EXPERIMENTAL OPTIMIZATION AND CHARACTERIZATION OF AN O/W COSMETIC CREAM BASED ON A NON-IONIC SELF-EMULSIFYING SYSTEM

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Abstract

Non-ionic self-emulsifying bases have gained attention in cosmetic formulation because they are less irritating than ionic surfactants, stable across a wide pH range, and capable of forming liquid crystalline gel networks that improve cream consistency and long-term stability.
The aim of this study was to experimentally optimize an O/W cosmetic cream by varying the concentration of a non-ionic self-emulsifying base that further be used to incorporate Niacinamide as Cosmetic Active.
The Experimental Matrix included three levels of the Emulsifying Base (4%, 6% and 8%). Three test formulations were prepared with different levels of emulsifying compound and evaluated for Organoleptic properties, pH, Density, Spreadability and Physical Stability under Accelerated Conditions.
Among the prepared formulations, F2 exhibited the most favorable balance of physicochemical properties and physical stability exhibiting appropriate viscosity for topical application, homogeneous appearance with no phase separation under accelerated conditions, wider diameter of spreadability in plate and smaller droplet size compared to other formulations, indicating efficient emulsification.
Key words: Non-Ionic Self-Emulsifying System, O/W Cosmetic Cream,Cosmetic Formulation

Introduction

Oil-in-water (O/W) cosmetic creams remain one of the most widely used topical delivery systems due to their light skin feel, ease of spreading, and ability to incorporate both active ingredients with hydrophilic and lipophilic character. The physical stability and sensory properties of these systems are strongly influenced by the type and concentration of the emulsifying agent used. Non-ionic self-emulsifying bases have gained attention in cosmetic formulation because they are less irritating than ionic surfactants, stable across a wide pH range (Aultron's Pharmaceutics, 2013), and capable of forming liquid crystalline gel networks (Seppic, 2025) that improve cream consistency and long-term stability. Examples include Polawax, Emulsifying Wax NF, and Ceteareth-20/Cetearyl Alcohol systems. However, the final texture, viscosity, and stability of the cream are highly dependent on the concentration of the Emulsifying Base used. Insufficient emulsifier leads to phase separation, while excess amounts can produce a heavy, waxy, or soapy after-feel that reduces consumer acceptance (RAHN, 2026).
Despite the widespread use of non-ionic self-emulsifying systems, limited data are available on the systematic optimization of emulsifier concentration in relation to physicochemical properties and stability of O/W creams intended for cosmetic use. Suppliers provide us with range as well as limits for emulsifiers use however, to determine the “Sweet Spot” experimental studies are required. Therefore, the aim of this study was to experimentally optimize an O/W cosmetic cream by varying the concentration of a non-ionic self-emulsifying base.
The Experimental Matrix included three levels of the Emulsifying Base (Low 4%, Middle 6% and High 8%). Three test formulations were prepared with different levels of emulsifying

compound and evaluated for organoleptic properties, pH, density, spreadabilityand physical stability under accelerated conditions (Elham Y Al-Barghouthy, 2025), (Ana Simões, 2020), (Zahra Mirzapou, 2025).
For the test formulations, the majority of the O/W emulsion ingredients (listed in the table below) were kept at consistent levels; conversely, the non-ionic emulsifier was considered as the primary variable.

Table 1.General example of O/W cream formulation (Roger L McMullen, 2014)

Ingredients	**Ranges**
Water Phase	qs to 100%
Oil Phase	10-35%
Emulsifier Systems	3-5% (Depends on Emulsifier type)
Stabilizers/Thickeners	0.5-2%
Humectants	3-5%
Preservative	0.5-1% (Depends on Preservative type)
Vitamin E	0.5-1%
EO or Aroma	0.5-1%

Materials And Methods

Materials

Deionized Water was obtained from the Deionizer Apparatus of Faculty of Mathematical and Natural Sciences, Univeristy of Tetovo; Emulsifying Base for preparation of Cosmetic Creams - Emulgade SE-PF (Glyceryl Stearate, Ceteareth-20, Ceteareth-12, Cetearyl Alcohol, and Cetyl Palmitate)Manufactured by BASF Personal Care and purchased from Galafarm DOO Skopje, Republic of North Macedonia; Cetyl Alcohol produced by Riedel-de Haen;n-Propyl p-hydroxybenzoate Manufactured by Sigma-Aldrich Chemie GmbH, Darmstadt, Germany; Methyl 4-hydroxybenzoate Manufactured by Fluka Chemicals; Glycerin (1,2,3-Propanetriol), Prunus Amygdalus Dulcis Oil (Almond Oil) and Cinnamomum zeylanicum Essential Oil were purchased from Fitofarm DOO Skopje, Republic of North Macedonia.

Methods

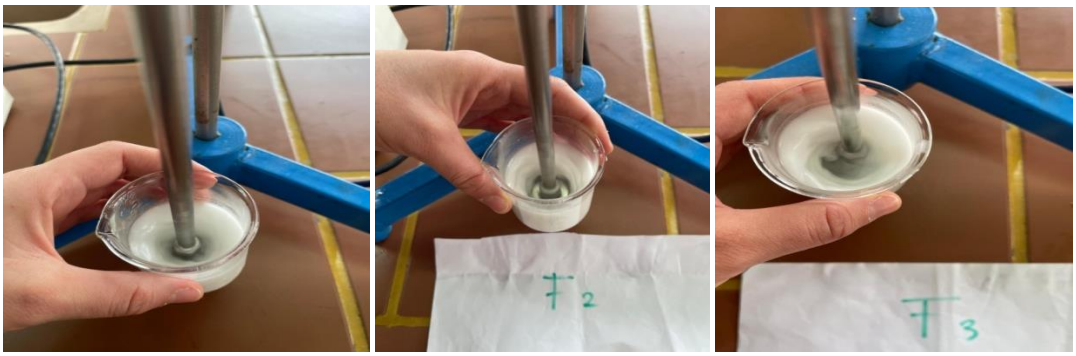
2.2.1. Formulation Development of Test Cosmetic Creams: With aim on finding the so called "Sweet Spot" or the optimal ratio of Emulsifying Base that gives the best properties to the Cream Formulation, three formulations were developed. Further in this paper, formulations are coded as: F1, F2 and F3, corresponding to each formulation of the study.In the following tables are displayed the ingredients and amounts of three of the formulations in this experimental work.

Table 2.Test Formulations Ingredients and their Amount

Ingredients	F1	F2	F3	Role in Formulation	Limits of use
Phase A	-	-	-	-	-
Deionized Water	37.62 g	36.62 g	35.62 g	Water Phase	≈ 60%
Glycerin	1.5 g	1.5 g	1.5 g	Humectant	2-5%

Methyl Paraben	0.085g	0.085g	0.085g	Preservative	0.4%
Propyl Paraben	0.04 g	0.04 g	0.04 g	Preservative	0.14%
Phase B	-	-	-	-	-
Sweet Almond Oil	7.5 g	7.5 g	7.5 g	Oil Phase	15-25%
Cetyl Alcohol	1 g	1 g	1 g	Co-Emulsifier	0.5-6%
Emulgade SE-PF	2 g	3 g	4 g	Emulsifier	2-8%
Phase C	-	-	-	-	-
Cinnamon EO	0.25 g	0.25 g	0.25 g	Fragrance	0.5-1%

Fig 1.Homogenization of O/W test formulations F1(left),F2(middle) and F3(right)



In the formulation process an Analytical Measuring Balance (Mettler Toledo PM300) it utilized to measure the exact amount of the ingredients in three of the formulations. Since the formulation is biphasic, two different beakers are used with aim of preparing both phases, subsequently, the beakers are added to Water Bath previously heated to 60 ˚ C until the Oil Phase (Phase B) is totally melted. Following that, the Water Phase (Phase A) was slowly added to Oil Phase while passing it in Homogenizer (Glas-Col GKH GT Motor Control) for 3 minutes at 2000 rpm. At last, after temperature reaches 40 ˚ C we add Cinnamon EO since it is unstable at higher temperature (Jiageng Guo 1, 2024).

2.2.2. Organoleptic Characterization: It is well known that Organoleptic Characterization, of diverse Cosmetic Cream formulations, evaluates sensory attributes such as: Color, Odor, Appearance and Homogenity in Appearance as well as Texture of the Cream Formulation (Johnny Bullón, 2021) (Magdalena Bîrsan, 2025).
All of these parameters were checked for F1, F2 and F3 and displayed in the results part.

2.2.3. pH Measurement; pH value for all three formulations were checked in two different manners in order to deliver more accurate results. We used Universal Indicator Paper (pH 1-14) as well as Semi Solid Test Pen (pH range 0.00-14.00, Accuracy 0.1 pH) that was previously calibrated using three calibration buffers including here: 4.00, 6.86 and 9.18. After every calibration process, the pH meter probe was rinsed with Deionized Water and Blotted with tissue paper. Method as described by (Carli, 2025) suggests that pH of Cosmetic Cream formulation should be measured by Universal Indicator Paper and pH meter without diluting it previously with water as it can affect the final results. (Muthanna F. Abdulkarim, 2010) as well, in their study have conducted pH measurement without dilution of sample. The paper was immersed into the cream formulation for 15 seconds and after that we read the results. As it

pertains to pH meter, the probe was immersed into the formulation until it reached stability in the showing result. pH Value is measured at 21-22 ˚C that complies with room temperature, in which the formulations are recommended to be stored.

Fig 2.pH meter and Buffer Solutions

2.2.4. Density Measurement : Density is defined as the ratio of the mass of a substance to the volume it occupies at a given temperature and pressure (Ojeda, NA). Based on Archimedes Equation, ρ=m/V, regarding density (Hughes, 2006) has used previously to measure diverse liquids so we applied this principle to measure density for three of our formulations in the absence of a specific density checking device. The temperature of the ambience where we conducted the measurements was 22 ˚ C which complied with the requirements of measuring the density in room temperature. First and foremost, an analytical balance (0.01 g) is mandatory for this measurement as well graduated cylinder. The empty graduated cylinder wasmeasured in the analytical scale and afterwards tared. Then the graduated was filled with 10 ml of cream then tapped it into plain surface for 5 times to get it leveled to 10 ml and remove air bubbles. At last, we checked the weight of the cream formulations in the graduated cylinder and calculated the density utilizing Archimedes Equation given above.

Fig 3.Graduated Cylinder with Cream on the Analytical Balance

2.2.5. Spreadability in Plate: With aim on assessing cream formulation Spreadability, Parallel-Plate Method was employed (Elham Y Al-Barghouthy, 2025). A total of 1 gram cream formulation was added into flat surface then covered with square-shaped glass plate. Spreadability was tested after adding diverse weights: 50g,100g, 150g and 200g above the plate for 1 minute each. Afterwards, the diameter was measured by ruler in three different sides and SD from the Mean was calculated using Microsoft Excel 2016.

Fig 4.Cream Spreadability tested in Parallel-Plate Method

2.2.6. Spreadability in Skin: Spreadability in skin was tested immediately after formulation process. Small amount of the cosmetic cream was applied in the upper part of the hand, gently with circular movements.Subsequently, the time of full skin absorption was assessed.

*2.2.7. Accelerated Stability Study :*Accelerated Stability study for F1, F2 and F3 were carried out utilizing Centrifugation Method. Three samples from all formulations were added to centrifuge tubes and labeled with codes. The tubes were placed in parallel manner in order to balance the rotor and ensure safe operation. As we had three samples, we added an empty tube to balance the last. An Eppendorf Centrifuge 5415 C was utilized to carry out the Accelerated Stability Study with parameters, 3000 rpm for 30 minutes as described by (Zahra Mirzapou, 2025), (Anđela Dragićević, 2023), (Ivana Arsić, 2012).The samples were checked both, Visuallyas well leveraging Optical Microscope.

Fig 5.Centrifuge(Left)and Centrifuge tubes filled with test formulations(Right)

2.2.8. Microscopic analysis: Optical Microscope model Nikon Eclipse E100 was used to analyze three samples of the formulations after Centrifuge Operation. Magnification of 40X/0.65 and distance ≈0.6mm, droplet dispersion was assessed. Samples were placed into microscopic glass slide using Cotton Swab and the amount was minimal, 2 drops of the formulation.

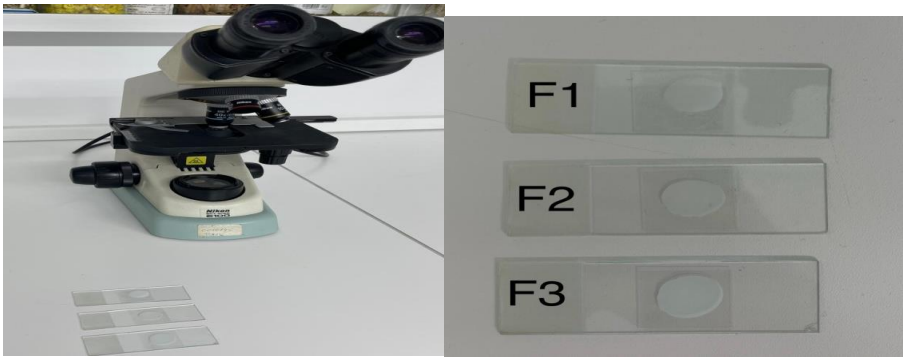


Fig 6.Optical Microscope (Left) and Glass Slides with test formulations (Right)

2.2.9. Hypersensitivity Reaction (Patch Test): With the purpose of assessing Hypersensitivity Reaction of the formulations, a skin patch test was employed (Kaushal K. Verma, 2020). Three tapes filled with cream in the middle and coded as F1, F2 and F3 were stuck in the forearm and left for 12 hours to assess a possible early allergic reaction on the skin. Visual inspection of the skin was conducted to check for possible side effects of the formulations on the skin.

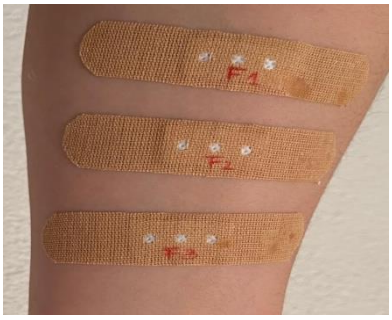


Fig 7.Skin performed Patch Test

Results

3.1.*Organoleptic Characterization :* The characteristics of three visually inspected formulations are listed below in the table.

Table 3. Organoleptic Characterization of Test Formulations

Formulations	Color	Odor	Appearance and Texture
F1	White	Mildly Cinnamon	White, soft cream, Homogeneous.
F2	White	Mildly Cinnamon	White, milky cream, Smooth and Homogeneous.
F3	White	Mildly Cinnamon	White, Thick-Viscous cream, Holding its shape.

3.2. pH Measuremen: As initially, the Paper Indicator was used to assess the pH range of the cream, from the color change it is clear that three of the formulations fall between 6-7 pH range as the color is orange- slightly green.

Fig 8.pH measurement by Universal Paper Indicator. F1 (Left), F2 (Middle) and F3 (Right

On the other hand, results obtained by utilizing the calibrated pH meter are displayed below:

Table 4.pH measurements

Formulation	pH Value
F1	6.47
F2	6.32
F3	6.29

3.3.*Density Measurement;* Density of the three test formulations was mathematically calculated, leveraging Archimedes Equations thus, we obtained the results as below:

Table 5.Density measurements

Formulation	Mass	Volume	Result
F1	11.61 g	10 mL	ρ= 11.61/10=1.161 g/mL
F2	12.18 g	10 mL	ρ=12.18/10=1.218 g/mL
F3	13.42 g	10 mL	ρ=13.42/10=1.342 g/mL

3.4.Spreadability in Plate and on Skin

Table 6. F1 Spreadability in Plate

Measurements	Weight of Glass Plate	50g	100g	150g	200g
M1	6 cm	6.6 cm	6.7 cm	7.1 cm	7.5 cm
M2	5.8 cm	6.6 cm	6.9 cm	7 cm	7.4 cm
M3	6.2 cm	6.6 cm	6.9 cm	7 cm	7.3 cm
Mean	6	6.6	6.833333	7.033333	7.4
SD	0.163299	8.88178E-16	0.094281	0.04714	0.08165

Table 7. F2 Spreadability in Plate

Measurements	Weight of Glass Plate	50g	100g	150g	200g
M1	7.1 cm	7.6 cm	8 cm	8.4 cm	8.6 cm
M2	7.1 cm	7.9 cm	8 cm	8.3 cm	8.7 cm
M3	7.6 cm	8 cm	8 cm	8.5 cm	8.8 cm
Mean	7.266667	7.833333333	8	8.4	8.7
SD	0.235702	0.169967317	0	0.08165	0.08165

Table 8. F3 Spreadability in Plate

Measurements	Weight of Glass Plate	50g	100g	150g	200g
M1	5.4 cm	5.6 cm	6.1 cm	6.5 cm	6.7 cm
M2	5.5 cm	6.0 cm	6.2 cm	6.4 cm	6.8 cm
M3	5.5 cm	5.9 cm	6.2 cm	6.6 cm	6.9 cm
Mean	5.466667	5.833333333	6.166667	6.5	6.8
SD	0.04714	0.169967317	0.04714	0.08165	0.08165

As it can be observed from the tables displayed above, three measurements of diameter were carried out for each weight addition on the plate, to ensure more accurate results. As it pertains to spreadability on skin, all of the formulations were absorbed successfully in the skin 1 minute after applying.

3.5.Accelerated Stability Study and Microscopic Analysis

No visual change was observed after Centrifugation process, all of the test formulations remained intact visually. On the other hand, microscopic analysis shows that after Centrifugation process, the most stable product is F2, exhibiting smaller dispersed oil droplets into water phase and lacking big droplets that were observed in F1 and F3.

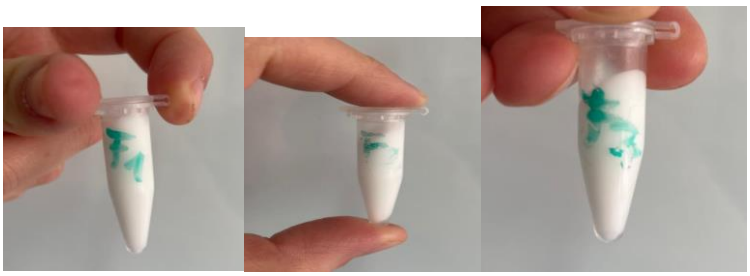


Fig 9. Test Formulations in Centrifugal tubes

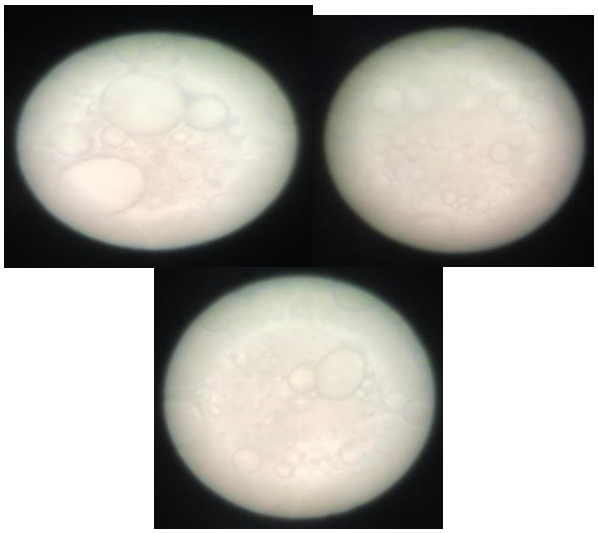


Fig 10. Optical Microscope Visualisation of F1(Left), F2(Midde) and F3 (Right)

3.6.Hypersensitivity Reaction (Patch Test): From the patch test, no visible changes in skin were detected after 12 hours.

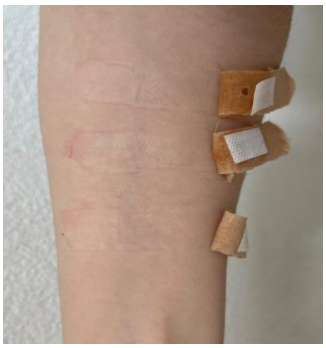


Fig 11. Skin Patch test after 12 hours

Discussion And Conclusion

As Manufacturer suggests, Emulgade SE-PF use is recommended to be between 2 - 8% of the total formulation for Cosmetic Creams (BASF). The range seems to be quite wide thus, the

physico-chemical properties changes in the cream formulations can be witnessed. Therefore, our Designed Matrix in three levels of our independent variable, considered the self-emulsifying system in three points as mentioned in the Introduction part, all falling within the tolerated limits for this ingredient. Other ingredients levels remained intact, thus, their role in the formulation is not to be discussed in this article.

In table 2, the levels of all ingredients are included with aim on delivering safe product from the formulation development stage hence, all the three formulations are safe and their amounts are justified. Temperature of preparation is adjusted based on Oil Phase ingredients melting points and the stability of the ingredients in this temperature was also considered to ensure higher quality of the products.

Organoleptic characteristics suggested that the most appropriate test formulation is F2 since it exhibited better texture and appearance considering the purpose of this formulation, incorporation of Niacinamide as an active. F1 and F2 exhibited softer and better Cream texture compared to F3.

pH values of all of formulations were not falling into the preferred range of pH for Cosmetic Face Cream (4.5-5.5) (Saba M. Ali, 2013) (H Lambers, 2006), however Citric Acid solution (50:50, Citric Acid/Water) was prepared to modify pH level of the formulations. On the other side, literature suggests that Niacinamide Cream formulations, in order to improve its activity, pH of formulation should remain between 5.0 to 7.0, more precisely pH 6 (Chem, 2026). Below 4.5, Niacinamide may convert into nicotinic acid (Thomas Sjöberg, 2026, p. NA), which can cause irritation and flushing.

The amount of Parabens in this product is within the tolerated limits by Regulatory Authorities,<0.8% for mixture of parabens (NA, 2008) (Commission, 2009) and the pH of the formulation is appropriate with their antimicrobial and antifungal activity (2-8) (E. Mani-López, 2016).

It is pivotal to mention that the measurement of Density is not conducted by specialized device thus the values are approximate. Density value areincreasing from F1 to F3 that may be attributed to its ability of the emulsifier to create Lamellar Crystal structure (Seppic, 2025) that prevent oil droplets from coalescing and separating.

When it comes to spreadability in plate optimal values, 5-7 cm (Aryan, 2024) are the optimal values that are reached by all of the test formulations however is evident that F2 exhibits better spreadability properties than the other formulations. Skin spreadability is better in F1 and F2 since they got absorbed quickly in skin and didn’t leave oily stains after application.

All three formulations resulted stable after Centrifugation Process, however, Microscopic Analysis suggests that the most stable formulation is F2 since the Oil Droplets were more uniform and smaller. The ones containing larger droplets may be subjected to system disbalance faster. In this case it is also suggested to adjust Homogenization time and speed in order to get more uniform and smaller dispersed droplets in Water Phase (Zahra Rahma Namira, 2021).

Lastly, an early hypersensitivity reaction was not observed by any of the test formulations however, it is worth mentioning that Hypersensitivity reactions can happen after 24, 48 and 72 hours (Antonino Romano, 2008) thus more detailed studies are preferred.

This study demonstrated the experimental optimization of an O/W cosmetic cream using different concentrations of a non-ionic self-emulsifying base. Among the prepared formulations, F2 exhibited the most favorable balance of physicochemical properties and physical stability. It showed appropriate texture for topical application, homogeneous appearance with no phase separation under accelerated conditions, and smaller droplet size compared to other formulations, indicating efficient emulsification. Formulations with lower emulsifier levels lacked sufficient structure and displayed early signs of instability (Bigger oil droplets dispersed in water phase), while higher levels resulted in excessive viscosity and an

undesirable waxy after-feel. Based on these findings, F2 was selected as the optimal base for further development and incorporation of Actives. As (Sousa, 2022) states in his article, O/W emulsions are the preferred ones compared to W/O types as they offer a light texture that is easy to rinse off and suitable for moisturizer formulations (as in our case) due to improved release of active ingredients to the skin (Rahmat Muliadi, 2025). Future work will focus on incorporating Niacinamide as a model active ingredient to evaluate the system's ability to deliver functional benefits while maintaining stability.

In addition, the role of the co-emulsifier will be re-assessed by preparing a modified version of F2 lacking co-emulsifier, in order to simplify the formula and investigate whether the primary non-ionic self-emulsifying base alone can provide adequate stability, texture and spreadability. Overall, the results provide a rational basis for selecting emulsifier concentration in non-ionic O/W cream systems and establish a suitable platform for subsequent formulation of active-containing cosmetic products.

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