylsuccinate from 5% to 2.5% leads to a measurable decrease in emulsification efficiency and physical stability.

However, the lower concentration still produced emulsions with acceptable rheological characteristics and may represent a useful compromise when a lighter and less highly structured texture is desired. The findings therefore suggest that 5% remains the optimal concentration for maximising stability, while 2.5% can be considered a viable alternative when sensory properties are prioritised over maximum physical robustness.

4.5. Series 5 — Polymers Study

Three rheological polymers — Xanthan Gum (0.15%), Hydroxyethylcellulose (0.40%), and Polyacrylate Crosspolymer-11 (0.40%) — were evaluated as sole stabilisers in the absence of Cetearyl Alcohol. For Xanthan Gum was preferred not to exceed 0.15% concentration since it is not recommended in standard cosmetic formulation for pleasant texture.

4.5.1. Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate

The main physicochemical parameters of Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate evaluated for Series 5 are presented in Table 26.

Table 26: Physicochemical results for Series 5 on Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate

Trial	Oil phase	Stabilisers	Centrifuge	pH t₂₄	Spindle	Viscosity t₀ (2.5rpm)	Viscosity t₂₄ (2.5rpm)	Micro
17	Mix 20%	Xanthan Gum 0.15%	creaming ~50%	6.4	S01	N.M.	N.M.	2 - 10 µm
18	Mix 20%	Hydroxyethylcellulose 0.40%	creaming ~40%	6.5	S01	1,520	1,808	2 - 5 µm
19	Mix 20%	Polyacrylate Crosspolymer-11 0.40%	No phase separation	6.1	S02	8,560	8,944	1 – 3 µm

Note: “Mix 20%” indicates the total oil-phase concentration in the formulation. The oil phase contains Caprylic/Capric Triglyceride, Coco-Caprylate/Caprates and Hydrogenated Polydecene in

equal proportions (approximately 6.7% each). XG = Xanthan Gum; CA = Cetearyl Alcohol; N.M. = Not Measurable.

Xanthan Gum alone at 0.15% (Trial 17) did not stabilise the emulsion and creamed at approximately 50% under centrifugation, with too low viscosity to be measurable. Hydroxyethylcellulose at 0.40% (Trial 18) offered an improvement, with narrow droplets (2–5 μm) — but the centrifuge outcome remained at ~40% creaming. The cellulose derivative builds a hydrogel matrix that retards droplet sedimentation but does not anchor droplets sufficiently. Polyacrylate Crosspolymer-11 at 0.40% (Trial 19) produced the best result: viscosity reached 8,944 mPa·s at t_{24} , with perfect centrifuge stability and the finest droplets observed for this emulsifier across the entire programme (1–3 μm). Figure 10 shows the appearance of the three emulsion samples formulated with Sorbitan Laurate, Polyglyceryl-4 Laurate, and Dilauryl Citrate after centrifugation.

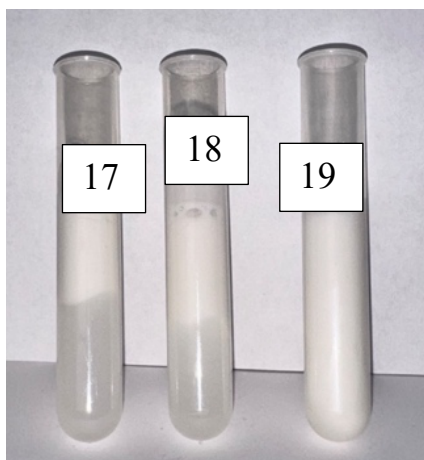


Figure 10: Appearance of the three emulsion samples formulated with Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate after centrifugation.

4.5.2. C14-22 Alcohols / C12-20 Alkyl Glucoside

Table 27 summarizes the physicochemical results of C14-22 Alcohols / C12-20 Alkyl Glucoside obtained for Series 5.

Table 27: Physicochemical results for Series 5 of C14-22 Alcohols / C12-20 Alkyl Glucoside

Trial	Oil phase	Stabilisers	Centrifuge	pH t ₂₄	Spindle	Viscosity t ₀ (2.5rpm)	Viscosity t ₂₄ (2.5rpm)	Micro
17	Mix 20%	Xanthan Gum 0.15%	Creaming ~50%	7.3	S01	13,000	10,880	2 – 10 µm
18	Mix 20%	Hydroxyethylcellulose 0.40%	Acceptable	7.4	S01	20,400	16,720	5 – 10 µm
19	Mix 20%	Polyacrylate Crosspolymer-11 0.40%	Light creaming	6.6	S02	44,080	43,280	1 – 5 µm

Note: “Mix 20%” indicates the total oil-phase concentration in the formulation. The oil phase contains Caprylic/Capric Triglyceride, Coco-Caprylate/Caprates and Hydrogenated Polydecene in equal proportions (approximately 6.7% each). XG = Xanthan Gum; CA = Cetearyl Alcohol.

Xanthan Gum (Trial 17) provided 10,880 mPa·s at t₂₄ with ~50% creaming — indicating that without fatty alcohol to build the co-crystalline phase, the lamellar network of the emulsifier alone is prone to rehydration and network erosion. Hydroxyethylcellulose (Trial 18) showed a time-dependent viscosity reduction (from 20,400 to 16,720 mPa·s) consistent with network relaxation. Polyacrylate Crosspolymer-11 (Trial 19) achieved the highest viscosity in this series (44,080 mPa·s, stable at t₂₄) with the smallest droplets (1–5 µm) and only slight creaming. However, the persistence of creaming confirms that Cetearyl Alcohol serves not merely as a rheological aid but as a structural co-component essential for lamellar network formation at the oil–water interface — a role that cannot be replicated by any water-phase polymer alone. The microscopic appearance of Trials 18 and 19 was also evaluated, as shown in Figure 11.

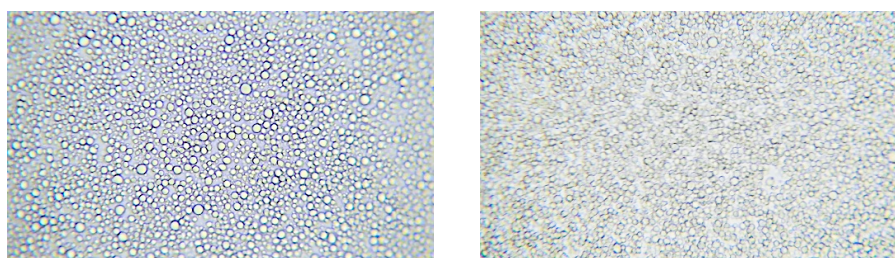


Figure 11: Microscopy picture of Trial 18 (on the left) and 19 (on the right) of C14-22 Alcohols / C12-20 Alkyl Glucoside

4.5.3. Sodium Starch Octenylsuccinate

The physicochemical results of Sodium Starch Octenylsuccinate in Series 5 are reported in Table 28.

Table 28: Physicochemical results for Series 5 of Sodium Starch Octenylsuccinate

Trial	Oil phase	Stabilisers	Centrifuge	pH t ₂₄	Spindle	Viscosity t ₀ (2.5rpm)	Viscosity t ₂₄ (2.5rpm)	Micro
15	Mix 20%	Xanthan Gum 0.15%	Light sedimentation	5.7	S06	167,000	220,000	2 – 20 μ m
16	Mix 20%	Hydroxyethylcellulose 0.40%	No phase separation	5.8	S06	209,000	168,000	5 – 30 μ m
17	Mix 20%	Polyacrylate Crosspolymer-11 0.40%	No phase separation	5.7	S06	245,000	333,000	1 – 10 μ m

Note: “Mix 20%” indicates the total oil-phase concentration in the formulation. The oil phase contains Caprylic/Capric Triglyceride, Coco-Caprylate/Caprate and Hydrogenated Polydecene in equal proportions (approximately 6.7% each). XG = Xanthan Gum; CA = Cetearyl Alcohol; N.M. = Not Measurable.

The modified starch maintained the characteristic ultra-high viscosity observed for Pickering systems across all polymer combinations. Xanthan Gum (Trial 15) produced a viscosity of 220,000 mPa·s at t₂₄ but generated a sedimented phase at the base of the centrifuge tube, suggesting localised structural instability despite the high bulk viscosity. Microscopic examination revealed a dense population of well-dispersed droplets with no clear evidence of extensive coalescence. Figure 12 shows the microscopic appearance of Trial 17 formulated with Sodium Starch Octenylsuccinate.

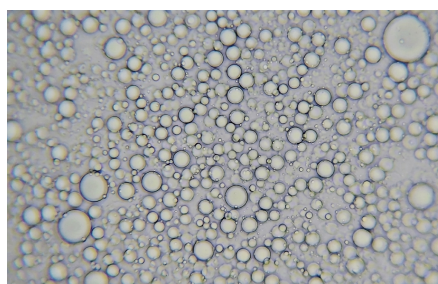


Figure 12: Microscopy picture of Trial 17 of Sodium Starch Octenylsuccinate

Hydroxyethylcellulose (Trial 16) yielded a stable system with a perfect centrifuge result and moderate droplet size (5–30 μm). Polyacrylate Crosspolymer-11 (Trial 17) achieved the highest viscosity recorded in the entire experimental programme, increasing to 333,000 $\text{mPa}\cdot\text{s}$ at t_{24} , while maintaining perfect centrifuge stability and a fine droplet distribution (1–10 μm).

4.6. Series 6 — Method Study

This series was designed to evaluate the influence of the emulsification process on the performance of the selected emulsifiers. In the modified direct emulsification process, an amount of water is added after emulsion formation (Trials 20). In the Lin method, the aqueous phase is introduced progressively into the oil phase under controlled shear, without the addition of polymers (Trials 21). The study aimed to assess how each emulsifier responds to different processing conditions in terms of emulsion stability, viscosity development, and microstructural characteristics.

4.6.1. Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate

Table 29 summarizes the physicochemical results obtained for Series 6 formulated with Sorbitan Laurate, Polyglyceryl-4 Laurate, and Dilauryl Citrate.

Table 29: Physicochemical results for Series 6 on Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate

Trial	Oil phase	Stabilisers	Centrifuge	pH t_{24}	Spindle	Viscosity t_0 (2.5rpm)	Viscosity t_{24} (2.5rpm)	Microscopy
20	Mix 20%	XG 0.15% + CA 1%	creaming	6.3	S01	708	748	3 - 5 μm
21	Mix 20%	XG 0.15% + CA 1%	creaming	6.5	S01	N.M.	N.M.	5 - 20 μm

Note: “Mix 20%” indicates the total oil-phase concentration in the formulation. The oil phase contains Caprylic/Capric Triglyceride, Coco-Caprylate/Caprate and Hydrogenated Polydecene in

equal proportions (approximately 6.7% each). XG = Xanthan Gum; CA = Cetearyl Alcohol; N.M. = Not Measurable.

In this series, the emulsifier system showed a clear dependence on the emulsification process, with a marked divergence in performance between the two investigated methods. Trial 20, performed using the modified direct emulsification process, resulted in a more structured system, visible by the comparison between microscopy pictures with Trial 3. Although a certain degree of instability was still observed in centrifugation tests (creaming), microscopy revealed a significant improvement compared to the reference formulation, with a finer and more uniform droplet distribution (3–5 μm), as it is shown in Figure 13. This suggests that the post-emulsification water addition step may have contributed to a more effective organization of the interfacial layer, improving droplet formation and initial stabilization. A comparison of the microscopic appearance of Trials 20 and 3 is presented in Figure 13.

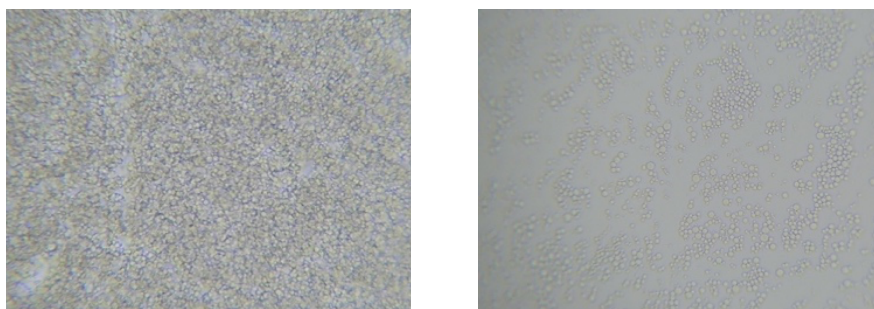


Figure 13: Comparison of microscopy pictures of Trial 20 and Trial 3 of Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate

In contrast, Trial 21, prepared using the Lin progressive emulsification method, showed a complete loss of functional performance. The system was not analytically characterisable in terms of viscosity and exhibited creaming upon centrifugation. From a microstructural perspective, a broader and less controlled droplet distribution (5–20 μm) was observed, indicating inefficient droplet breakup and poor stabilization under progressive water incorporation.

4.6.2. C14-22 Alcohols / C12-20 Alkyl Glucoside

The physicochemical characterization of Series 6 formulated with C14-22 Alcohols / C12-20 Alkyl Glucoside is reported in Table 30.

Table 30: Physicochemical results for Series 6 of C14-22 Alcohols / C12-20 Alkyl Glucoside

Trial	Oil phase	Stabilisers	Centrifuge	pH t₂₄	Spindle	Viscosity t₀ (2.5rpm)	Viscosity t₂₄ (2.5rpm)	Microscopy
20	Mix 20%	XG 0.15% + CA 1%	Creaming	7.2	S03	9,280	20,920	5 – 10 μm
21	Mix 20%	XG 0.15% + CA 1%	Separated	7.2	S01	944	Separated	Separated

Note: “Mix 20%” indicates the total oil-phase concentration in the formulation. The oil phase contains Caprylic/Capric Triglyceride, Coco-Caprylate/Caprate and Hydrogenated Polydecene in equal proportions (approximately 6.7% each). XG = Xanthan Gum; CA = Cetearyl Alcohol; N.M. = Not Measurable.

The emulsifier system based on C14-22 Alcohols / C12-20 Alkyl Glucoside showed a generally higher baseline performance and a more pronounced response to changes in processing conditions. In Trial 20, carried out using the modified direct emulsification process, the formulation exhibited a strong improvement compared to the reference condition, particularly in terms of rheological behavior. Viscosity increased from 14,400 (Trial 3) to 20,920 mPa·s (Trial 20) at t₂₄. Microscopically, the system maintained a fine droplet distribution (5–10 μm) but was more uniform compared to 3–15 μm in Trial 3, suggesting that the modified process enhanced emulsification efficiency and network formation. However, despite these positive features, creaming was still observed under centrifugation, indicating that the system remained only partially resistant to stress conditions. The microscopic characteristics of Trials 20 and 3 were compared, as illustrated in Figure 14.

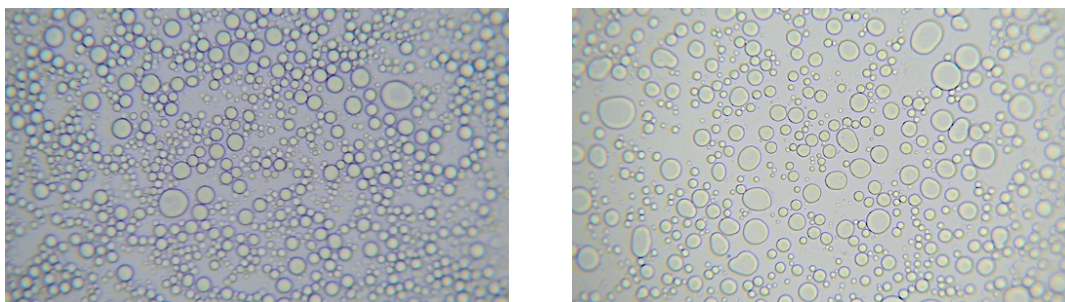


Figure 14: Comparison of microscopy pictures of Trial 20 and Trial 3 of C14-22 Alcohols / C12-20 Alkyl Glucoside

In contrast, Trial 21 resulted in a complete collapse of the emulsion structure. Both rheological and microstructural analyses confirmed full instability, with separation occurring and no measurable or meaningful viscosity development.

4.7. Series 7 — Inorganic Pigments Study

Inorganic, non-coated pigments (iron oxides and titanium dioxide, combined 3.78% w/w) were incorporated into emulsions prepared with two of the three emulsifying systems, with 4% of Polyglyceryl and APG emulsifier, and 5% of modified starch.

The alkyl glucoside-based emulsifier was therefore excluded from the analysis, following immediate phase separation upon pigment addition in preliminary trials. This instability is attributable to electrostatic incompatibility: inorganic pigment particles carry surface charges that interact with the lamellar structures formed by this system, disrupting interfacial organisation and precipitating coalescence. The microscopic appearance observed for Trial 18 is presented in Figure 15.

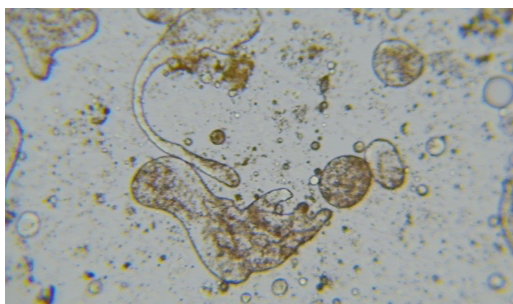


Figure 15: Microscopy picture of Trial 18 of C14-22 Alcohols / C12-20 Alkyl Glucoside

4.7.1. Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate

The physicochemical characterization of Series 7 is presented in Table 31.

Table 31: Physicochemical results for Series 7 on Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate

Trial	Oil phase	Stabilisers	Centrifuge	pH t ₂₄	Spindle	Viscosity t ₀ (2.5rpm)	Viscosity t ₂₄ (2.5rpm)	Microscopy
22	Mix 20%	XG 0.15% + CA 1%	Creaming	7.1	S03	1,460	1,548	2 – 8 µm

Note: “Mix 20%” indicates the total oil-phase concentration in the formulation. The oil phase contains Caprylic/Capric Triglyceride, Coco-Caprylate/Caprate and Hydrogenated Polydecene in equal proportions (approximately 6.7% each). XG = Xanthan Gum; CA = Cetearyl Alcohol.

The ester blend (4% concentration, Xanthan Gum + Cetearyl Alcohol) maintained acceptable physical parameters in the pigmented system, with a centrifuge outcome limited to creaming and a droplet size of 2–8 µm with uniform pigment distribution. It showed good compatibility between this emulsifier and the pigments.

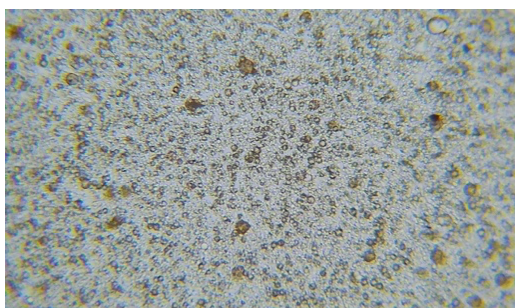


Figure 16: Microscopy picture of Trial 22 of Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate

4.7.2. Sodium Starch Octenylsuccinate

The physicochemical properties of Series 7 were evaluated, and the corresponding results are reported in Table 32.

Table 32: Physicochemical results for Series 7 of Sodium Starch Octenylsuccinate

Trial	Oil phase	Stabilisers	Centrifuge	pH t ₂₄	Spindle	Viscosity t ₀ (2.5rpm)	Viscosity t ₂₄ (2.5rpm)	Microscopy
18	Mix 20%	XG 0.15% + CA 1%	No phase separation	6.3	S04	42,640	31,840	5 – 20 µm

Note: “Mix 20%” indicates the total oil-phase concentration in the formulation. The oil phase contains Caprylic/Capric Triglyceride, Coco-Caprylate/Caprate and Hydrogenated Polydecene in equal proportions (approximately 6.7% each). XG = Xanthan Gum; CA = Cetearyl Alcohol.

The modified starch at 5% concentration also achieved satisfactory stability, with perfect centrifuge resistance and a droplet size distribution of 5–20 µm. However, during the sensory assessment, the emulsion appeared less stable, as phase separation was visually evident, with the oil phase tending to migrate out of the aqueous matrix. Microscopic analysis was also performed on Trial 18, as illustrated in Figure 17.

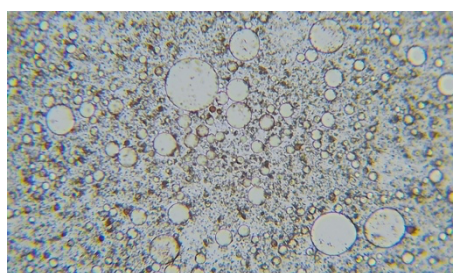


Figure 17: Microscopy picture of Trial 18 of Sodium Starch Octenylsuccinate

4.8. Overall Sensory

4.8.1. Emulsifier Comparison

The three emulsifying systems were evaluated by a trained panel of five evaluators applying 0.06 g of each formulation over a standardized 5×5 cm skin area, using seven texture attributes on a 0–10 numerical scale. Results are reported as mean panel scores. Table 33 presents the mean sensory scores obtained for the three emulsifying systems across the evaluated texture attributes.

Table 33: Mean sensory scores ($n = 5$, scale 0–10) for the three emulsifying systems across texture attributes

Parameter	Ester-Based	APG	Modified Starch
Pickup	3.0	7.0	7.8
Thickness	3.0	6.6	6.8
Spreadability	7.9	6.8	6.9
Soaping Effect	2.2	7.5	3.2
Absorption Rate	5.8	4.2	6.5
Shine Effect	5.8	7.4	4.0
Residual Amount	5.4	7.1	3.6

The sensory profiles reveal distinctly differentiated fingerprints. The ester blend is characterised by low pickup (3.0) and low thickness (3.0), consistent with a light, fluid texture that does not feel heavy on initial contact, combined with the highest spreadability of the three systems (7.9) and the lowest soaping effect (2.2). The white cast is minimised for this emulsifier due to the balanced HLB of its component mixture and the moderate interfacial organisation of the film. Absorption rate is moderate (5.8), and shine (5.8) and residual amount (5.4) indicate a light to medium after-feel. The panel descriptors 'silky' and 'cushion' confirm the non-greasy, cushioning character.

The alkyl glucoside system displays the highest pickup (7.0), thickness (6.6), shine (7.4), and residual amount (7.1) of the three systems, consistent with the rich, occlusive texture expected from a lamellar liquid-crystal emulsion forming a persistent lipid film on the skin. The high white cast (7.5) is a recognised limitation of long-chain fatty alcohol systems: Cetearyl Alcohol in both the emulsifier and the stabilizer contributes a white, soap-like film upon mechanical blending with skin. The lower absorption rate (4.2) further reflects the occlusive character of the film. Panel descriptors — 'oily', 'greasy', 'velvet' — capture the dual character of richness and drag appreciated in nourishing formulations but limiting in fast-absorbing products.

The modified starch shows a balanced profile with high pickup (7.8) and thickness (6.8), good spreadability (6.9), low white cast (3.2), and — most distinctively — the lowest residual amount (3.6) and high absorption rate (6.5). These attributes correspond

to the Pickering emulsion character: the thin polymer interfacial film breaks down rapidly upon skin contact, releasing oil quickly without leaving a prolonged coating. Panel descriptors ('velvet', 'soft touch', 'silky') reflect the clean, powdery after-feel that is a hallmark of starch-based emulsifiers and is particularly valued in lightweight skincare.

To facilitate visual comparison of the sensory fingerprints generated by the three emulsifier systems, the panel scores are summarised in the radar chart shown in Figure 18.

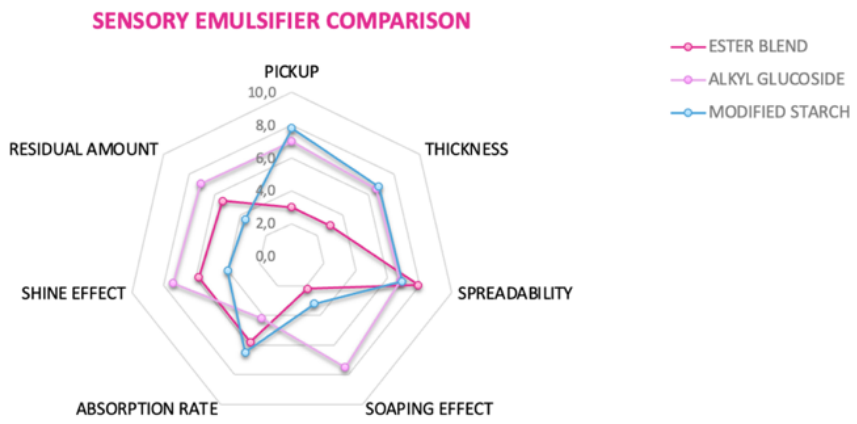


Figure 18: Sensory fingerprints of the three emulsifier systems evaluated by the panel

4.8.2. Pigments Emulsifier Comparison

The two stable systems were evaluated by a trained sensory panel (n = 5) on six attributes relevant to colour cosmetic performance, as it is summarized on Table 34.

Table 34: Mean sensory evaluation scores for pigmented emulsions (Series 7), panel of five evaluators, scale 0–10.

Parameter	Ester-Based	Modified Starch
Spreadability	8.2	7.9
Mattifying Effect	7.0	3.8
Color Homogeneity	7.3	1.9
Coverage	6.3	2.2
Blendability	7.6	2.6
Residual Amount	5.8	2.4

The ester blend outperformed the modified starch across all colour-specific attributes. Mattifying effect (7.0 vs 3.8) and color homogeneity (7.3 vs 1.9) scores were particularly divergent, indicating that the ester blend distributes pigments uniformly and reduces skin gloss effectively. Coverage (6.3 vs 2.2) and blendability (7.6 vs 2.6) were substantially higher for the ester blend, consistent with a finer, more homogeneous pigment-emulsion matrix. Spreadability was comparable (8.2 vs 7.9). The low residual amount for the modified starch (2.4 vs 5.8) indicates rapid skin absorption without pigment transfer — which, while desirable in moisturising products, limits cosmetic efficacy in pigmented formulations where surface-level coverage is the functional endpoint.

In Figure 19, the radar chart of these two emulsions:

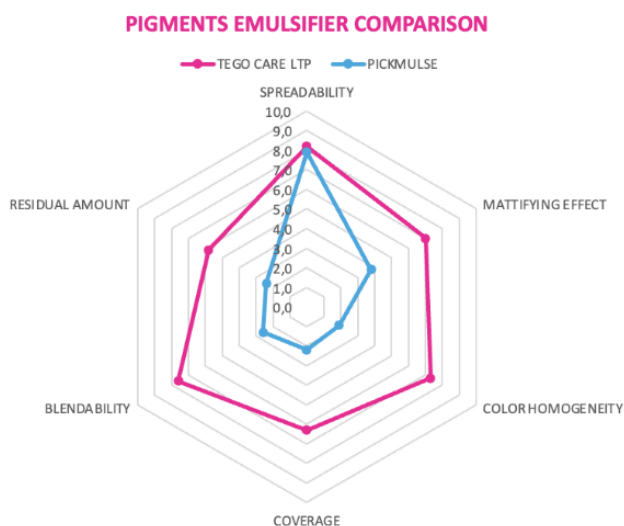


Figure 19: Sensory fingerprints of the two coloured emulsions evaluated by the panel

4.9. Three-Month Stability Study under Ambient Storage

The screening campaign described in Series 1–7 relied on physicochemical readings collected at preparation (t_0) and after twenty-four hours (t_{24}), in combination with centrifugation, an accelerated test designed to rapidly discriminate between

formulation variables rather than to predict shelf life under realistic storage conditions. To complement this short-term dataset with a more stringent assessment of physical stability, the binary stabiliser system identified in Trial 3 of Series 1 for each of the three emulsifying systems (Xanthan Gum 0.15% combined with Cetearyl Alcohol 1%) was monitored under ambient storage over three months, with pH and viscosity readings recorded at t_{24} , one month, two months, and three months. This longer observation window allows the identification of slow degradation phenomena, such as delayed coalescence, Ostwald ripening, or progressive network reorganisation, that are not captured by accelerated testing alone.

4.9.1. Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate

The results recorded over the three-month observation period are summarised in Table 35:

Table 35: Three-month stability data for Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate (Trial 3, Series 1)

Time point	Visual appearance	pH	Spindle	Viscosity (2.5/5/10 rpm, mPa·s)
t_{24h}	Homogeneous	6.7	S01	916 / 580 / 363
1 month	Homogeneous	6.3	S01	928 / 616 / 388
2 months	Homogeneous	6.3	S01	928 / 632 / 388
3 months	Phase separation	—	—	—

Over the first two months, the formulation displayed an apparently favourable trend: pH decreased moderately from 6.7 to 6.3 and viscosity at 2.5 rpm increased slightly from 916 to 928 mPa·s, a pattern consistent with progressive consolidation of the Xanthan Gum–Cetearyl Alcohol network and slow equilibration of the interfacial film. The strength of this system lies in this apparent short- and medium-term robustness: the formulation withstood the centrifugal stress applied during screening (Trial 3, Series 1) and remained visually homogeneous, with stable rheological readings, for a period that would ordinarily be considered sufficient to validate a prototype. However,

this strength is offset by a critical weakness that only emerged beyond the two-month mark: by the third month, the emulsion had undergone complete phase separation. This delayed failure indicates that the interfacial film supported by this low-HLB sorbitan ester blend, while adequate to resist short-term mechanical and centrifugal stress, lacks the long-term colloidal resilience required for extended shelf life.

4.9.2. C14-22 Alcohols, C12-20 Alkyl Glucoside

The results recorded over the three-month observation period are summarised in Table 36:

Table 36: Three-month stability data for C14-22 Alcohols, C12-20 Alkyl Glucoside (Trial 3, Series 1)

Time point	Visual appearance	pH	Spindle	Viscosity (2.5/5/10 rpm, mPa·s)
t_{24h}	Homogeneous	7.4	S03	14,400 / 7,920 / 4,060
1 month	Homogeneous	7.1	S03	14,400 / 7,600 / 4,160
2 months	Homogeneous	7.2	S03	13,880 / 7,560 / 4,040
3 months	Homogeneous	7.2	S03	12,600 / 6,800 / 3,890

This system displayed the most robust long-term behaviour of the three baseline emulsions. The pH remained essentially constant throughout the study, drifting only marginally from 7.4 to 7.2, while viscosity decreased gradually and predictably across the full three-month span, from 14,400 to 12,600 mPa·s at 2.5 rpm (a reduction of approximately 12.5%), with the relative ranking between the three measured shear rates preserved at every time point. No creaming, coalescence, or phase separation was observed at any stage. The principal strength of this formulation lies in its stabilising mechanism: the lamellar gel network formed by the alkyl glucoside emulsifier together with the co-emulsifying fatty alcohols continues to mature and reinforce the continuous phase well beyond the initial 24-hour observation window, conferring genuine long-term thermodynamic and kinetic stability rather than a transient rheological plateau. The slow, monotonic decline in viscosity is consistent with gradual crystal perfection and minor water release from the interdigitated bilayer structure, a physically benign process that does not compromise emulsion integrity. The only point of relative

weakness is the cumulative loss of the initial viscosity, which, if extrapolated beyond the three-month window, could eventually translate into a perceptible softening of texture in a finished product; periodic monitoring beyond this study would therefore be advisable to confirm a true asymptotic plateau rather than continued gradual decline.

4.9.3. Sodium Starch Octenylsuccinate

The results recorded over the three-month observation period are summarised in Table 37:

Table 37: Three-month stability data for Sodium Starch Octenylsuccinate (Trial 3, Series 1)

Time point	Visual appearance	pH	Spindle	Viscosity (2.5/5/10 rpm, mPa·s)
t_{24h}	Homogeneous	5.8	S05	68,800 / 40,800 / 23,440
1 month	Homogeneous	5.8	S05	48,000 / 28,800 / 17,560
2 months	Homogeneous	5.6	S04	42,080 / 25,120 / 15,200
3 months	Homogeneous	5.5	S04	27,920 / 17,080 / 10,400

The modified-starch system presented the most ambiguous long-term profile of the three. Its principal strength is the complete absence of macroscopic phase separation at any time point over the three months; this Pickering-type mechanism, unlike the interfacial films of the other two systems, does not rely on continuous-phase viscoelasticity alone and therefore remains effective even as the surrounding network evolves. However, this optical stability conceals a substantial underlying weakness: viscosity declined markedly and progressively throughout the study, from 68,800 mPa·s at t₂₄ to 27,920 mPa·s at three months, a reduction of approximately 59%, with the most pronounced drop occurring within the first month alone. This was accompanied by a parallel, more modest decrease in pH from 5.8 to 5.5. This combination of optical stability with pronounced rheological softening suggests that the Pickering particle layer at the droplet interface remains intact and continues to prevent coalescence, but that the secondary thickening network responsible for the very high initial consistency, likely arising from particle–particle interactions and partial swelling of starch granules in the continuous phase, is not stable over time.

4.9.4. Comparative Assessment

Taken together, the three-month dataset demonstrates that short-term physicochemical screening, while effective for ranking formulation variables and selecting stabiliser combinations, is not fully predictive of long-term shelf stability. Each emulsifying system, despite passing the initial centrifugation and t_{24} screen at the binary-stabiliser level, revealed a distinct long-term vulnerability that became apparent only beyond this window: the sorbitan ester system underwent delayed but complete phase separation between the second and third month, the alkyl polyglucoside system showed the closest behaviour to genuine long-term stability, with only a moderate and apparently self-limiting viscosity decline, and the modified-starch system retained visual integrity throughout but lost approximately 59% of its initial viscosity, exposing a structural weakness in its secondary thickening network rather than in its primary emulsifying mechanism.

4.10. Rationale for Product Development

The seven experimental series converge on a coherent and consistent characterisation of each emulsifying system's technical identity, enabling an evidence-based assignment to three distinct product typologies. The assignment of each emulsifier to a specific product format was not predetermined but emerged from the cumulative evidence of the seven experimental series. The key decision criteria were: (i) pigment compatibility, which immediately distinguished the ester blend from the other two systems; (ii) oil-phase tolerance, which favoured the alkyl glucoside system for high-lipid formats; and (iii) sensory profile, which directed the modified starch toward a lightweight, low-residue application. On this basis, the Sorbitan Laurate / Polyglyceryl-4 Laurate / Dilauryl Citrate blend is proposed for a tinted, pigment-compatible facial emulsion; the C14-22 Alcohols / C12-20 Alkyl Glucoside system for a rich, occlusive body cream; and Sodium Starch Octenylsuccinate for a lightweight, fast-absorbing

milky toner. The rationale for each assignment, together with the resulting formulation parameters, is presented in the following sections.

4.10.1. Anti-Pollution BB Cream: SL / PGL-4 Laurate / Dilauryl Citrate

The data from Series 1–7 collectively identify this system as the most suitable candidate for a tinted, lightweight facial emulsion. Series 1–4 established that the supplier-recommended 2% concentration is insufficient for robust stabilisation even when combined with Xanthan Gum and Cetearyl Alcohol (Trial 3), and that doubling the concentration to 4% markedly improves both droplet fineness and centrifuge behaviour (Series 4, Trials 12–16). This improved performance window was directly confirmed under conditions representative of the final product: in the pigmented system (Series 7, Trial 22 — 4% emulsifier, 20% oil phase, Xanthan Gum and Cetearyl Alcohol), the formulation produced a finely dispersed emulsion (2–8 μm) with a stable, and a centrifuge outcome limited to mild creaming due to low viscosity, with no coalescence — a profile well suited to a leave-on facial product that must remain uniformly spreadable over time. Beyond physical stability, this system showed excellent wettability of inorganic pigments, as confirmed by the superior Series 7 sensory scores for colour homogeneity (7.3) and blendability (7.6), both substantially higher than those recorded for the modified starch (Table 21). Taken together, these results support the selection of the 4% Sorbitan Laurate / Polyglyceryl-4 Laurate / Dilauryl Citrate system for the anti-pollution BB cream.

4.10.2. Anti Age Body Cream: C14-22 Alcohols / C12-20 Alkyl Glucoside

The alkyl glucoside system has intrinsic capacity to build lamellar liquid-crystal networks, making it uniquely suited for an emollient, barrier-reinforcing body cream. Series 4 demonstrated that doubling the concentration to 4% produced a marked

improvement in stability and structuring across the oil-load range tested: at 20% oil phase (Trial 14), the system reached perfect centrifuge stability and a narrow droplet distribution (2–10 μm); at 30% oil (Trial 16), the positive results confirm that this emulsifier tolerates substantially higher oil loads. This combination of high oil-phase tolerance and lamellar structuring is precisely what is required of a rich body emulsion. Sensory data reinforce this assignment: the high shine (7.4) and residual amount (7.1) scores, which would be limiting in a facial product, translate into a sustained emollient film that signals deep hydration in a body-care context, while the biomimetic lamellar structure offers a genuine functional benefit for dry or barrier-compromised skin. Processing parameters also matter for this system: Series 6 showed that the modified direct emulsification process improved both viscosity and droplet uniformity relative to the Series 1 reference. The modified direct process is therefore recommended for manufacturing, since progressive oil addition appears to disrupt the cooperative crystallisation mechanism on which the lamellar network depends. The final formulation accordingly retains Cetearyl Alcohol and incorporates a high oil phase (~32%) comprising shea butter, olive-derived lipid fractions, alkane-based emollients, and medium-chain triglycerides, with hydroxyethylcellulose included to reinforce continuous-phase structure.

4.10.3. Milky Toner: Sodium Starch Octenylsuccinate

The modified starch is a system capable of producing stable emulsions at low oil fractions (as little as 10%), while maintaining the lowest residual amount (3.6) and highest absorption rate (6.5) of the three emulsifiers. These attributes precisely match the requirements of a milky toner — a Korean skincare-inspired hybrid format positioned between a toner and an emulsion, characterised by an aqueous-dominant, rapid-absorbing texture that delivers a lipid phase without heaviness. Series 2 confirmed perfect centrifuge stability at 10% oil and the standard 5% emulsifier concentration (Trial 4), and Series 4 showed that, even when concentration was

reduced to 2.5%, the system retained acceptable — though not perfect — stability at both 10% and 20% oil (Trials 11–14), with 2.5% identified as a viable compromise when a lighter, less structured texture is prioritised over maximum physical robustness. Since the final toner formulation uses an even lower oil phase (~8%) than the lowest level tested in that series, the interfacial demand on the emulsifier is expected to be lower still, further supporting the choice of 2.5% for this application. It is worth noting that Series 7 demonstrated perfect centrifuge stability for the pigmented system at the standard 5% concentration (Trial 18), but the same trial showed visible oil migration during the sensory assessment — a limitation that, together with the comparatively weak colour-attribute scores recorded in Table 34, reinforces the decision to direct this emulsifier toward an unpigmented, low-oil format rather than the tinted BB cream. The velvety, silky sensory descriptors recorded by the panel (Table 33) align with the clean-finish, no-residue expectation of the milky-toner category.

CHAPTER 5 – PRODUCT DEVELOPMENT

Following the evaluation of the stability, rheological behaviour, sensory performance, and microstructural characteristics of the investigated emulsifier systems, this chapter addresses their application in finished product development. The formulation results were used to define suitable product concepts, with particular attention to the relationships among emulsion properties, intended use, dispensing system, and packaging design.

5.1. The packaging study

The transition from systematic trials to finished product required packaging solutions capable of preserving the stability achieved during formulation. For each of the three products, the dispensing system was selected as a functional extension of the texture and behaviour characterised in the previous chapters, while the overall packaging concept — pastel, iridescent glass with an embossed modular motif inspired by the geometry of hand-crocheted granny squares — was developed to support a youthful, design-conscious luxury positioning.

The anti-pollution BB cream, formulated as a fluid, lightweight emulsion with a fine, homogeneous pigment dispersion, was paired with a glass dropper closure. This format enables precise single-dose delivery for a fluid, tinted product and limits unnecessary exposure of the photoprotective and antioxidant actives to air. The packaging concept developed for the anti-pollution BB cream is presented in Figure 20.



Figure 20: Packaging concept developed for the anti-pollution BB cream (front, side, top views, and 3D representation)

The milky toner, the most fluid of the three formulations, was packaged in a glass bottle fitted with an orifice-reducer cap. By restricting flow rate and droplet size at the point of dispensing, this closure limits both product wastage and air ingress into the bottle — a relevant precaution for a low-viscosity, more delicate colloidal system — while the slow, controlled pour reinforces a ritualistic, premium gesture at the point of use. The packaging concept developed for the Milky Toner is presented in Figure 21.



Figure 21: Packaging concept developed for the Milky Toner (front, side, top views, and 3D representation)

The body cream, formulated as a noticeably thicker and more structured emulsion intended for higher-volume daily application, was matched to a pump-dispenser glass bottle. This format ensures consistent single-action dosing, minimizes hand-to-product contact and the associated risk of microbial contamination over the product's use life, and reduces waste relative to open jar formats.

Across all three products, glass was retained as the primary packaging material for its chemical inertness and impermeability to oxygen and moisture, properties of particular relevance for the more fluid, oxidation-sensitive formulations, while its weight and finish reinforce the premium positioning of the line. The shared embossed motif across formats translates the modular, handcrafted aesthetic of crochet textile work into the packaging language, indirectly echoing, at a conceptual level, the layered and combinatorial approach underlying the formulation work itself.

Nevertheless, the suitability of the selected packaging should be confirmed through appropriate packaging–formula compatibility studies, including assessing potential interactions between the formulation and the packaging material and their possible effects on product stability and quality throughout the intended shelf life. The proposed packaging design for the Body Cream is shown in Figure 22.



Figure 22: Packaging concept developed for the Body Cream (front, side, top views, and 3D representation)

5.2. BB Cream Anti-Pollution

The BB cream was designed as a tinted, oil-in-water emulsion combining light-to-medium pigment coverage with a protective, anti-pollution functional claim. The final formulation developed for the BB cream is reported in Table 38.

Table 38: Final formulation of BB cream

PHASE	INCI NAME	w/w %
A	Aqua	q.s. to 100
	Xanthan Gum	0.1-0.5
A1	Sodium Phytate	<0.5
	Glycerin	0.5-2
	Ectoin	<1
B	Caprylic/capric Triglyceride	5-10
	Coco-caprylate/Caprates	5-10
	Hydrogenated Polydecene	5-10
	Cetearyl Alcohol	0.5-2
	Sorbitan Laurate, Polyglyceryl-4 Laurate, Dilauryl Citrate	2-5
B1	CI 77891	2-5
	CI 77492	0.5-1
	CI 77499, CI 77491, CI 77492	<0.5
C	Ammonium Acryloyldimethyltaurate/VP Copolymer	<0.5
D	Propanediol, Aqua, Lespedeza Capitata Leaf/Stem Extract	0.5-1
E	Aqua, Propanediol, Camellia Japonica Flower Extract	0.5-1
F	Phenoxyethanol, Ethylhexylglycerin	0.5-1
G	Parfum	0.1-1
H	Lactic Acid	q.s.

5.2.1. Manufacturing Process

The BB cream was prepared through a conventional oil-in-water (O/W) emulsification process. Phase A was prepared by dispersing Xanthan Gum in water under mechanical stirring before at room temperature and after at 40°C. It was followed by the addition of the water-soluble ingredients of Phase A1 until complete dissolution was achieved. Separately, the oil phase (Phase B), containing the emollients, fatty alcohol, and emulsifier system, was heated to 60°C. The aqueous phase was heated to the same temperature. The pigment blend (Phase B1) was prepared by weighing each pigment

with a 10% extra and was then ground together. It was subsequently weighed to the right final amount and incorporated into Phase B under continuous stirring to ensure homogeneous colour distribution. After emulsification under a turbo emulsifier, the emulsion was cooled under moderate agitation. The Ammonium Acryloyldimethyltaurate/VP Copolymer was incorporated and swollen into the emulsion to guarantee a more stable product. The remaining ingredients (Phases D–G) were added sequentially below 40°C. The pH was adjusted if necessary, and the product was mixed until complete homogenization.

The emulsification temperature was intentionally reduced from 75 to 60°C, as preliminary formulation trials demonstrated that higher temperatures negatively affected the performance of the emulsifier system, resulting in poor emulsion formation and reduced physical stability. The lower processing temperature promoted the formation of a stable and homogeneous emulsion.

5.2.2. Ingredient Selection and Formulation Design

Colour was incorporated through a trichromatic inorganic pigment system comprising titanium dioxide (CI 77891), iron oxide yellow (CI 77492), and iron oxide brown (CI 77499, CI 77491, CI 77492), each dispersed as pre-wetted slurries in the oil phase.

The anti-pollution functional claim of the BB cream was built into the formulation by selecting and combining three functional actives that target distinct aspects of pollution-induced skin damage. The rationale for this multi-target approach reflects the current understanding of pollution-related cutaneous stress, which involves oxidative radical generation and disruption of circadian skin homeostasis and therefore cannot be effectively addressed by a single-mechanism ingredient.

Ectoin is a *cyclo amino acid derivative* produced naturally as an extremolyte by halophilic and thermophilic microorganisms of the genus *Halomonas elongata* and related species that inhabit environments of extreme osmotic stress. As a compatible

solute, ectoin accumulates intracellularly at high concentrations without disrupting enzyme function, thereby stabilising macromolecular structures by forming preferential hydration shells around proteins and lipid membranes. At the cellular level, ectoin has been shown to stabilise lipid bilayer fluidity, reduce membrane permeability to reactive oxygen species, and protect heat-shock protein expression under UV, particulate, and cytokine stress conditions. In cosmetic formulation at concentrations between 0.05% and 0.20%, published in vitro and clinical studies have demonstrated that ectoin reduces interleukin-1 β (IL-1 β) and tumour necrosis factor- α (TNF- α) release in keratinocyte cultures exposed to fine particulate matter (PM_{2.5}) and diesel exhaust particles, and attenuates the transient receptor potential ankyrin-1 (TRPA-1)-mediated inflammatory cascade activated by polycyclic aromatic hydrocarbon (PAH) adsorption onto the skin surface.¹⁶

The *Lespedeza Capitata* leaf/stem extract addresses a dimension of anti-pollution protection that has emerged more recently in the cosmetic ingredients literature: the disruption of the epidermal circadian clock by both particulate pollution and high-energy visible (blue) light. *Lespedeza capitata* (bush clover) is a temperate legume whose aerial parts are rich in flavonoid glycosides, isoflavones, and condensed tannins that interact with the clock gene network at the level of the BMAL1/CLOCK transcription factor complex. The epidermis maintains an autonomous circadian oscillator governing keratinocyte proliferation, desquamation, DNA repair, and antioxidant enzyme expression (catalase, superoxide dismutase, glutathione peroxidase) in a time-dependent manner. Pollution-derived aryl hydrocarbon receptor (AhR) activation has been shown to phase-shift the epidermal circadian clock by cross-talking with the CLOCK–BMAL1 transcription complex, resulting in diminished nocturnal antioxidant capacity and impaired diurnal barrier repair. The flavonoid-rich fraction of *Lespedeza capitata* extract has been reported to mitigate this AhR-mediated clock disruption in in vitro keratinocyte models, supporting circadian resilience of the skin against repeated urban pollution exposure. At the dosage employed, the extract

contributes both direct antioxidant activity via its phenolic content and a chronobiological regulatory function targeting the epidermal oscillator.^{17,18}

The Camellia Japonica flower contributes a further antioxidant and soothing dimension to the anti-pollution complex. The flowers of *Camellia japonica* accumulate a characteristic profile of polyphenolic secondary metabolites including catechins, gallic acid derivatives, and anthocyanin precursors with demonstrated radical-scavenging activity against superoxide anion, hydroxyl radical, and singlet oxygen species. These reactive oxygen species are generated by the photochemical reaction of urban particulate matter — particularly its transition metal and quinone fraction — with epidermal biomolecules upon skin contact, and their neutralisation by a phenolic antioxidant is complementary to, rather than redundant with, the membrane-stabilising mechanism of ectoin. Published in vitro data support the ability of camellia flower polyphenols to reduce NADPH oxidase activation and to inhibit matrix metalloproteinase-1 (MMP-1) expression in UVA-exposed fibroblasts, providing a mechanistic basis for its combined antioxidant and soothing activity.¹⁹

The combination of Ectoin, Lespedeza Capitata extract, and Camellia Japonica extract therefore addresses the anti-pollution claim through three complementary mechanisms: (i) membrane and protein stabilisation under osmotic and oxidative stress (Ectoin); (ii) circadian clock protection and AhR-pathway modulation (Lespedeza Capitata); and (iii) direct radical neutralisation and MMP inhibition (Camellia Japonica). This multi-target approach is consistent with current expert-consensus guidance on the formulation of credible anti-pollution functional claims in leave-on facial products.

5.3. Anti-Age Body Cream

The body cream was developed as a richer, structuring emulsion intended for daily anti-age body care, combining a substantial emollient and occlusive load with a defined

cosmeceutical actives package. The composition of the final Body Cream formulation is presented in Table 39.

Table 39: Final formulation of Body Cream

PHASE	INCI NAME	w/w %
A	Aqua	q.s. to 100
	Xanthan Gum	0.1-0.5
A1	Hydroxyethylcellulose	0.5-1
A2	Glycerin	2-5
	Sodium Hyaluronate	<1
A3	Sodium Phytate	<0.5
	Allantoin	<1
	Niacinamide	1-5
	Chlorphenesin	<0.3
B	Caprylic/capric Triglyceride	5-10
	Coco-caprylate/Caprates	5-10
	C13-15 Alkane	2-5
	Butyrospermum Parkii Butter	2-5
	Hydrogenated Ethylhexyl Olivates, Hydrogenated Olive Oil Unsaponifiables	2-5
	Caprylic/Capric/Myristic/Stearic Triglyceride	2-5
	C14-22 Alcohols, C12-20 Alkyl Glucoside	2-5
	Cetearyl Alcohol	0.5-1
C	Aqua	q.s.
D	Phenoxyethanol, Ethylhexylglycerin	0.5-1
E	Glycerin, Aqua, Hydroxypropyl Cyclodextrin, Palmitoyl Tripeptide-38	0.5-2
F	Lecithin, Tocopherol, Ascorbyl Palmitate, Citric Acid	0.5-2
G	Gold Pearl	<1
H	Parfum	<1
I	Lactic Acid, Aqua	q.s.

5.3.1. Manufacturing Process

The anti-age body cream was prepared using a modified standard oil-in-water emulsification process. The aqueous phase was prepared by dispersing Xanthan Gum before at room temperature and after heating at 40°C. Subsequently, Hydroxyethylcellulose was dispersed in water at 40°C and after heating at 75°C. To

complete the aqueous phase, Glycerin, Sodium Hyaluronate, Sodium Phytate, Allantoin, Niacinamide, and Chlorphenesin were added under magnetic stirring. In parallel, the oil phase was prepared by combining the Emollients, Shea Butter, Olive-Derived Lipids, Triglycerides, Emulsifier, and Cetearyl Alcohol. Both phases were heated separately to 75°C and subsequently emulsified under a turbo emulsifier. After the formation of the emulsion, the cooling water (phase C) was added, and the system was cooled to 30°C under continuous stirring. The remaining ingredients, including the preservative system, peptide complex, antioxidant blend, pearl pigment, fragrance, and pH adjuster, were added sequentially.

The emulsification temperature of 75°C was selected to ensure complete melting and homogeneous incorporation of the lipidic components, particularly the butter, structured triglycerides, and fatty alcohols, thereby promoting the formation of a stable cream with the desired consistency and sensory properties.

5.3.2. Ingredient Selection and Formulation Design

The emollient system of the body cream was designed to be both generous in quantity and diverse in lipid polarity. The oil phase combines caprylic/capric triglyceride, cococaprylate/caprate, C13-15 alkane, shea butter, a hydrogenated ethylhexyl olivate/hydrogenated olive oil unsaponifiables blend, and caprylic/capric/myristic/stearic triglyceride, together with cetearyl alcohol as a co-emulsifying wax. This multi-emollient architecture covers all relevant lipid function classes: the medium-chain triglycerides and alkyl esters provide spreading and sensory lightness; the alkane provides a dry-touch silicone-alternative that does not oxidise; the shea butter and olive unsaponifiables provide occlusion and lipid replenishment; and the mixed triglyceride wax contributes solid-phase structuring to the overall cream rheology.

The actives introduced are Allantoin, Niacinamide and a Matrixyl, a type of signal peptide complex, together with a tocopherol-based antioxidant complex.

Palmitoyl Tripeptide-38 is a fatty acid-conjugated synthetic signal peptide composed of the amino acid sequence lysine–threonine–threonine–lysine–serine (KTTKTS), palmitoylated at the N-terminal lysine residue. This structural modification confers amphiphilic character, enabling the peptide to partition at lipid-membrane interfaces and to resist proteolytic degradation while maintaining diffusibility through the stratum corneum lipid matrix. The KTTKTS sequence derives from the natural collagen $\alpha 2$ chain and, in its palmitoylated form, has been shown to function as a matrikine — a collagen-derived messenger fragment that signals dermal fibroblasts to upregulate extracellular matrix (ECM) synthesis. Specifically, Palmitoyl Tripeptide-38 has been reported in in vitro fibroblast culture studies to stimulate the synthesis of six ECM components simultaneously: collagen I, collagen III, collagen IV, fibronectin, hyaluronic acid, and laminin-5. This multi-target ECM stimulation is mechanistically superior to single-matrix-component approaches, as the age-related deterioration of the dermal ECM involves the concomitant loss of structural collagen (types I and III), basement membrane organisation (type IV collagen and laminin), and fibroblast–matrix adhesion (fibronectin). The cyclodextrin vehicle (hydroxypropyl cyclodextrin) in the commercial delivery system encapsulates the palmitoyl tripeptide in a cavity-forming oligosaccharide complex, protecting the active from oxidation and hydrolysis during storage and improving its bioavailability at the stratum corneum–dermis interface by facilitating desorption from the delivery vehicle.²⁰

Niacinamide (nicotinamide, the amide form of vitamin B3) is one of the most extensively characterised cosmetic actives in the published dermatological and cosmetic science literature. Its mechanisms of action relevant to an anti-age body care positioning are multiple and well-supported by clinical evidence: (i) niacinamide serves as a precursor for the co-enzymes nicotinamide adenine dinucleotide (NAD⁺) and nicotinamide adenine dinucleotide phosphate (NADP⁺), which are indispensable for cellular energy metabolism, DNA repair, and the enzymatic regulation of oxidative stress; (ii) at concentrations between 2% and 5%, clinical studies have demonstrated

that topical niacinamide significantly reduces TEWL and increases stratum corneum ceramide and free fatty acid content, improving barrier function by stimulating the synthesis of serine palmitoyl transferase, the rate-limiting enzyme in the de novo ceramide biosynthesis pathway; (iii) niacinamide inhibits the melanosome transfer from melanocytes to keratinocytes by a mechanism involving the paracrine signalling suppression of the prostaglandin E2 (PGE2) and thromboxane B2 (TXB2) pathways, contributing to an even skin tone.^{21,22}

Allantoin (5-ureidohydantoin) is a purine metabolite (end product of purine catabolism in most mammals other than humans) with a long history of use in cosmetic and pharmaceutical skin-care formulations. Its primary mechanisms of action relevant to this formulation are (i) keratolytic activity: allantoin stimulates the controlled desquamation of the stratum corneum by loosening the cohesive forces between corneocytes, resulting in the shedding of dull, thickened surface cells and the exposure of a smoother, more hydrated skin surface; (ii) wound-healing and anti-inflammatory activity: allantoin promotes the proliferation of fibroblasts and keratinocytes; and (iii) skin-conditioning activity: through its mild protein-denaturing action on denatured surface keratin, allantoin softens and improves the texture of dry, rough skin, which is the predominant skin condition of the body surface targeted by this product. Allantoin functions primarily as a soothing and skin-conditioning complementary agent to niacinamide, rather than as a primary active.^{23–24}

5.4. Milky Toner

The milky toner was conceived as a lightweight, lotion-like leave-on product positioned between a conventional aqueous toner and a fluid emulsion, intended to deliver hydration and stratum corneum barrier support immediately following the cleansing step. The final composition developed for the Milky Toner is detailed in Table 40.

Table 40: Final formulation of Milky Toner

PHASE	INCI NAME	w/w %
A	Aqua	q.s. to 100
	Xanthan Gum Crosspolymer-2	<0.5
A1	Glycerin	2-5
	Butylene Glycol	2-5
	Sodium Hyaluronate	<1
A2	Sodium Starch Octenylsuccinate	2-5
A3	Sodium Phytate	<0.5
	Chlorphenesin	<0.3
B	Coco-caprylate/Caprate	2-5
	C13-15 Alkane	2-5
C	Aqua	q.s. (carrier)
	Madecassoside, Asiaticoside, Centella Asiatica Leaf Extract	<1
	Maltodextrin, Lactobacillus Ferment, Aqua	<1
D	Phenoxyethanol, Ethylhexylglycerin	0.5-1
E	Ceramide NP, Ceramide AP, Ceramide EOP, Phytosphingosine, Cholesterol, Behenic Acid, Polyglyceryl-10 Stearate, Polyglyceryl-6 Behenate, Glycerin, Cetearyl Alcohol, Glyceryl Stearate, Sodium Cetearyl Sulfate, Triethyl Citrate, Sodium Levulinate, Potassium Sorbate, Citric Acid, Aqua	<1
F	Lecithin, Tocopherol, Ascorbyl Palmitate, Citric Acid	<1
G	Parfum	<0.5
H	Lactic Acid, Aqua	q.s.

5.4.1. Manufacturing Process

Phase A was prepared by dispersing Xanthan Gum Crosspolymer-2 in water and swelling under a turbo emulsifier at room temperature and 40°C. It was followed by the incorporation of Phase A1, previously prepared, under a turbo emulsifier. Afterwards, the modified starch was added and worked under a turbo emulsifier. Phase A3 was added under continuous stirring. The oil phase (Phase B) was prepared separately and heated to 65°C. The aqueous phase was heated to the same temperature and emulsified with the oil phase under high-shear mixing. After the formation of a uniform emulsion, the formulation was cooled while maintaining moderate agitation. The post-emulsification ingredients (Phases C–H), including the Centella asiatica derivatives and ferment complex, which were previously melted into water (Phase C),

preservative system, ceramide blend, antioxidant mixture, fragrance, and pH adjuster, were incorporated sequentially below 40°C to preserve their functionality.

An emulsification temperature of 65°C was selected as the optimal processing condition, ensuring efficient emulsification while maintaining good physical stability and a homogeneous milky appearance throughout storage.

5.4.2. Ingredient Selection and Formulation Design

Sodium hyaluronate was introduced to reinforce the primary hydrating claim. Sodium hyaluronate is the sodium salt of hyaluronic acid (HA), a linear glycosaminoglycan composed of alternating N-acetyl-d-glucosamine and d-glucuronic acid disaccharide units. Owing to its exceptional water-binding capacity, sodium hyaluronate at the concentrations employed in cosmetic formulation (0.1–0.5%) forms a viscoelastic hydration reservoir on the skin surface that reduces transepidermal water loss (TEWL) through a physical hygroscopic mechanism. At the molecular weight range typical of cosmetic-grade sodium hyaluronate (800 kDa to 1.2 MDa), the polymer remains largely at the stratum corneum surface, where it also reinforces the natural moisturising factor (NMF) pool and contributes to visible surface smoothness. The combination of sodium hyaluronate, glycerin, and butylene glycol in the aqueous phase constitutes a synergistic humectant system: glycerin provides immediate water-binding and is readily absorbed into the stratum corneum, while butylene glycol functions as a secondary humectant and penetration enhancer that facilitates the deeper delivery of co-formulated actives, and sodium hyaluronate creates a sustained surface hydration reservoir. The balanced use of these three humectants avoids the potential tackiness associated with high-concentration single-humectant formulations.²⁵

Centella Asiatica Leaf extract, a fermented maltodextrin ingredient, and a multi-component ceramide complex. The rationale for this combination reflects established formulation logic for the milky toner category, in which soothing, barrier-reinforcing, and microbiome-supportive functions are increasingly combined in a single leave-on

product applied to skin immediately after cleansing, when the barrier is transiently at its most permeable.²⁶

The *Centella Asiatica* extract is standardised to its principal bioactive triterpenoid saponins: madecassoside and asiaticoside. These *pentacyclic triterpenoid glycosides* have been studied extensively in the context of wound healing, fibroblast activation, and epidermal barrier recovery. *Madecassoside* (the glycoside of madecassic acid) and *asiaticoside* (the glycoside of asiatic acid) exert their primary soothing mechanism through inhibition of NF-κB nuclear translocation and consequent suppression of pro-inflammatory cytokine cascades. In parallel, asiaticoside has been shown to stimulate type I collagen synthesis in dermal fibroblasts, supporting the recovery of the dermal extracellular matrix following repetitive mild irritation. At the dosage employed, the extract is positioned as a soothing agent targeting post-cleansing reactive skin, consistent with the widespread use of *Centella asiatica* triterpenoids in formulations for sensitive and compromised skin barriers.^{27,28}

The fermented maltodextrin ingredient represents the application of controlled fermentation biotechnology to cosmetic ingredient production. In this ingredient, maltodextrin serves as the carbon source for *Lactobacillus*-species fermentation, yielding a complex mixture of short-chain lactic acid oligomers, postbiotic metabolites, and low-molecular-weight peptides generated by proteolytic activity during the fermentation process. This biologically derived fraction is incorporated into cosmetic formulations for two complementary purposes: (i) the low-molecular-weight fraction, including free amino acids and di/tripeptides released during fermentation, is more readily absorbed by the epidermis than corresponding non-fermented macromolecular precursors; and (ii) the postbiotic fraction — comprising cell wall fragments, exopolysaccharides, and short-chain fatty acids produced by the *Lactobacillus* culture — has been reported to interact favourably with the resident skin microbiome, selectively supporting the growth of commensal bacteria (principally *Staphylococcus*

epidermidis) while limiting the adhesion of pathogenic species. This microbiome-supportive mechanism is of relevance in a post-cleansing product, as cleansing agents partially disrupt the microbiome equilibrium through surfactant-mediated damage to bacterial cell membranes. The fermented ingredient therefore contributes a microbiome-restorative function that is mechanistically distinct from, and additive to, the anti-inflammatory action of the *Centella asiatica* extract.^{29,30}

The multi-component ceramide complex is the most mechanistically sophisticated component of the toner active ingredient system. Ceramides are the primary lipid class of the stratum corneum lamellar body system, constituting approximately 50% by weight of total intercellular lipids; they are essential structural components of the lamellar bilayer arrays that confer the selective barrier function of the stratum corneum. The complex employed here combines three ceramide subspecies — ceramide NP (N-stearoyl phytosphingosine, with a molecular composition equal to Phytosphingosine base + Stearic acid), *ceramide AP* (α -hydroxy fatty acid ceramide with a phytosphingosine backbone), and *ceramide EOP* (esterified ω -hydroxy ceramide, the "linker ceramide" responsible for covalent binding to cornified envelope proteins) — together with phytosphingosine, cholesterol, and behenic acid. This specific combination reflects the established ceramide biology of the human stratum corneum, in which barrier integrity and resilience are associated not with a single ceramide species in isolation but with a balanced molar ratio of ceramide, cholesterol, and free fatty acids forming a liquid-ordered lamellar phase. The inclusion of ceramide EOP is particularly noteworthy, as this ω -esterified species is the ceramide subtype most directly involved in the covalent binding of the lamellar body secretion to the cornified envelope, and its depletion is pathognomonic of the barrier disruption observed in atopic dermatitis and transient post-cleansing barrier compromise. The co-formulated phytosphingosine functions additionally as a precursor for de novo ceramide biosynthesis via the serine palmitoyl transferase pathway, providing both a direct

structural contribution and a biosynthetic substrate for endogenous ceramide replenishment.^{31–34}

5.5. Comparative Physicochemical Characterisation of the Developed Formulations

The instrumental characterization data obtained for the three final formulations are compared in Table 41.

Table 41: Comparative instrumental characterisation data for the three final formulations

Parameter	BB Cream	Body Cream	Milky Toner
pH (t₀ / t_{24h})	6.8 / 6.8	6.3 / 6.3	6.2 / 6.2
Viscosity at 2.5 rpm (t₀ / t_{24h})	3,008 / 3,984 (Spindle S02)	71,600 / 76,800 (Spindle S05)	9,056 / 9,600 (Spindle S03)
Centrifugation test	Pigment sedimentation; no emulsion phase separation	Stable; light precipitate in gold-pigment variant only	Slight phase separation observed
Optical microscopy (droplet diameter)	Uniform, 2–5 µm	Coarse but uniform, 2–20 µm	Fine, 2–10 µm; localised oil-rich patches

The table presents the comparative physicochemical characterisation of the three developed formulations, namely the BB Cream Anti-Pollution, Body Cream Anti-Age, and Milky Toner, evaluated immediately after preparation (t₀) and after 24 hours of storage at ambient temperature (t₂₄). All formulations maintained a stable pH throughout the observation period, indicating satisfactory short-term chemical stability. Distinct rheological profiles were observed among the products, reflecting their intended cosmetic applications. Centrifugation testing confirmed the overall physical stability of the formulations, with no significant emulsion breakdown observed. Optical microscopy revealed generally homogeneous droplet distributions, with droplet sizes consistent with the expected microstructure of each formulation.

Overall, the results demonstrate that all three formulations possessed suitable physicochemical properties and satisfactory short-term stability for their intended cosmetic applications.

CHAPTER 6 – CONCLUSIONS

The comparative evaluation of three natural-origin emulsifying systems showed that an emulsifier's performance cannot be judged by its ability to form an emulsion alone. Physical stability, viscosity, droplet distribution and sensory properties all shifted depending on the oil phase composition, the presence of stabilisers, the emulsifier concentration and the preparation method. A common experimental design across the three systems made these differences visible and gave a basis for matching each emulsifier to an appropriate product.

6.1. Implications of the Emulsifier Comparison

The three systems occupied distinct formulation spaces. Sorbitan Laurate/Polyglyceryl-4 Laurate/Dilauryl Citrate depended strongly on the surrounding formulation for physical stability: at the initial concentration, combining it with Xanthan Gum and Cetearyl Alcohol improved the emulsion structure, and increasing its concentration widened its usable formulation range. Its behaviour with inorganic pigments was particularly informative — of the three systems, it offered the most promising basis for a tinted facial product — though some instability persisted even after formulation adjustments.

C14-22 Alcohols/C12-20 Alkyl Glucoside, by contrast, developed viscosity and structure more readily, especially at a higher oil fraction, making it suited to a richer product where body and a more persistent sensory feel were desired. This came with its own dependence on concentration and processing conditions, and the instability seen once pigments were added confirmed that good performance in an uncoloured emulsion does not transfer automatically to formulations containing solid particles.

Sodium Starch Octenylsuccinate followed a different logic altogether. It stabilised several individual oils effectively, in some cases without any additional stabiliser, and its fast absorption and low residual feel supported use in a lighter product. Lowering its concentration compromised physical stability, and pigment incorporation introduced further limitations — a reminder that technical stability and the sensory/textural requirements of the finished formulation have to be weighed against each other.

No single formulation variable improved every property across all three systems: higher viscosity did not necessarily prevent creaming, and a fine droplet distribution or a good centrifugation result — while useful evidence under the tested conditions — could not on its own guarantee long-term stability. Selecting an emulsifier therefore meant reading several measurements together rather than trusting any one favourable result.

6.2. From Experimental Trials to Product Development

These results fed into three prototypes: an Anti-Pollution BB Cream, an Anti-Age Body Cream and a Milky Toner, each built around the emulsifier whose strengths best matched the format — the ester-based system for the pigmented BB cream, the alkyl glucoside system for the more structured body cream, and the modified starch for the lighter, fast-absorbing toner.

Moving from screening formulations to finished prototypes tested the approach further. With additional ingredients and specific texture, function and dispensing requirements, the prototypes did not behave in ways fully predictable from the simpler screening formulations. Final characterisation confirmed that all three concepts could be

formulated and assessed, while also flagging aspects of their physical performance still needing optimisation.

Choosing an emulsifier, in other words, is only one part of a larger formulation decision: oil phase, rheology modifiers, actives, pigments and manufacturing process all interact, and a system that performs well in early screening can behave differently once the full ingredient list is in place. The experimental series is best treated as a guide to formulation choices, to be confirmed by direct testing of the finished product rather than assumed from screening alone.

6.3. Limitations and Outlook

The three-month observation period provided an important perspective on the limits of accelerated and short-term assessments. The baseline ester-based formulation remained visually homogeneous during the initial part of storage but eventually underwent phase separation. The modified-starch formulation retained its visual integrity while showing a substantial reduction in viscosity. The alkyl glucoside formulation showed the most consistent behaviour over the period examined, although the duration of the study does not establish its full shelf life. Together, these outcomes demonstrate that changes in appearance and rheology must both be considered when evaluating stability.

The results also distinguish the stability of the screened baseline emulsions from that of the three finished prototypes. The longer observation period concerned selected formulations from the experimental comparison; it cannot be used to assign the same storage behaviour to the BB cream, body cream or milky toner. Each finished formulation requires its own stability programme, including monitoring under relevant storage conditions and assessment of changes in appearance, pH, viscosity and microstructure over time.

Further work should address the limitations identified for each product. For the BB cream, optimisation should focus on improving resistance to creaming while preserving a homogeneous pigment distribution and a suitable facial texture. For the body cream, the stability of the complete formulation should be confirmed after incorporation of its active ingredients. For the milky toner, additional work is needed to establish whether its lighter consistency can be maintained without compromising physical stability. Packaging–formula compatibility studies should also be conducted for the selected containers and dispensing systems before their suitability can be confirmed.

The comparative approach provides a framework that can be applied to other natural-origin emulsifiers and product formats. Its value lies in connecting controlled changes in formulation and processing to measurable differences in emulsion behaviour, then using those differences to make product development decisions. The findings support a formulation strategy in which stability, rheology, microstructure and sensory performance are evaluated together, with longer-term testing used to confirm the choices made during initial screening.

6.4. General Considerations and Outlook

The three emulsifying systems studied represent three structurally and mechanistically distinct approaches to the formulation of natural-origin oil-in-water emulsions: an ester system relying on classical interfacial film mechanics, a fatty-alcohol-glucoside pair exploiting lamellar liquid-crystal co-assembly, and a modified polysaccharide operating through a Pickering-type particle adsorption mechanism. That each of these systems, despite sharing the same product category and the same regulatory sustainability positioning, generates a profoundly different formulation space underlines the importance of a rigorous, empirically grounded screening phase in natural emulsifier selection. The methodology developed in this thesis — seven

controlled experimental series applied in parallel across three emulsifiers, combined with sensory profiling and functional product translation — may serve as a transferable framework for future comparative emulsifier studies, adaptable to other emulsifier classes or product categories as the cosmetic industry continues to expand its portfolio of bio-derived functional ingredients.

REFERENCES

1. Tadros, T. F. *Emulsion Science and Technology*. (Wiley-VCH, 2009).
2. Tauer, K. A Little (Theory): Emulsion Stability Emulsions-Part 2.
3. *Introduction to Cosmetic Emulsions and Emulsification*. (Published on behalf of the International Federation of Societies of Cosmetic Chemists by Micelle, 2010).
4. Texter, J. Pickering emulsions and dispersions—an early perspective. *Colloid Polym. Sci.* **300**, 587–592 (2022).
5. Leal-Calderon, F., Schmitt, V. & Bibette, J. *Emulsion Science B A S I C P R I N C I P L E S* SECOND EDITION.
6. COSMOS-standard AISBL. COSMOS-standard: Standard per cosmetici biologici e naturali. Version 3.1 (1 June 2020).
7. Holmberg, K., Jönsson, B., Kronberg, B. & Lindman, B. *SURFACTANTS AND POLYMERS IN AQUEOUS SOLUTION*. www.wileyeurope.com (2002).
8. Cozzoli, T. Skinification, la rivoluzione nel mondo della bellezza. *Mabella* (15 May 2024).
9. BBC News. K-beauty: From social media trend to economic powerhouse. *BBC News* (2 January 2026).
10. From Seoul to the World: How K-beauty Innovation Is Shaping Global Beauty Markets - MEIYUME.
11. Meilgaard, Morten., Civille, G. Vance. & Carr, B. Thomas. *Sensory Evaluation Techniques*. (CRC Press, Taylor & Francis Group, CRC Press is an imprint of the Taylor & Francis Group, an Informa business, 2016).

12. Moussour, M., Lavarde, M., Pensé-Lhéritier, A. M. & Bouton, F. Sensory analysis of cosmetic powders: personal care ingredients and emulsions. *Int. J. Cosmet. Sci.* **39**, 83–89 (2017).
13. Alal, H. From Patented Quinoa Starch Technology.
14. Cetearyl Alcohol (Emollient): Cosmetic Ingredient INCI.
15. Terescenco, D., Savary, G., Clemenceau, F., Merat, E., Duchemin, B., Grisel, M. & Picard, C. The alkyl polyglucoside/fatty alcohol ratio effect on the formation of liquid crystal phases in binary systems. *J. Mol. Liq.* **253**, 45–52 (2018).
16. ECTOIN THE NATURAL ALLERGY PROTECTION MOLECULE
SCIENTIFIC DOSSIER.
17. LESPEDEZA CAPITATA FLOWER:LEAF:STEM EXTRACT —
Moumoujus.
18. Chititala, R.-D., Lungu, I. I., Marin, G.-A., Mitran, A.-M., Caba, I.-C., Lungu, A., Robu, S., Mircea, C., Stefanache, A., Hancianu, M. & Cioanca, O. Comparative Analysis of Lespedeza Species: Traditional Uses and Biological Activity of the Fabaceae Family. *Molecules* **30**, 2013 (2025).
19. Pereira, A. G., Garcia-Perez, P., Cassani, L., Chamorro, F., Cao, H., Barba, F. J., Simal-Gandara, J. & Prieto, M. A. *Camellia japonica*: A phytochemical perspective and current applications facing its industrial exploitation. *Food Chem. X* **13**, 100258 (2022).
20. Kachooeian, M., Mousivand, Z., Sharifikolouei, E., Shirangi, M., Firoozpour, L., Raoufi, M. & Sharifzadeh, M. Matrixyl Patch vs Matrixyl Cream: A Comparative In Vivo Investigation of Matrixyl (MTI) Effect on Wound Healing. *ACS Omega* **7**, 24695–24704 (2022).

21. Farris, P. K. & Lain, T. >>SKINCARE SCIENCE Niacinamide: A Multi-Functional Cosmeceutical Ingredient.
22. Marques, C., Hadjab, F., Porcello, A., Lourenço, K., Scaletta, C., Abdel-Sayed, P., Hirt-Burri, N., Applegate, L. A. & Laurent, A. Mechanistic Insights into the Multiple Functions of Niacinamide: Therapeutic Implications and Cosmeceutical Applications in Functional Skincare Products. *Antioxidants* 13, 425 (2024).
23. Saucedo-Acuña, R. A., Meza-Valle, K. Z., Cuevas-González, J. C., Ordoñez-Casanova, E. G., Castellanos-García, M. I., Zaragoza-Contreras, E. A. & Tamayo-Pérez, G. F. Characterization and In Vivo Assay of Allantoin-Enriched Pectin Hydrogel for the Treatment of Skin Wounds. *Int. J. Mol. Sci.* 24, 7377 (2023).
24. Ulhôa Araújo, L. I., Grabe-Guimarães, A. I., Carla Furtado Mosqueira, V. I., Martins Carneiro III, C. & Márcia Silva-Barcellos, N. I. *Profile of Wound Healing Process Induced by Allantoin 1 Perfil Do Processo de Cicatrização Induzido Pela Alantoína. Acta Cirúrgica Brasileira* vol. 25.
25. Zanchetta, C., Scandolera, A. & Reynaud, R. Hyaluronic Acid in Topical Applications: The Various Forms and Biological Effects of a Hero Molecule in the Cosmetics Industry. *Biomolecules* vol. 15 Preprint at <https://doi.org/10.3390/biom15121656> (2025).
26. Gray, N. E., Alcazar Magana, A., Lak, P., Wright, K. M., Quinn, J., Stevens, J. F., Maier, C. S. & Soumyanath, A. Centella asiatica: phytochemistry and mechanisms of neuroprotection and cognitive enhancement. *Phytochem. Rev.* 17, 161–194 (2018).
27. Gohil, K. J., Patel, J. A. & Gajjar, A. K. Pharmacological Review on Centella Asiatica: A Potential Herbal Cure-All. www.ijpsonline.com.
28. Handayani, R., Febriyanti, R. M., Muhaimin, M. & Chearunisaa, A. Y. Centella asiatica (L.) Urb. in skin health and cosmeceuticals: mechanisms, clinical evidence,

and advanced delivery systems. *Pharmacia* vol. 72 Preprint at <https://doi.org/10.3897/pharmacia.72.e167217> (2025).

29. Dou, J., Feng, N., Guo, F., Chen, Z., Liang, J., Wang, T., Guo, X. & Xu, Z. Applications of Probiotic Constituents in Cosmetics. *Molecules* 28, 6765 (2023).

30. Majchrzak, W., Motyl, I. & Śmigielski, K. Biological and Cosmetical Importance of Fermented Raw Materials: An Overview. *Molecules* vol. 27 Preprint at <https://doi.org/10.3390/molecules27154845> (2022).

31. Harrison, I. P. & Spada, F. Breaking the Itch–Scratch Cycle: Topical Options for the Management of Chronic Cutaneous Itch in Atopic Dermatitis. *Medicines* 6, 76 (2019).

32. Schröter, A. The Role of Ceramide [AP] for the Structural Assembly of Stratum Corneum Lipid Model Membranes. PhD thesis, Martin Luther University Halle-Wittenberg

33. ANECO. Ceramide NP Structure, Skin Benefits & Cosmetic Uses.

34. Mijaljica, D., Townley, J. P., Hondros, A., Hewson, C., Harrison, I. P. & Spada, F. Considering Phytosphingosine-Based Ceramide Formulations for Atopic Skin Care. *Dermato* 4, 5–22 (2024).

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Beki, chiamarti migliore amica non è sbagliato, ma ormai non è più sufficiente. Ci sono rapporti che nascono in un momento della vita e non evolvono. Il nostro, invece, è cresciuto insieme a noi. Ha dovuto cambiare forma molte volte, perché siamo cambiate noi, e credo che sia proprio questo ciò che più gli ha permesso di diventare quello che è oggi. Non siamo più le bambine che si sono conosciute, né le adolescenti che pensavano di sapere già tutto della vita. Abbiamo idee diverse da quelle che avevamo allora, caratteri più definiti, responsabilità nuove. Eppure continuiamo a riconoscerci. Tu conosci le mie contraddizioni, gli errori di cui non vado fiera, le insicurezze che nascondo meglio e quelle che, invece, non ho mai saputo nascondere. Hai assistito a

cambiamenti che mi hanno resa diversa dalla persona che avevi conosciuto e non mi hai mai fatto sentire che, per continuare a volermi bene, avessi il dovere di restare uguale. Forse è questo che negli anni ha trasformato la nostra amicizia in qualcosa che per me assomiglia alla famiglia: la certezza di non dover meritare continuamente il proprio posto nella vita dell'altra. Con te non ho bisogno di essere particolarmente brillante, forte o felice. Posso arrivare senza avere le parole giuste, posso essere confusa, posso cambiare idea. E ciò è per me una delle forme più preziose di intimità che la vita mi abbia regalato.

Non so come saranno le nostre vite tra dieci o vent'anni, e forse oggi ho imparato che non è necessario saperlo. Quello che so è che non riesco a raccontare davvero chi sono senza, prima o poi, arrivare anche a voi.

Ad *Emanuele*, hai conosciuto la ragazza che iniziava l'università e oggi sei accanto a quella che la conclude. Sembrano due persone molto diverse e, in parte, lo sono. Nel mezzo ci sono state scelte, cambiamenti, successi, fallimenti, momenti di grande sicurezza e altri in cui ho rimesso in discussione quasi tutto. Tu non hai semplicemente assistito a questa trasformazione: hai saputo rispettarla. Ed è probabilmente questo ciò per cui ti sono più grata. Tu non mi hai mai fatto percepire la mia crescita come una minaccia per noi. Non mi hai mai chiesto di essere meno ambiziosa, meno curiosa, meno indipendente per rendere il nostro rapporto più semplice. Mi hai lasciata libera senza farmi sentire distante, e mi sei rimasto accanto senza mai trasformare la tua presenza in un limite. Mi hai insegnato che l'amore non è qualcuno che completi ciò che mi manca, ma qualcuno con cui poter essere una persona intera. Hai imparato a distinguere quando avevo bisogno di una soluzione e quando, invece, avevo soltanto bisogno che qualcuno restasse lì. Hai celebrato le mie soddisfazioni senza appropriartene e hai saputo dirmi la verità anche quando sarebbe stato più semplice assecondarmi. Mi hai sostenuta, ma non mi hai mai risparmiato la responsabilità delle mie scelte. Non so quale forma prenderà la vita che stiamo costruendo, né credo sia

necessario definirla tutta adesso. So però che quando penso al futuro ti immagino accanto a me.

Alla mia sorella a quattro zampe, *Olly*, devo il ringraziamento più semplice e forse più puro. Grazie per la strada che hai condiviso con me, senza sapere cosa fosse un esame, una tesi o una scadenza, ma comprendendo perfettamente quando avevo bisogno di compagnia. Mi hai aspettata, hai festeggiato ogni ritorno come se fosse un evento straordinario e hai riempito di presenza anche i pomeriggi più silenziosi. Nel tuo amore non ci sono condizioni, aspettative o parole da trovare: c'è soltanto la felicità di esserci vicine. Sono eternamente grata per aver conosciuto attraverso di te questa forma di amore puro. Mi manchi.

Ringrazio la mia famiglia, numerosa, rumorosa e impossibile da contenere in poche righe. La *zia Chiara*, lo *zio Gian Marco*, *Giulia* e *Alberto*; lo *zio Marco*, *Elmore*, la *zia Eva*, *Francesco* e *Barbara*; la *zia Titti*, lo *zio Salpo*, e ad *Ale*, che nonostante la distanza riesce sempre a esserci. Grazie a tutti voi perché ogni mio traguardo diventa immediatamente una festa collettiva, perché sapete trasformare l'orgoglio in abbracci, messaggi e tavolate, e perché mi avete sempre fatta sentire parte di qualcosa di più grande di me. Le famiglie non sono perfette, ma la nostra possiede un modo tutto suo, intenso e rumoroso, di dire amore. Sapere di avere così tante persone da cui tornare è uno dei privilegi più grandi della mia vita e, senza dubbio, il mio vanto più grande.

Un pensiero particolare va agli *zii Marco* e alla *zia Chiara*, con cui sono pronta a iniziare un nuovo capitolo della mia vita scout. Dopo tanti anni vissuti da una prospettiva diversa, oggi mi preparo ad affrontarlo con un ruolo nuovo e nuove responsabilità. Sapere di poterlo fare accanto a voi mi dà sicurezza: sono certa che, con il vostro esempio e la vostra guida, potrò imparare a dare il meglio di me e a restituire almeno una parte di ciò che lo scoutismo ha dato a me.

Un grazie speciale va alla *zia Titti*, pronta ad accogliermi in azienda con un entusiasmo e un affetto che hanno qualcosa di materno. Ti stimo profondamente per il modo in cui

affronti il tuo lavoro e sono felice di sapere che potrò muovere i primi passi in questa nuova realtà anche accanto a te. Spero di imparare tanto dalla tua esperienza e, con il tempo, di riuscire a trovare il mio posto e il mio modo di contribuire. Non avrei potuto desiderare una presenza migliore al mio fianco per iniziare questo nuovo capitolo.

Alla mia *nonna Nucci*, una delle presenze più preziose della mia vita. Con te ho imparato che si può continuare a essere curiosi del mondo a qualsiasi età, fare domande, interessarsi, voler capire. Mi hai insegnato che l'amore si riconosce nelle cose più semplici. Nei piatti preparati mentre studiavo, nel condividere progetti all'uncinetto, nelle mille attenzioni con cui ti sei presa cura di me senza aspettarti che me ne accorgessi. Ho avuto la fortuna di averti accanto nella quotidianità, di tornare a casa e trovarti lì. Per questo oggi, dentro questo traguardo ci sei tu.

Al mio *nonno Franco*. Più passa il tempo, più capisco che sentire la mancanza di qualcuno non significa soltanto desiderare di tornare ai momenti vissuti insieme. Significa soprattutto desiderare quelli che non abbiamo potuto vivere. In questi anni avrei voluto raccontarti tante cose. Avrei voluto che mi vedessi crescere, che conoscessi la persona che sono diventata e che fossi qui oggi, anche solo per poter incrociare il tuo sguardo e sapere cosa avresti pensato di me. Ci sono momenti in cui mi sembra ingiusto che la mia vita abbia continuato ad aggiungere pagine alle quali tu non hai potuto assistere. Poi penso che, in realtà, una parte di te è rimasta in tutte quelle che sono venute dopo. Sei nei racconti, nei ricordi, nelle abitudini della nostra famiglia e in quel pensiero che arriva improvvisamente anche nelle giornate più normali. Mi manchi in un modo che il tempo ha reso più silenzioso, ma non meno profondo. E oggi, in un giorno così importante per me, avrei voluto semplicemente averti qui.

Alla *nonna Pia*, briosa, eccentrica e probabilmente la persona più generosa che conosca. Il tuo è sempre stato un bene senza misura, fatto di attenzioni, vizi e di quel desiderio instancabile di rendere felici le persone che ami. Una parte bellissima della mia infanzia porta il tuo nome: le giornate al mare, i pomeriggi sul cutter a mangiare il ciambellone, le partite a biglie e la cabina dei 37 così piena di giochi che sembrava non

esserci più spazio per noi. Da bambina vivevo tutto questo come la normalità; crescendo ho capito quanto fossi fortunata. Di te amo la vitalità, la libertà e quel tuo modo inconfondibile di essere sempre, profondamente, te stessa. E mi fa sorridere sapere che, per quanto possa crescere, accanto a te resterò sempre un po' quella bambina viziata e felice a cui un gelato in più non si negava mai.

Al *nonno Lino*. Di te conosco soprattutto ciò che hai lasciato, e forse è proprio questo a farmi capire quanto possa essere profonda l'impronta di una persona. Il tuo nome appartiene alla storia della nostra famiglia da molto prima che io fossi in grado di comprenderne il significato. Tra poco entrerà anch'io in quella storia e ciò che fino a ieri osservavo da figlia e da nipote diventerà parte della mia vita. Mi emoziona pensare che qualcosa iniziato prima di me possa arrivare fino alle mie mani. E insieme all'emozione sento la responsabilità di trattarlo con rispetto, senza pensare che ciò che ho ricevuto mi appartenga semplicemente perché porto questo cognome. Vorrei riuscire a dare anch'io qualcosa a ciò che avete costruito, con il mio carattere, le mie idee e il mio modo di vedere il futuro. Vorrei, un giorno, poter pensare che saresti stato felice di vedermi lì.

Ai miei *genitori*. Da bambini l'amore dei propri genitori sembra quasi una legge naturale: c'è, e basta. Solo diventando grandi si comincia a intuire tutto ciò che esiste dietro quel "c'è". Oggi so che dietro la libertà con cui ho potuto scegliere ci sono state anche le vostre rinunce; dietro la serenità con cui ho potuto studiare, viaggiare, provare e cambiare idea c'era qualcuno che si preoccupava perché io potessi farlo. Non mi avete mai fatto sentire il peso di ciò che mi stavate dando e forse è proprio per questo che ho impiegato così tanto tempo a comprenderne davvero il valore. Grazie per avermi cresciuta con la certezza di avere un posto sicuro in cui tornare. Grazie per avermi lasciato la libertà di sbagliare senza deludervi, cambiare senza perdervi, riuscire senza dovervi dimostrare qualcosa. Oggi che la mia vita sta diventando sempre più mia, capisco quanto sia stato importante avere radici così forti da potermi permettere di andare lontano. Vi amo naturalmente come una figlia ama i propri genitori, ma oggi vi

guardo anche come persone. E vi stimo. Vedo meglio le vostre fatiche, le imperfezioni, le scelte difficili e tutto quello che avete costruito giorno dopo giorno. Mi auguro, un giorno di riuscire a creare per le persone che amo la stessa sensazione di casa che voi avete creato per me.

Mamma, hai sempre saputo distinguere quando avevo bisogno di una spinta e quando, invece, avevo soltanto bisogno di sentirmi dire che potevo fermarmi. Conosci le mie paure anche quando provo a raccontartele come se fossero problemi razionali e spesso capisci che qualcosa non va dal modo in cui dico la prima parola al telefono. Hai ascoltato discorsi su materie di cui probabilmente avresti fatto volentieri a meno, seguito progetti, cambiamenti, partenze, ritorni e crisi che qualche giorno dopo facevano sorridere anche me. E soprattutto hai saputo esserci senza impedirmi di andare. Crescendo mi capita sempre più spesso di riconoscerti in me. In alcuni gesti, nel modo in cui mi prendo cura delle persone, nella determinazione e persino in quelle cose che da adolescente giuravo che non avrei mai fatto come te. Un tempo avrei protestato. Oggi ne sono felice. Perché se c'è una donna dalla quale sono orgogliosa di aver ereditato qualcosa, quella donna sei tu.

Babbo, per tutta la vita ho sentito che credevi in me. A volte persino più di quanto facessi io. Il tuo modo di guardarmi mi ha dato sicurezza, ma mi ha anche fatto venire voglia di meritare quella fiducia. Eppure non hai mai trasformato le tue aspettative in una strada obbligata: mi hai lasciata cercare la mia, anche quando significava allontanarmi da ciò che conoscevi meglio. Adesso, per la prima volta, le nostre strade stanno per incontrarsi davvero. L'idea di lavorare accanto a te mi emoziona perché so che conoscerò una parte di te che fino ad oggi ho osservato soltanto da lontano. Ci saranno cose che mi insegnerai, altre sulle quali probabilmente discuteremo e momenti in cui dovremo imparare a guardarci non soltanto come padre e figlia. E forse è proprio questo che aspetto di più. Vorrei riuscire a costruirmi il mio posto accanto a te senza vivere nella tua ombra, ma senza dimenticare tutto ciò che posso imparare dalla tua esperienza. E spero che, negli anni, il nostro rapporto possa arricchirsi anche di questo:

della possibilità di costruire qualcosa insieme. Non desidero soltanto renderti orgoglioso. Desidero che un giorno tu possa guardarmi e riconoscere in me qualcosa che mi hai trasmesso, insieme a qualcosa che sono riuscita a costruire da sola.

A mio fratello *Nicola*, per sempre il mio bimbo piccolo, anche se oggi mi trovo testimone dell'uomo meraviglioso che stai diventando. Essere tua sorella maggiore mi ha fatto credere per molto tempo di doverti proteggere. Vorrei poterti risparmiare tutto ciò che fa male, soprattutto quelle delusioni che conosco già e che vorrei evitarti prima ancora che tu possa incontrarle. Ma sto imparando che volerti bene significa anche accettare di non poterlo fare. La tua vita deve essere tua. Avrai il diritto di sbagliare strada, cambiare idea e non sapere immediatamente cosa fare dopo. Avrai momenti in cui ti sembrerà che tutti gli altri abbiano capito come si diventa grandi tranne te. Ti assicuro che non è così. Ti auguro il coraggio di non diventare ciò che gli altri si aspettano. Vorrei soltanto che imparassi a guardarti con un po' della fiducia con cui ti guardo io. Per ora, posso solo prometterti che non dovrai mai essere bravo, forte o felice per meritarti il mio amore. Sarò orgogliosa di te nei tuoi traguardi, ma voglio che tu sappia che lo sarò allo stesso modo nelle tue cadute, perché niente di ciò che riuscirai o non riuscirai a fare cambierà mai quanto sono fiera di essere tua sorella.

Arrivata alla fine, mi accorgo che questo traguardo non chiude soltanto un corso di studi. Chiude un tempo della mia vita in cui il futuro poteva ancora essere rimandato al prossimo esame, al prossimo semestre, alla prossima laurea. Per anni l'università, e prima così la scuola, è stata il modo in cui misuravo le giornate, le paure e le soddisfazioni. Mi ha insegnato la disciplina, mi ha costretta a fare i conti con i miei limiti e mi ha mostrato che spesso sono capace di molto più di quanto credo. Mi ha portata lontano da casa, mi ha fatto incontrare persone che non avrei mai conosciuto e mi ha permesso di diventare, un passo alla volta, più simile alla donna che ambisco a essere.

Oggi saluto questo mondo con nostalgia, ma senza rimpianto. Non perché io abbia già tutte le risposte, ma perché ho finalmente accettato che diventare adulti non significhi

averle. È questione di assumersi la responsabilità delle proprie scelte, restare quando sarebbe più semplice fuggire, cambiare direzione quando quella presa non ci somiglia più e continuare a costruire anche senza la certezza del risultato. Davanti a me c'è il lavoro, ci sono nuovi progetti, responsabilità vere e una vita che non sarà più scandita dagli appelli. Fa paura, ma è una paura diversa: non quella di non essere pronta, bensì quella che accompagna tutte le cose importanti prima di cominciare. Entro in questo nuovo capitolo portando con me ciò che ho imparato e, soprattutto, le persone che mi hanno condotta fin qui. Se oggi riesco a guardare avanti con fiducia è perché so di avere radici profonde e mani pronte a stringere le mie nei momenti in cui ne avrò bisogno. Questo titolo è mio, ma la strada che mi ha portata a ottenerlo è piena delle vostre impronte. Grazie di cuore a tutti voi per essere parte della mia vita e per aver reso questo traguardo molto più di un punto di arrivo.

Con questa abbiamo ufficialmente concluso il mio percorso accademico,

A chi ha fatto parte della strada percorsa

E a chi continuerà a esserci in quella che verrà.

Con gratitudine e amore,

Da oggi, Dottoressa Magistrale Emma Terenzi.