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Research Article

Influence of natural oils on the textural and rheological properties of cosmetic creams

Antoniya Andonova[1], Viliana Gugleva[2], Yoana Sotirova[2], Krastena Nikolova[3], Marina Marcheva[4], Zhana Petkova[5], Velichka Andonova[2]

1 *Cosmetology MSc, Faculty of Pharmacy, Medical University of Varna, Varna, Bulgaria*
2 *Department of Pharmaceutical Technologies, Faculty of Pharmacy, Medical University of Varna, Varna, Bulgaria*
3 *Department of Physics and Biophysics, Faculty of Pharmacy, Medical University of Varna, Varna, Bulgaria*
4 *Department of Crop Science, Agricultural University – Plovdiv, Plovdiv, Bulgaria*
5 *Department of Chemical Technology, University of Plovdiv "Paisii Hilendarski", Plovdiv, Bulgaria*

Corresponding author: Viliana Gugleva (viliana.gugleva@mu-varna.bg)

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Abstract

Creams are semisolid dosage forms widely used for pharmaceutical and cosmetic purposes due to their pleasant appearance, easy spreadability, and the possibility to deliver hydrophobic and hydrophilic active agents. The aim of the current study was to evaluate the impact of type and concentration of different oil phases on the mechanical and rheological properties of cosmetic creams. For this purpose, a series of blank and anti-age creams were prepared applying the hot homogenization method (9000 rpm for 5 minutes). The blank creams contained an emulsifying base (Neofin Nat 8% w/w) and varying types of lipid phase: 1) babassu oil (8% w/w), 2) *Cannabis sativa* (2% w/w) and *Camelina sativa* (6% w/w) oils, 3) babassu (6% w/w) and *Cannabis sativa* (2% w/w) oils, and 4) babassu (6% w/w) and *Camelina sativa* (2% w/w) oils. The anti-age creams contained additionally *Jasminum sambac* flower extract (5% w/w) and Argireline® solution (5% w/w). The spreading, mechanical, and rheological properties of the developed formulations were investigated. The anti-age cream based on babassu (6% w/w) and *Camelina sativa* (2% w/w) oils exhibited suitable textural and rheological characteristics that would facilitate its application onto skin and provide sufficient contact time to exert its beneficial effects.

Keywords

babassu oil, *Camelina sativa* oil, *Cannabis sativa* oil, gas chromatography, rheological studies, textural analysis

Introduction

Creams are biphasic topical formulations obtained by the mixture of aqueous and oil phases. According to the type of obtained emulsion, they are often classified as hydrophilic (O/W, oil/water emulsion) and hydrophobic (O/W, water/oil emulsion). Hydrophilic creams are usually preferred for cosmetic application, as they have a non-greasy texture, pleasing textural and sensorial properties, and an easy process of spreadability and removal (Bîrsan et al. 2022). Their preference among the consumers is widely related to their texture properties, which are highly influenced by the formulation's composition. Currently, one of the tendencies in cosmetics development is the use of natural ingredients, as they are environmentally sustainable, hypoallergenic, safe, and exert numerous beneficial effects (nourishing, antioxidant, anti-age) on the skin (Hirata et al. 2022). In light of this trend the developed in the current studies cosmetic creams contained various natural-sourced ingredients such as vegetable oils (babassu, *Cannabis sativa*, *Camelina sativa*), *Jasminum sambac* flower extract, as well as natural preservatives and antioxidants (beta-carotene).

Babassu oil is extracted from the nuts of Babassu palm and is widely used as an emollient and moisturizer in cosmetic products (Da Silva et al. 2020). It contains primarily saturated fatty acids, most abundant of which are lauric (≈ 47%), myristic (15–20%), and palmitic acid (≈ 8%), as well as unsaturated ones such as oleic (between 12 and 18%) and linoleic acid (approx. 2%) (Melo et al. 2019). The method of extraction highly affects the quality of the derived oil. For pharmaceutical and cosmetic purposes, the preferred technique is the cold-pressed extraction, as it preserves its chemical composition and maintains its resistance against oxidation (Melo et al. 2019; Zanine et al. 2023).

Hemp seed oil is derived from the seeds of *Cannabis sativa* L. and is a natural source of polyunsaturated acids, most abundant of which are linoleic (55%) and alpha-linolenic acid (18%), proteins (20–25%), carbohydrates (20–30%), and minerals (Şeker and Esen 2021). The quantitative ratio between the unsaturated fatty acids is considered most appropriate for human health and metabolism, and in terms of dermal application, it is essential for maintenance of the natural hydration of the skin barrier (Mikulcová et al. 2017). In addition to its moisturizing properties, *Cannabis sativa* oil is known to exert anti-inflammatory effects and to alleviate skin irritation and pruritus (Şeker and Esen 2021).

Camelina oil is obtained from the seeds of *Camelina sativa*, an oilseed crop from the Brassicaceae family cultivated in the semi-arid regions of Europe, Russia, and North America (Ibrahim and Habbasha 2015; Neupane et al. 2022). It contains a high amount of polyunsaturated fatty acids (50–60%), ω-3 (35–40%), and ω-6 fatty acids (15–20%), as well as tocopherols (between 700 and 800 mg/kg seeds) (Abramovič et al. 2007; Imbrea et al. 2011). When applied topically, Camelina oil favorably affects skin hydration, improves elasticity, and protects the skin from premature aging due to oxidative stress (Crăciun et al. 2019). Various environmental factors, such as soil composition, rainfall, and ambient temperature, may affect the quality and the quantitative composition of the oil. For instance, high temperatures lead to reduced oil concentration, whereas continuous rainfall affects the levels of phospholipids, tocopherols, and phytosterols (Riaz et al. 2022).

Jasminum flower extract and Argireline® solution were also included in the cream's composition. The flowers of Arabian jasmine (*Jasminum sambac*) have well-pronounced anti-inflammatory and antimicrobial properties and are capable of improving skin turgor, hydration, and brightening the skin (Karpe et al. 2024). Considering that the olfactory evaluation is an important element of the development of a cosmetic product, *Jasminum sambac* extract also contributes to the pleasant aroma of the final product. Argireline, also known as acetyl-hexapeptide-8, is used in cosmetics as a safe alternative to botulinum toxin. Structurally, it is a peptide containing the sequence Ac-Glu-Glu-MetGln-Arg-Arg-NH_2 (acetyl-glutamyl-glutamyl-methionyl-L-glutaminyl-arginyl-arginyl-amine) (Blanes-Mira et al. 2002). Its mechanism of action is related to the inhibition of the soluble SNARE (soluble N-ethylmaleimide-sensitive factor attachment protein receptor) complex. Argireline competes with SNAP-25 (synaptosomal associated protein 25) for the position in the complex, and its subsequent destabilization inhibits neurotransmitter release from the vesicle and prevents Ca^{2+}-induced exocytosis. Therefore, the muscle contraction weakens, the muscle relaxes, and the formation of facial lines and wrinkles is prevented (Blanes-Mira et al. 2002; Kluczyk et al. 2021).

The aim of the current study was to evaluate the impact of the type and ratios of different oil phases, as well as the inclusion of active ingredients, on the textural characteristics (firmness, cohesiveness, and adhesiveness) and rheological properties of the developed cosmetic formulations.

Materials and methods

Materials

Cold-pressed hemp oil (*Cannabis sativa* seed oil) and refined babassu oil (*Orbignya oleifera* seed oil) were ordered from Dobika Trend Ltd., Bulgaria (https://www.ekomama.net). Camelina oil is extracted from a cultivated variety in Bulgaria, grown and financed by the Bulgarian national science fund international project КР - 06-ДО 02/4. Emulsifying bases for the preparation of cosmetic creams Neoderm (behenyl alcohol, polyethylene glycol ether-25 of cetyl alcohol, cetyl alcohol, polyethylene glycol-8 stearate, PEG-8 stearate) and Neofin Nat (cetearyl alcohol, polyglyceryl-3 stearate, caprylic/capric triglycerides, sodium stearoyl lactylate, hydrogenated coconut oil, shea butter, octyldodecanol, beeswax) were ordered from Dobika Trend Ltd., Bulgaria (https://www.ekomama.net). Jasmine extract (*Jasminum sambac* extract), solution of Argireline® (acetyl hexapeptide-8) peptide, beta-carotene (*Daucus carota* extract), and natural preservatives for cosmetics (Conservante Natural—potassium sorbate, sodium benzoate, benzyl alcohol, water) were ordered by Dobika Trend Ltd., Bulgaria (https://www.ekomama.net).

Methods

Extraction of Camelina sativa *oil*

Camelina sativa seed oil is extracted from a cultivated variety in Bulgaria, grown and financed by the Bulgarian national science fund international project КР-06-ДО 02/4, using the cold pressing technique. The oil obtained was filtered and stored at 4 °C.

Determination of fatty acid composition, total tocopherols, and individual tocopherol composition of glyceride oil isolated from Camelina sativa *seeds*

The fatty acid content of *Camelina sativa* oil was determined using the gas chromatography (GC) method. Fatty acid methyl esters (FAME) were purified by silica gel TLC on 20 × 20 cm plates coated with a 0.2 mm silica gel 60 G layer (Merck, Darmstadt, Germany) with a mobile phase n-hexane:acetone 100:8 (v/v). GC was performed on an HP 5890 (Hewlett Packard GmbH, Austria) gas chromatograph equipped with a 30 m × 0.25 mm (inner diameter) InnoWax capillary column (crosslinked with polyethylene glycol, Hewlett Packard GmbH, Austria) and a flame ionization detector. The column temperature was elevated from 165 °C to 240 °C (4 °C/min); injector and detector temperatures were 260 °C. The carrier gas was nitrogen at a flow rate of 0.8 cm^3/min; the split was 100:1. Identification was performed by comparison of retention times with those of a standard mixture of fatty acids subjected to GC under identical experimental conditions.

Preparation of cosmetic creams

Preparation of cream bases

A series of cream bases were prepared using the emulsifying base Neofin Nat (8% w/w), to which different types of oil phases (8% w/w total content) were added: babassu oil 8% (w/w) (C1); hemp oil 2% (w/w) and camelina oil 6% (w/w) (C2); babassu oil 6% (w/w) and hemp oil 2% (w/w) (C3); babassu oil 6% (w/w) and camelina oil 2% (w/w) (C4). Accurately weighed amounts of the emulsifying base and the oil phase were melted at 80 °C. The required quantity of purified water was heated to the same temperature, after which the two phases were mixed and homogenized using an ULTRA-TURRAX T25 digital homogenizer (IKA-Werke, Staufen, Germany) at 9000 rpm for 5 min. After reaching a temperature of 38 °C, the preservative (1.5%) (w/w) and the antioxidant beta-carotene (1%) were added. The mixture was re-homogenized for 2 minutes (9000 rpm) until the formation of thick viscous consistency.

Another series of cream bases were prepared by using emulsifying base Neoderm (8% w/w) and an oil phase containing: babassu oil 8% (w/w) (C5); hemp oil 2% (w/w); camelina oil 6% (w/w) (C6); and 16% babassu oil (C7) was added. The cream bases were prepared according to the technological scheme described above.

Preparation of cosmetic anti-age creams

After the preliminary studies, three models of cream bases were selected and further loaded with the active ingredients. The creams were prepared following the described protocol, with the difference that in the cooling phase, in addition to the preservative and antioxidant, jasmine extract (5%) (w/w) and argireline solution (5%) (w/w) were also added. Their quantity was subtracted from the aqueous phase to maintain the quantitative ratios constant.

Characterization of cosmetic creams

Physical appearance

The appearance of the prepared cosmetic bases and creams was visually evaluated in terms of color, odor, homogeneity, and uniformity (Chauhan and Gupta 2020).

Determination of the type of emulsion

The emulsion type was determined by the water dilution method. For this purpose, 5 g of the prepared creams were placed in a beaker containing 20 mL of purified water. O/W creams are uniformly dispersed in the aqueous phase, whereas in the case of lipophilic (W/O) creams, two separate phases are observed (Chauhan and Gupta 2020).

Emulsion stability

The stability of the prepared cream bases and antiaging creams was evaluated by centrifuging the formulations at 10,000 rpm for 10 min (Patel et al. 2022) using a microcentrifuge (D2012 Plus, DLAB Scientific, Rowland St. City of Industry, CA, USA). Creams are considered stable when no phase separation is observed after the experiment.

pH determination

The pH value of developed creams (10% w/w aqueous dispersions) was determined using a portable pH meter (pH 70 Vio, XS Instruments, Carpi, Italy), calibrated before the experiment with standard buffer solutions (pH 4.00 and 7.00). The result is presented as means (± standard deviation, SD) of three measurements (Chauhan and Gupta 2020).

Spreadability

The spreadability of the creams was evaluated according to a previously described methodology (Dantas et al. 2016). For this purpose, 0.5 g of the tested creams were placed on a glass plate in a pre-drawn circle (Ø = 2 cm). After that, a second plate weighing 0.5 kg was placed over the semisolid sample. The experiment was conducted within 5 min, and, at its end, the spreading diameter for each individual composition was measured. The test was performed three times.

Textural analysis

A *Belle* texture analyzer (Agrosta Overseas, Serqueux, France) was used to investigate the mechanical properties of the developed semisolids. A cylindrical probe (Ø = 18 mm) was compressed in the formulation and adjusted to operate in a single compression mode. The following parameters were set: 5 kg cell load, pre- and test speed 3 mm/s, and insertion depth 5 mm. All measurements were performed in triplicate (Sotirova et al. 2023).

Rheological studies

Rheological studies were performed using the HAAKE™ Viscotester™ 550 (Thermo Fisher Scientific, Waltham, MA, USA), equipped with an SV DIN coaxial cylinder sensor. The samples were analyzed under shear rates varying from 0.0123 s^{-1} to 1000 s^{-1}. Each semisolid was examined three times at 32 ± 1 °C. Shear stress as a function of shear rate was investigated. Two non-linear models were used to obtain the main rheological parameters: the power law model (PLM) and the Herschel-Bulkley model (HBM) (Table 1).

Statistical analysis

Data was processed with SPSS software, version 26.0 (IBM Corp., Armonk, NY, USA). All results are presented as mean value ± standard deviation (SD). Differences between the means were assessed by one-way analysis of variance at a *p*-value of less than 0.05. Their subsequent comparison was performed by Duncan's test. The coefficients in the rheological model were obtained by using OriginLab 2022.

Results and discussion

Extraction of *Camelina sativa* oil

Camelina (*Camelina sativa*) seeds needed for the oil extraction were obtained from a certified organic field in 2023. A minimum agricultural technique was applied, such as organic fertilizer and insecticides approved for use in biofarms. No plant diseases were detected, and the crop was harvested in good phytosanitary condition. The resulting product (camelina seeds) was subjected to mechanical cold pressing to extract the oil, which was stored at 4 °C for subsequent research. The extracted oil in the current study amounts to 35%, which is in accordance with the results obtained from other research groups, reporting that *Camelina sativa* seeds contain oil between 38% and 43% (Krzyżaniak and Stolarski 2019; Walia et al. 2021; Veljković et al. 2022).

Determination of fatty acid composition, total tocopherols, and individual tocopherol composition of glyceride oil isolated from *Camelina sativa* seeds

The fatty acid composition, total tocopherols, and individual tocopherol composition of the glyceride oil isolated from *Camelina sativa* seeds were determined using the gas chromatography method. The analysis showed that the extracted oil contained 34.8% fat, 11.7% saturated fatty acids (SFA), and 88.3% unsaturated fatty acids (UFA), of which monounsaturated were 33.2% and polyunsaturated were 55.1%. Twenty-one fatty acids were detected, most present of which were α-linolenic acid (ALA) (31.3%), linoleic acid (LA) (19.9%), oleic acid (15.2%), eicosenoic acid (14.4%), and palmitic acid (6.1%). Our results agree with other studies, according to which the main fatty acid in *Camelina sativa* seed oil is ALA, varying between 22.8 and 38.4% (Anderson et al. 2019; Jankowski et al. 2019). ALA and LA are essential, polyunsaturated fatty acids. ALA belongs to the ω-3 group, while LA is a ω-6 fatty acid. It is well known that ω-3 and ω-6 FA are essential to maintaining the skin's natural hydration and retaining moisture in it.

Table 1. Mathematical models applied to calculate the rheological parameters of the semisolids (Leusheva et al. 2021).

Model	Mathematical equation
Power law model (PLM)	$\tau = K \cdot \gamma^n$
Herschel-Bulkley model (HBM)	$\tau = \tau_0 + K \cdot \gamma^n$

Note: τ, shear stress; γ, shear rate; τ_0, yield stress; K, consistency index; n, power law index.

Regarding the content of tocopherols, the total content was equal to (832 ± 41) mg.kg^{-1}, with γ-tocopherol (95.1 ± 0.5)% being present in the highest amount. According to other studies (Fan and Eskin 2013; Mushtaq 2021), camelina oil has a high content of total tocopherols, varying between 695 mg.kg^{-1}and 994 mg.kg^{-1} for crude oil and between 580 mg.kg^{-1} and 1564 mg.kg^{-1} for refined oil. Camelina seed oil is estimated to be a better source of tocopherols than canola, olive, soybean, sesame, and sunflower oils (Belayneh et al. 2015).

The estimated qualitative and quantitative composition of tocopherols and fatty acids in *Camelina sativa* seed oil determines the possible beneficial effects of its application in cosmetic products, mainly cosmetic creams with an anti-aging effect.

Preparation and characterization of cream bases

In preliminary studies, cream bases were prepared by varying the oil content and the type of self-emulsifying base (Table 2). The concentration of the self-emulsifying bases Neofin Nat and Neoderm (8% w/w) was chosen based on the information provided in the technical specification and of the individual oils (babassu, hemp, and camelina) according to the relevant literature (Sousa Vieira et al. 2017; Lubart et al. 2023; Biochemica® Camelina Oil Natural: https://www.hallstarbeauty.com/product/biochemica-oil-nat/ (accessed 10.05.2024)).

In the models based on Neofin Nat and an oil phase content of 8%, creams with a characteristic creamy consistency and smooth texture were obtained (Fig. 1), in contrast to the formulations with Neoderm (C5 and C6), which were successfully emulsified but retained their fluid consistency even after cooling to room temperature. The obtained results can be explained by the differences in the components of the two self-emulsifying bases. Neofin Nat contains beeswax, which contributes to the formation of a creamy consistency with a lower total oil phase (below 10%). Unsatisfactory results were also obtained with the two-fold increase in the oil phase (16% w/w) in combination with Neoderm (model C7), where a homogeneous

Table 2. Composition, visual appearance, and pH values of cream bases.

Composition (% w/w) Visual appearance, pH	C1	C2	C3	C4	C5	C6	C7
Neofin Nat	8%	8%	8%	8%	–	–	–
Neoderm	–	–	–	–	8%	8%	8%
Babassu oil	8%	–	6%	6%	8%	–	16%
***Cannabis sativa* oil**	–	2%	2%	–	–	2%	–
***Camelina* oil**	–	6%	–	2%	–	6%	–
Antioxidant (β-caroten)	1%	1%	1%	1%	1%	1%	1%
Preservative	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%
Purified water	q.s. to 100%	q.s. to 100%	q.s. to 100%	q.s. to 100%	q.s. to 100%	q.s. to 100%	q.s. to 100%
Visual appearance	White cream	Light green cream	Light yellow cream	Pale yellow cream	White viscous fluid	Light green viscous fluid	White viscous fluid
pH value	5.61 ± 0.04	6.00 ± 0.07	5.86 ± 0.02	6.12 ± 0.08	5.62 ± 0.05	6.24 ± 0.03	5.64 ± 0.02

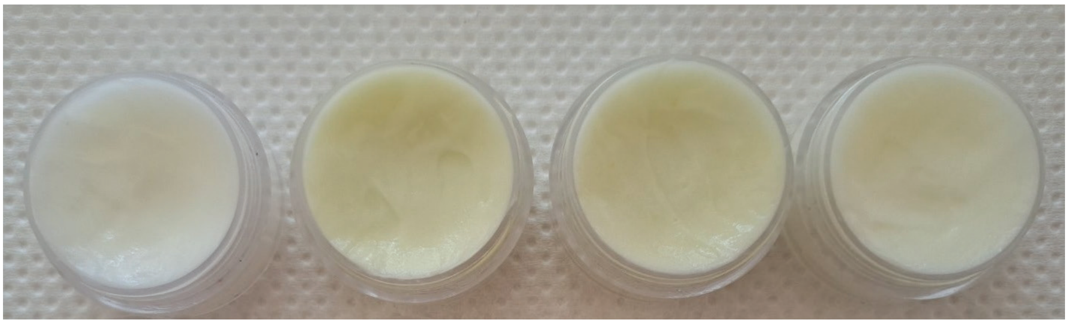


Figure 1. Physical appearance of cream bases.

emulsion was formed without reaching a viscous consistency upon cooling.

Based on the preliminary studies conducted, the models based on Neofin Nat and total oil phase content (8% w/w) were selected for further characterization.

As evident from Fig. 1, all cream-base models are characterized by a creamy consistency, a smooth texture, and a homogeneous appearance. The observed color differences are due to the inherent characteristics of the individual native oils. The presence of hemp oil in the composition determines the observed pale green/pale yellow color in models C2 and C3, respectively. Regarding pH, all cream base models are characterized by values suitable for dermal application (within the range of 5.61–6.24), which determines their good tolerance during application.

Studies evaluating the emulsion type and assessing their stability under "stress" conditions are essential to characterizing creams. The prepared cream bases are emulsions of the O/W type, characterized by excellent physical stability after centrifugation at 10,000 rpm for 10 min without the presence of phase separation.

The subsequent stage in the preliminary studies was the assessment of the mechanical properties (hardness, cohesiveness, and adhesiveness) and the spreadability of the prepared cream bases to choose a suitable model for subsequent loading of the active ingredients—jasmine extract and argireline solution. In the studied cream bases, an inverse relationship was observed between the creams' hardness and their spreadability (Table 3). Higher spreadability values are generally preferred when developing cosmetic products for application over a larger body area to facilitate the application process. In this regard, successive studies were carried out using models C1, C2, and C4, which have greater firmness.

Preparation and characterization of anti-age creams

Table 4 and Fig. 2 present the composition and physical appearance of the anti-age creams (denoted with the abbreviation L: loaded).

The prepared anti-age creams are characterized by a smooth texture and a viscous consistency (Fig. 2). A slight jasmine fragrance and higher pH values, probably due to the addition of argireline solution (pH 6.0–7.0), can be outlined as differences from the cream bases. Regarding their physical stability, the anti-age creams retain their homogeneous texture after centrifugation (10,000 rpm for 10 minutes), an essential requirement in developing biphasic dermal formulations.

Spreadability

The spreadability of dermal formulations is an important parameter related to their uniform distribution on the skin, which affects their effectiveness. The cream bases and the anti-age creams based on babassu oil (C1 and C1L, respectively) are characterized by the highest spreadability values. In contrast, the models containing *Cannabis sativa* oil and *Camelina sativa* oil (C2 and C2L) exhibit the lowest (Table 5). Including jasmine extract and argireline solution in creams decreases the spreadability

Table 3. Mechanical properties of cream bases.

Model	Spreadability, mm (± S.D)	Firmness, g (± S.D)	Cohesiveness, g.s (± S.D)	Adhesiveness, g.s (± S.D)
C1	73.17 ± 2.25[a]	42.00 ± 2.00[a,b]	54.97 ± 3.64[b]	-4.17 ± 1.70[b]
C2	64.00 ± 1.73[b]	48.67 ± 3.21[a]	65.43 ± 3.91[a]	-8.83 ± 2.89[b]
C3	74.67 ± 1.53[a]	37.00 ± 5.00[b]	50.06 ± 8.41[c]	-4.33 ± 2.21[a]
C4	71.17 ± 3.88[a]	47.33 ± 4.62[a]	61.97 ± 4.52[a,b]	-5.33 ± 1.10[a,b]

Table 4. Composition, visual appearance, and pH values of anti-age creams.

Composition (% w/w) Visual appearance, pH	C1L	C2L	C4L
Neofin Nat	8%	8%	8%
Babassu oil	8%	–	6%
***Cannabis sativa* oil**	–	2%	–
***Camelina* oil**	–	6%	2%
Antioxidant (β-caroten)	1%	1%	1%
Preservative	1.5%	1.5%	1.5%
Jasmine extract	5%	5%	5%
Argireline	5%	5%	5%
Purified water	q.s. to 100%	q.s. to 100%	q.s. to 100%
Visual appearance	White cream	Pale green cream	Pale yellow cream
pH	5.82 ± 0.09	6.18 ± 0.06	6.33 ± 0.08

while maintaining the tendency to the effect of individual oils. The observed difference in spreadability diameters after loading with the active ingredients was statistically significant only in the models containing babassu oil in their composition (C1, C4, and C1L, C4L) ($p < 0.05$).

The differences in the characteristics of the oils can explain the obtained results. Among the investigated oils, only babassu oil is in a solid physical state at room temperature, has the highest melting point, and contains predominantly (over 50%) saturated fatty acids (lauric and myristic). The latter probably interacts with the other lipid phase components, affecting the creams' firmness and, respectively, the spreadability.

Mechanical properties of cream bases and anti-age creams

Firmness

The resistance of a material to localized deformation, i.e., hardness or firmness, is defined as the maximum force recorded during uniaxial compressive deformation (Almeida et al. 2017). Again, a factor with a significant influence appears to be the type of oil phase. Here, the presence of babassu oil contributes to lower firmness values (Table 6). The inclusion of jasmine extract and argireline solution also affected the parameter in question, i.e., it led to an increased firmness in all samples. The obtained results correlate with the spreadability data, yet the changes are not statistically significant.

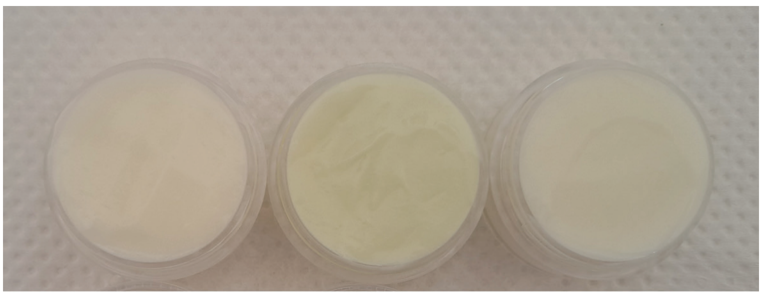
Cohesiveness

Cohesiveness is the force needed to deform a sample during textural analysis and is graphically expressed as the positive area under the force-time curve (Wróblewska et al. 2020). The lowest cohesiveness values were found for the babassu oil-based creams (C1 and C4). After the active agents were included in creams, higher cohesiveness was observed. The increased value was expected since there is a directly proportional relationship between firmness and cohesiveness. However, only the formulation based on babassu oil and camelina oil (C4L) was significantly more cohesive ($p < 0.05$) (Table 6).

Table 5. Spreadability and mechanical properties of creams presented as mean (± S.D).

Model	Spreadability, mm	Firmness, g	Cohesiveness, g.s	Adhesiveness, g.s
C1	73.17 ± 2.25[a]	42.00 ± 2.00[c]	54.97 ± 3.64[c]	-4.17 ± 1.70[a]
C2	64.00 ± 1.73[c,d]	48.67 ± 3.21[a,b]	65.43 ± 3.91[a,b]	-8.83 ± 2.89[b]
C4	71.17 ± 3.88[a,b]	47.33 ± 4.62[a,b,c]	61.97 ± 4.52[b,c]	-5.33 ± 1.10[a]
C1L	67.00 ± 1.32[b,c]	44.33 ± 3.06[b,c]	58.03 ± 4.29[b,c]	-5.00 ± 0.44[a]
C2L	62.00 ± 1.50[d]	49.33 ± 0.58[a,b]	64.00 ± 1.80[b]	-6.03 ± 0.46[a,b]
C4L	63.67 ± 3.06[c,d]	51.33 ± 2.52[a]	72.07 ± 5.05[a]	-6.50 ± 1.15[a,b]

Means in each column followed by a different superscript letter are significantly different ($p < 0.05$) as analyzed by Duncan's test.



C1L C2L C3L

Figure 2. Physical appearance of anti-age creams.

Table 6. Rheological parameters of the cream bases calculated using PLM and HBM.

Type of model	C1	C2	C4
PLM	K = 33.725 ± 1.308 Pa·s n = 0.224 ± 0.007 R^2 = 0.9714	K = 16.424 ± 1.890 Pa·s n = 0.349 ± 0.020 R^2 = 0.8980	K = 17.868 ± 1.478 Pa·s n = 0.273 ± 0.150 R^2 = 0.9140
HBM	τ_0 = 5.541 ± 3.969 Pa K = 26.693 ± 3.831 Pa·s n = 0.263 ± 0.020 R^2 = 0.9710	τ_0 = 3.694 ± 7.973 Pa K = 9.241 ± 4.561 Pa·s n = 0.477 ± 0.075 R^2 = 0.4980	τ_0 = 0.000 ± 4.684 Pa K = 17.868 ± 4.461 Pa·s n = 0.273 ± 0.035 R^2 = 0.9140

Mean values with different superscript letters in a column differ significantly ($p < 0.05$) as analyzed by Duncan's test.

Adhesiveness

The resulting force-time textural plot provides insights into the adhesiveness of the sample tested. Graphically presented as the negative area under the curve, it corresponds to the force required to break the intermolecular attraction between a substance and the surface of a given material. This parameter reflects the ease of removal, and regarding dermal dosage forms, it can also be interpreted as the degree of adhesion on the skin (Wróblewska et al. 2020; Baixauli et al. 2022). The highest adhesiveness value among the cream bases was observed in the *Cannabis sativa* oil-containing formulation (C2), whereas in the case of anti-age creams, the model based on babassu and *Camelina sativa* oil (C4L) was most adhesive (Table 6). Higher adhesiveness values correspond to improved skin retention, longer contact time, and a more pronounced effect.

Fig. 3A–C presents the textural analysis results.

Rheological studies

Two non-linear mathematical models were used to obtain the rheological characteristics of the developed creams, and the results are shown in Tables 6, 7.

PLM and HBM are among the most commonly used models for calculating the rheological parameters of semisolid dermal formulations. A significant difference ($p < 0.05$) in the determination coefficients of the creams with hemp oil and camelina oil (C2 and C2L) is noticeable for the two mathematical models. The PLM can better describe the rheological behavior of these semisolids. Samples C1 and C4L can also be attributed to this model, with a more negligible difference between R^2 values in PLM and HBM. In the base containing babassu oil and camelina oil (C4), as well as in the loaded babassu oil-based cream (C1L), the values of the determination coefficients in both mathematical models are equal. Since their yield stress (τ_0) equals zero (Table 1), their flow behavior can also be described by PLM.

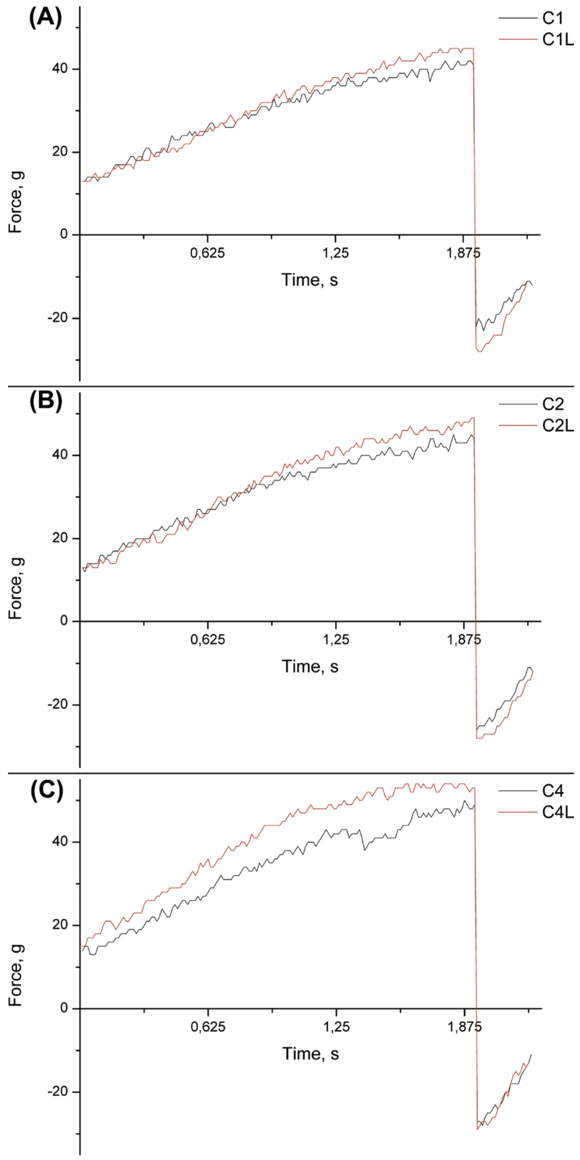


Figure 3. Force-time curves after textural analysis: **A.** Models C1 and C1L; **B.** Models C2 and C2L; **C.** Models C4 and C4L.

Table 7. Rheological parameters of the anti-aging creams calculated using PLM and HBM.

Type of model	C1L	C2L	C4L
PLM	K = 17.094 ± 1.000 Pa·s n = 0.255 ± 0.000 R^2 = 0.9280	K = 14.841 ± 1.161 Pa·s n = 0.294 ± 0.014 R^2 = 0.9260	K = 32.558 ± 0.978 Pa·s n = 0.181 ± 0.006 R^2 = 0.9660
HBM	τ_0 = 0.000 ± 3.815 Pa K = 17.094 ± 3.727 Pa·s n = 0.254 ± 0.030 R^2 = 0.9280	τ_0 = 2.955 ± 4.856 Pa K = 9.525 ± 3.611 Pa·s n = 0.392 ± 0.056 R^2 = 0.6910	τ_0 = 7.388 ± 3.918 Pa K = 23.804 ± 3.922 Pa·s n = 0.227 ± 0.021 R^2 = 0.9640

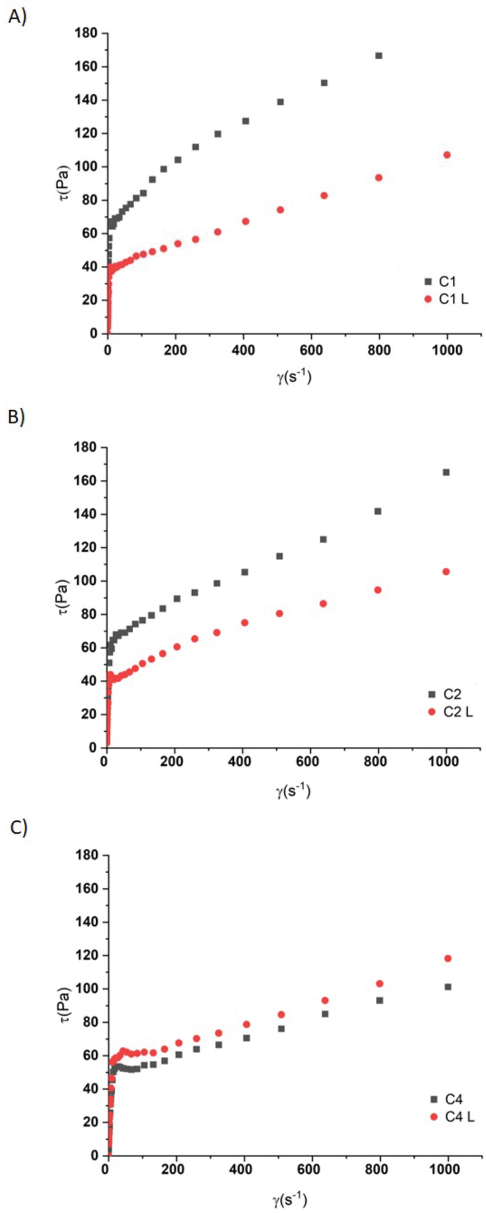


Figure 4. Flow curves of cream bases and anti-aging creams. **A.** C1 and C1L; **B.** C2 and C2L; **C.** C4 and C4L.

The power law index (*n*) is often used to define the flow type of fluids. According to its value, rheological behavior can be classified as pseudoplastic ($n < 1$), Newtonian ($n = 1$), or dilatant ($n > 1$) (Abdul Rahman et al. 2017). From the data presented in Tables 6, 7, it can be concluded that the prepared cream bases and anti-aging creams are non-Newtonian fluids characterized by pseudoplastic flow (Fig. 4).

When comparing the consistency coefficient (*K*) for the individual models, it is evident that higher K values characterize the babassu oil-containing cream bases. Regarding the anti-aging creams, better consistency (higher *K* and lower *n* values) is achieved in the C4L model.

The flow curves confirm the non-Newtonian behavior of the developed creams, as an increase in shear stress values with increasing shear rate was observed. In this type of flow, no yield stress is present, which indicates that the tested sample will begin to flow immediately after shear stress application. Higher values of (τ) after loading with argireline solution and jasmine extract were observed only for the cream based on babassu oil and camelina oil (Fig. 4C). The results are consistent with the data calculated by the mathematical models.

Conclusion

A series of cream bases and cosmetic creams were prepared, evaluating the effect of the different types and ratios of oil phases on the mechanical and rheological properties of the formulations. The investigated formulation variables strongly affect the textural characteristics of the formulation. The creams based on babassu oil are characterized by the highest spreadability and lowest firmness values, respectively. The highest firmness was observed in the models containing *Camelina sativa* oil in their composition. All the investigated models showed an increase in firmness after the inclusion of jasmine extract and argireline solution. The rheological studies showed that all formulations are non-Newtonian fluids characterized by pseudo-plastic flow. The rheological parameters (consistency coefficient (K) and power law index (n)) determined by various mathematical models showed that the most suitable consistency for dermal application exhibit cream based on babassu oil (6% w/w) and *Camelina sativa* oil (2% w/w). The formulation exhibits optimal strength, adhesiveness, and cohesiveness, as well as a suitable consistency, which would allow its easy application and ensure sufficient residence time to exert the desired cosmetic effect.

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statements

The authors declared that no clinical trials were used in the present study.

The authors declared that no experiments on humans or human tissues were performed for the present study.

The authors declared that no informed consent was obtained from the humans, donors or donors' representatives participating in the study.

The authors declared that no experiments on animals were performed for the present study.

The authors declared that no commercially available immortalised human and animal cell lines were used in the present study.

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Author contributions

Conceptualization: A.A., V.A., V.G; Investigation: A.A., V.G., Y.S., K.N., M.M. Z.P; writing sections:Y.S., K.N., M.M, Z.P.; writing original draft: A.A., V.G.; writing review and editing -V.A., V.G., K.N., M.M, Z..P., funding acquisition: K.N., V.A.

Author ORCIDs

Antoniya Andonova https://orcid.org/0009-0001-9979-639
Viliana Gugleva https://orcid.org/0000-0002-6681-8150
Yoana Sotirova https://orcid.org/0000-0001-9852-4643
Krastena Nikolova https://orcid.org/0000-0002-2617-4776
Marina Marcheva https://orcid.org/0000-0002-7568-7025
Zhana Petkova https://orcid.org/0000-0001-7798-9687
Velichka Andonova https://orcid.org/0000-0002-7369-1506

Data availability

All of the data that support the findings of this study are available in the main text.

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