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Comparative Evaluation of the Physicochemical, Antimicrobial and Stability profile of Olive oil, Almond oil and Coconut oil-based Emulgels

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ABSRTACT

The stratum corneum limits the dermal delivery of bioactive carrier oils such as almond oil, olive oil, and coconut oil, resulting in therapeutic failure. These oils could be formulated as emulgels to improve their penetration through the skin. To our knowledge, the properties of almond oil, coconut oil, and olive oil emulgels have never been compared. This work aims to formulate olive oil, almond oil, and coconut oil-based emulgels and evaluate their physicochemical, antimicrobial, and stability profile, for potential topical drug delivery. Nine emulgels, which differed in terms of the type and concentration of the carrier oil, were prepared using the spontaneous emulsification method. Their organoleptic properties, pH, viscosity, spreadability, antimicrobial activity, and accelerated and real-time stability profiles were evaluated using standard protocols. The emulgels exhibited acceptable organoleptic properties; pH values (5.2 to 5.7); spreadability (1-1.4 cm); and viscosity at 30 rpm: almond oil emulgels (384-794 cP); coconut oil emulgels (370-3620 cP); olive oil emulgels (798-9697 cP). The emulgels exhibited shear thinning behaviour; carrier oil concentration-dependent viscosity profile; and satisfactory accelerated and real-time stability profile. Formulations containing low concentrations of the carrier oil inhibited the growth of only *E. coli* (zone of inhibition: 7-10 mm) while those containing higher oil concentrations supported the proliferation of *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Escherichia coli*, and *Gardnerella vaginalis*. Olive oil emulgels were the most promising formulations based on their properties. Also, the physicochemical and antimicrobial profiles of emulgels are dependent on the type and concentration of their constituent carrier oil.

Keywords: Olive oil, Coconut oil, Almond oil, emulgels, physicochemical, antimicrobial

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Introduction

The human skin provides opportunities to deliver drugs via the transdermal route of administration due to its large surface area and accessibility. Moreover, this route of drug delivery avoids drug degradation under the influence of gastric acid and hepatic enzymes. However, the skin permeability barrier, stratum corneum, prevents the permeation of drugs and bioactive agents into underlying skin layers, whereas it permits dermal absorption of small and relatively hydrophobic therapeutic agents.[1] There are two main techniques to enhance drug transport across the skin, namely, the passive and active methods. The active strategies include iontophoresis,[2] sonophoresis,[3] Microneedles[4] and electroporation.[5] On the other hand, passive methods of drug permeation enhancement involve the use of natural and chemical permeation enhancers.[1]

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Although active drug delivery techniques facilitate rapid drug permeation into the skin, their clinical application is limited by their complexity and cost. Thus, passive drug delivery strategies are often exploited.

Essential oils are natural oily liquids containing a mixture of volatile compounds found in different parts of plants, such as flowers, fruits, leaves, and roots.

They are mainly composed of monoterpenes, sesquiterpenes, carbohydrates, alcohol, ethers, aldehydes, and ketones, and are extracted in small quantities using techniques such as steam and hydrodistillation.[6] They have been reported to enhance the dermal penetration of different hydrophilic and hydrophobic drugs.

Examples are eucalyptus oil, eucalyptol, turpentine oil, peppermint oil, and clove oil.[6] They are generally considered to be safer and less toxic than synthetic permeation enhancers. The activity of these permeation enhancers is facilitated through (1) the disintegration of the highly ordered intercellular lipid structure between corneocytes in stratum corneum, (2) interaction with intercellular domains of proteins, which induces their conformational modification, and (3) an increase in the partitioning of a drug in favour of the target body sites.[7]

Vegetable carrier oils are natural fixed oils pressed majorly from the seeds and they are used to formulate topical pharmaceutical products. Also, they are a mixture of heterogeneous lipids composed mainly of triglycerides and a low concentration of components such as free fatty acid, mono and diglycerides, sterol, phosphatides, fatty alcohol, and lipid-soluble vitamins.[8] Carrier oils differ from essential oils in terms of volatility, physicochemical properties, and aromatic characteristics, and they have been used as emulsifying agents, stabilizing agents, and

diluents for essential oils.[9] Also, they modify the barrier of the skin reversibly by fluidizing and disintegrating stratum corneum lipids, resulting in improved drug permeation into the skin.[10] Carrier oils or fatty acid-containing natural oils have efficiently facilitated transdermal penetration of both hydrophilic and lipophilic drugs.[11,12] Examples of carrier oils include jojoba oil,[13] olive oil, [12,14,15] almond oil, [16] and coconut oil. [17] Carrier oils have different pharmacological activities. For example, olive oil contains oleocanthal, which inhibits the synthesis of pro-inflammatory COX-1 and COX-2, and they exhibit similar therapeutic activity with conventional nonsteroidal anti-inflammatory drugs. Also, it contains oleic acid, which reduces the risk of oxidative deterioration.[18] Almond oil has a skin emollient and moisturising effect due to its Vitamin A and E content. Thus, it has been used to treat dry skin conditions such as psoriasis and eczema as well as fade scars and even skin tone.[19] Coconut oil exhibits various biological activities like anticancer, antimicrobial, analgesic, antipyretic, and anti-inflammatory properties *in vivo*. [20.] These carrier oils are usually messy when they are applied to the skin for nutrition or disease treatment, which prevents their patient acceptability. Also, the carrier oils do not penetrate efficiently into underlying skin tissues, which could facilitate their permeation to the systemic circulation.

Thus, emulsions were formulated to improve the aesthetic appeal of the bioactive oils as well as enhance their physicochemical and biological properties. They are thermodynamically unstable biphasic liquid systems that typically require emulsifiers to stabilize the formulation to prevent phase separation.[21] Emulsion products are suitable for formulating hydrophobic drugs as the drugs can be incorporated into the oily phase before mixing with water and emulsifiers. On the other hand, hydrogels are prepared by hydrating hydrophilic polymers, and they are beneficial for solubilizing and delivering hydrophilic agents [22].

Emulgels are an interesting class of topical dosage forms that combine emulsions and gels, and they have been investigated for topical and transdermal applications because they eliminate the limitations of emulsions and hydrogels such as poor solubilization of hydrophilic and hydrophobic therapeutic agents, respectively. Moreover, they are thixotropic, greaseless, spreadable, washable, emollient, non-staining, long shelf-life, and agreeable appearance.[23]

Previously reported almond oil emulgels contained 15 % almond oil and 5 % shea butter and Hydroxyethyl cellulose and Carbopol-based samples exhibited improved organoleptic and rheological properties compared to guar gum-based emulgels.[24] Santos and coworkers reported that propolis extract/almond oil-containing Carbopol-based emulgels exhibited porcine dermal bioadhesive force of 0.055±0.005 N and facilitated the release of about 60 % of the extract within 24 h.[25] However, the stability of the formulation was not investigated, thus their shelf-life cannot be predicted.

Elmarzugi reported that the most promising olive oil emulgels were formulated using Carbopol as the gel base, and it contained 50% olive oil The emulgel formulation exhibited acceptable droplet size, zeta potential, and stability profile, indicating that samples with high levels of carrier oil may still display improved colloidal stability if they are formulated using appropriate excipients.[26] Xanthan gum-based emulgels prepared using olive oil (8%) and myrtle oil (4%) displayed the most promising organoleptic, physicochemical, controlled drug release, and antimicrobial activity against *S. aureus* (Zone of inhibition: 24 mm) and *P. aeruginosa* (Zone of Inhibition: 23 mm).[27]

Hariyadi et al reported that the best coconut oil emulgels contained 30 % coconut oil and Carbopol 940 (2%) as a gelling agent.[17] Elmarzugi and Berdey & Voyt did not evaluate their accelerated and real-time stability profile,[24,26] thus the long-term stability of the newly developed emulgel formulation cannot be ascertained. Also, these emulgels may be prone to oxidative degradation due to the formulations' high level of carrier oils.[21]

The formulation of carrier oils as therapeutic emulgels for topical drug delivery could improve patient compliance with dosage regimen, resulting in reduced drug dosage and dosing frequency. Also, emulgels containing reduced oily phase concentration (<15 %) could exhibit satisfactory colloidal stability. To our knowledge, no studies have compared the properties of emulgels formulated using varying concentrations and types of carrier oils. This study aimed to formulate olive oil, coconut oil, and almond oil-based emulgels and evaluate their physicochemical, antimicrobial, and stability profiles to identify the promising formulation that could deliver therapeutic agents for dermal and transdermal applications.

Materials and Methods

Materials

Olive oil (Ekulo Ltd, Lagos), Almond oil (KTC Edibles, UK), Coconut oil (Biniowan Enterprises, Lagos), methyl paraben, propyl paraben (Loba Chemie, India), xanthan gum (Titan Biotech, India), polyethylene sorbitan monooleate (tween 80), clove oil (Molychem, India), and sorbitan monolaurate (span 20) (Acros Organics, USA), *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Escherichia coli*, *Gardnerella vaginalis (typed)* were obtained from the Laboratory, Department of Microbiology and Biotechnology, Faculty of Pharmacy, University of Lagos, Nigeria, Sterile Mueller-Hinton agar medium (Oxoid, Basingstoke, UK) and deionised water (Central Research Laboratory, University of Lagos, Nigeria).

Physicochemical analysis of essential oil and carrier oils

The physicochemical properties of almond oil, coconut oil, olive oil, and clove oil were evaluated using a previously reported method.[28] The solubility profile of almond oil, coconut oil, olive oil, and clove oil was evaluated using 20 % v/v of Tween 80. Other properties such as colour, clarity, form, and odour of the carrier oils and essential oil were recorded appropriately.

Nine emulgel formulations were prepared using the spontaneous emulsification technique.[29] First, blank emulsions were formulated, followed by the incorporation of the xanthan gum gel base. Briefly, xanthan gum gel (50 g) was prepared by dispersing a predetermined amount of xanthan powder in the calculated amount of distilled water maintained at 80 °C and the dispersion was stirred for 5 min, and stored for 2 h at room temperature to ensure gel hydration. Then, the blank emulsions were prepared using predetermined amounts of the aqueous and oily constituents (Table 1), and the different emulsions were incorporated into the gel base (1:1). Afterwards, the emulgel products were packed in wide-mouthed cream jars and they were protected from light and moisture.

Evaluation of emulgels

Organoleptic evaluation

The organoleptic properties of the emulgels such as colour, consistency, and homogeneity were evaluated by visual examination [29].

pH measurements

The pH of emulgel samples was determined using a digital pH meter (pH-3012B, Analytical Instruments, China). The emulgels (1 g) were diluted with 10 ml of deionised water before the probe of the pH meter was placed at various positions within the diluted emulgels and three pH readings were taken per sample in triplicates.[30]

Rheological evaluation

The viscosities of nine different emulgel samples were evaluated at 25 °C using a rotary viscometer (NDJ-8T, Mesulab Instruments, China) coupled with spindle 2. Briefly, the emulgels were secured into the sample holder, the spindle was lowered into the centre of the emulgels and the viscometer was rotated at different speeds (6, 15, 30, and 60 rpm), to determine the intrinsic and shear-dependent viscosities of the formulations.[29]

Spreadability evaluation

The emulgel formulations (1 g) were sandwiched between two glass slides, and the 20 g-weight was placed over the upper glass slide until no further spreading was evident. The difference in the spread circle diameter before and after the application of the 20 g-weight was recorded, which depicted the spreadability of the emulgels.[30]

Antimicrobial assay

The antimicrobial activities of blank emulgels were tested using the well diffusion method. A Sterile Mueller-Hinton agar medium was used for the antimicrobial assay of *Staphylococcus aureus*, *Pseudomonas*

aeruginosa, *Escherichia coli*, and *Gardnerella vaginalis*. The media were prepared and allowed to solidify in the Petri dishes. Then, 0.1 mL of the microbial suspension (10^6 CFU/mL) was streaked over the surface of the medium using a sterile glass spreader. The wells (10 mm) were made using a cork borer under aseptic conditions and the wells were filled with the emulgels. The Petri dishes were allowed to stand for 4 h before incubation. Afterward, the plates were incubated for 24 h at 37°C to facilitate microbial growth, and microbial inhibition zones were evaluated [29].

Accelerated stability studies: centrifugal analysis

Centrifugal analysis was carried out according to a previously reported method.[30] The test was carried out to evaluate the stability profile of the emulgels. The various emulgels (5 g) were transferred into centrifuge vials and secured in the Eppendorf Centrifuge 5810 (Sigma-Aldrich, UK), and the equipment was run at 4,000 rpm for 10 min over 2 cycles. The creaming index of the samples was evaluated as detailed below:

$$\text{Creaming index (\%)} = \frac{\text{HS}}{\text{HE}} \text{ x } 100 \quad \ldots\ldots (1)$$

Where HS is the height of the cream layer after centrifugal analysis, and HE is the total height of the emulgel formulation before centrifugation. The smaller the value of the creaming index, the more stable the emulgel.[29]

Real-time stability studies at 25 ± 2 °C/75% ± 5% RH and 40 ± 2 °C/75% ± 5% RH

The emulgels were secured in 5 mL vials, and their physical stability was studied under ambient conditions (25±2°C), and at elevated temperature (40±2°C) for 3 months. The samples were evaluated in terms of pH, colour, and odour changes as well as signs of phase separation at 0, 7, 15, 30, 60, and 90 days.[30]

Statistical analysis:

Data was collected in triplicates and expressed as mean ± standard deviation. GraphPad Prism version 10.2.3.403 software was used to conduct a One-Way Analysis of Variance/Bonferroni posthoc test of viscosity values of emulgels, with $p < 0.05$ indicating significant statistical differences between datasets.[31]

Results/Discussion

Physicochemical attributes of almond oil, coconut oil, olive oil, and clove oil

Table 2 shows the physicochemical properties of carrier oils and essential oil (clove oil), which served as permeation enhancers in the emulgel formulation. All the carrier oils were pale yellow, clear, flowing liquids with their unique smell, highly soluble in 20 % v/v of Tween 80, and the calculated density values of the bioactive oils ranged from 0.95 to 1.01 g/mL, which were comparable to that reported in the literature.[32–35]

Formulation of emulgels

The carrier oils investigated in our current study (almond oil, coconut oil, and olive oil) were formulated as emulgels (Table 1) to prevent messiness and cloth staining, which could result in poor patient acceptability of the bioactive oils for skin nutrition and disease treatment. In addition, these bioactive oils are not able to penetrate deeply into the dermis region of the skin, which is a prerequisite for bioactive oils to treat invasive skin diseases and pathological conditions requiring systemic drug delivery.

The vehicle is an important component of a formulation that determines the extent of solubilisation of the loaded drug; drug permeation and delivery to target sites as well as the therapeutic effectiveness of the drug product. Also, the type and concentration of oily phase, gelling agent, emulsifier, and preservatives are important parameters that dictate the formation and stability of emulgels.[36,37] All the studied emulgels were successfully formulated because an appropriate amount of oily and aqueous phases as well as surfactants and preservatives were used to prepare the emulgels. For instance, the oily phase that comprises almond oil, coconut oil, and olive oil ± clove oil ranged from 2.5 %-7.5 % and the gel base was prepared using xanthan gum (3%). This finding is in good agreement with previous studies on palm olein-based emulgels that remained stable for at least 3 months post-storage due to the xanthan gum content (3%)[29]

Organoleptic properties

The organoleptic attributes of emulgels influence patient acceptability and compliance [38]. The olive oil, almond oil, and coconut oil emulgels containing 5% and 7.5% of the fixed oil were off-whitish; homogenous; possessed agreeable odour; smooth consistency, and free of grittiness whereas samples containing low concentrations of olive oil, almond oil, and coconut oil (2.5%) appeared translucent due to their high gel content and low concentration of carrier oil used to generate the emulsion component of the emulgels.

Physicochemical properties of emulgels

The physicochemical attributes of the emulgels are presented in Table 3. The pH values of the emulgels (5.2-5.4) were suitable for dermal and transdermal drug delivery because the formulations with pH values that ranged from 5 to 7 have been reported to exhibit low skin sensitization values.[39] Nevertheless, the almond oil emulgels in the current study would induce less skin sensitisation than the almond oil/shea butter-based emulgels reported by Berdey & Voyt, which exhibited pH values from 5.9 to 6.4.[24] Also, palm olein-based emulgels containing 5% of carrier oil exhibited comparable pH to that of almond oil, coconut oil, and olive oil emulgels containing a similar amount of gel base and carrier oil (pH 5.5 versus 5.2).[29] These findings revealed that the type of oily components used to formulate emulgels could influence their pH values.

All the emulgels exhibited acceptable spreadability (1.1.-1.4 cm). The spreadable nature of emulgels is important for effective contact between the skin and the topical drug products to deliver therapeutic agents locally and systemically. In addition, almond oil, coconut oil, and olive oil emulgels containing 5 % of the carrier oil exhibited improved spreadability compared to palm olein-based emulgels containing a similar amount of gelling agent (xanthan gum: 3 %) and carrier oil (5%) (1.2 cm versus 0.4 cm). This finding revealed that the type of carrier oil used to formulate emulgels had a greater impact on their spreadability than the type of gelling agent used to formulate the emulsion component of the emulgels.

The viscosity of emulgels at 30-40 rpm depicted their intrinsic viscosity.[29] The emulgels exhibited an oily phase concentration-dependent viscosity profile (Figure 1) as the viscosity of the emulgels increased as the concentration of olive oil, almond oil, or coconut oil used to formulate the emulgels increased. Overall, emulgel samples formulated using 7.5% olive oil displayed the greatest intrinsic viscosity value (9696 cP at 30 rpm). The intrinsic viscosity value of palm olein-based emulgels prepared using 5 % of the carrier oil[29] was greater than that of almond oil and coconut oil-based emulgels (529 cP versus 384 cP versus 371 cP) ($p < 0.05$) but less than that of olive oil emulgels (1731 cP) containing similar concentrations of carrier oil. This finding revealed that the type of carrier oil influenced their rheological properties.

Surprisingly, emulgels containing 2.5% coconut oil displayed the highest viscosity values amongst the coconut oil-based emulgels at all evaluated shear rates (6—60 rpm). Also, emulgels containing 2.5% almond oil displayed greater viscosity values at all investigated shear rates (6 rpm—60 rpm) than those formulated using 5% almond oil. On the other hand, samples prepared using 7.5% almond oil exhibited greater viscosity values than those prepared using 5 % almond oil, revealing that the type and amount of oil used to formulate emulgels influenced their rheological profile.

All the studied emulgels exhibited shear thinning behaviour (Figure 1) as their viscosity values decreased with increasing shear rates from 6 to 60 rpm. This finding is in good agreement with earlier studies on almond oil/shea butter-based emulgels that displayed shear thinning behaviour.[24] This rheological property is particularly beneficial to remove the emulgels from containers with a pump system as the emulgels will be readily extruded. Also, the emulgels would be readily spread over the diseased skin area, facilitating improved drug residence over a prolonged period.

Emulgels containing 2.5% olive oil, almond oil, or coconut oil will be beneficial for improved solubilisation of hydrophilic drugs while those

containing 5-7.5% olive oil almond oil, or coconut oil will be useful to solubilize hydrophobic drugs. Interestingly, there was about a 6-fold increase in the intrinsic viscosity of emulgels containing 7.5% olive oil compared to formulations prepared using 5% olive oil. Also, the viscosity value of emulgels prepared using 5% olive oil was twice greater than that of emulgels formulated using 2.5% olive oil, suggesting that olive oil-based emulgels were the most promising formulation to improve the residence of the emulgel at the site of application.

Antimicrobial properties of the emulgels

The antimicrobial profiles of the emulgels are presented in Table 4. The *in vitro* and *in vivo* performances of emulgels are dependent on their physicochemical, biological, and stability profile.[40] Clove oil was included in the formulation to serve as a permeation enhancer, though it possesses intrinsic antibacterial properties.[41] Olive oil and coconut oil emulgels containing 2.5% and 5% of olive oil or coconut oil displayed zones of *E. coli* inhibition (ZOI) of 10 mm and 7 mm, respectively

Table 1: Composition of olive oil, almond oil, and coconut oil-based emulgels

Ingredient	OL 2.5	OL 5	OL 7.5	AL 2.5	AL 5	AL 7.5	CO 2.5	CO 5	CO 7.5
Xanthan gum (% w/w)	3	3	3	3	3	3	3	3	3
Olive oil (% v/w)	2.5	5	7.5	-	-	-	-	-	-
Almond oil (% v/w)	-	-	-	2.5	5	7.5	-	-	-
Coconut oil (% v/w)	-	-	-	-	-	-	2.5	5	7.5
Clove oil (% v/w)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Span 20 (%v/w)	4	4	4	4	4	4	4	4	4
Tween 80 (% v/w)	4	4	4	4	4	4	4	4	4
Methyl paraben (% w/w)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Propyl paraben (% w/w)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Water (q.s.)	100	100	100	100	100	100	100	100	100

Key: OL2.5/AL2.5/CO2.5: emulgels containing 2.5% of olive oil/almond oil/coconut oil; OL5/AL5/CO5: emulgels containing 5% of olive oil almond oil/coconut oil; OL7.5/AL7.5/CO7.5: olive oil emulgel containing 7.5% of olive oil/ almond oil/coconut oil

Table 2: Physicochemical analysis of carrier oils and essential oil

Oily component	Colour	Clarity	Form	Odour	Solubility	Density (g/mL)
Almond oil	Pale yellow	Clear	Flowing liquid	Fresh almond	+	0.946g/mL
Coconut oil	Pale yellow	Clear	Flowing liquid	Fresh Coconut	+	0.980g/mL
Olive oil	Pale yellow	Clear	Flowing liquid	Fresh olive	+	0.992g/mL
Clove oil	Pale yellow	Clear	Flowing liquid	Fresh Clove	+	1.010g/mL

Key: + = Solubility of test oil in 20 % v/v of Tween 80

On the other hand, the almond oil emulgel formulation containing 2.5 % almond oil was the only sample that exhibited antimicrobial activity against *E. coli* among the almond oil-based samples (ZOI: 10 mm). Samples containing 7.5% of all the studied fixed oils (olive oil, coconut oil, and almond oil) did not exhibit antimicrobial activity against all the tested microorganisms (*Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Escherichia coli*, and *Gardnerella vaginalis*). These findings may be due to the progressive dilution of clove oil present in the emulgel formulations by the carrier oil, resulting in the loss of antimicrobial activity of the blank emulgels. The antimicrobial zone of inhibition recorded for blank palm olein-based emulgels prepared using 5 % palm olein against *C. albicans* was greater than that reported for emulgels containing 5 % coconut oil and olive oil against *E. coli* (19 mm versus 7 mm). Surprisingly, emulgels containing 5 % almond oil did not exhibit any antimicrobial activity against *S. aureus*, *P. aeruginosa*, *E. coli*, and *G. vaginalis*. These findings revealed that the antimicrobial activity of emulgels is dependent on the type of carrier oils as well as the type of test organisms.[29]

Accelerated stability profile of emulgels

According to Stoke's equation, the velocity of creaming is indirectly proportional to the viscosity of the dispersion medium.[42] Emulsifiers or gelling agents that increase the viscosity of the continuous medium could improve the overall stability of the emulgel.[29,43] Based on centrifugal analysis, all the studied emulgels displayed excellent stability profiles as they did not show any sign of phase separation. Also, the creaming layer was not evident as the product appears as a single-phase system. This finding may be due to the polymeric gel base prepared using xanthan gum (3%), which prevents phase separation. This finding is in good agreement with earlier studies on palm olein-based emulgels prepared using 3 % xanthan gum as gel base, which did not exhibit phase separation after centrifugation.[29]

Real-time stability profile of emulgels

The stability profiles of the emulgels are presented in Table 5. The emulgels exhibited excellent real-time stability profile as there were no changes in their colour, odour, texture, and phase separation was not evident in the products over the 3 months-study periods. This finding may be due to the adequate level of xanthan gum (3%) that was used to formulate the emulgels. There was a good correlation between the accelerated and real-time stability profiles of the studied emulgels. These findings are in good agreement with previous studies on fluconazole emulgels formulated using 3% xanthan gum that was stable during accelerated and real-time stability studies.[29]

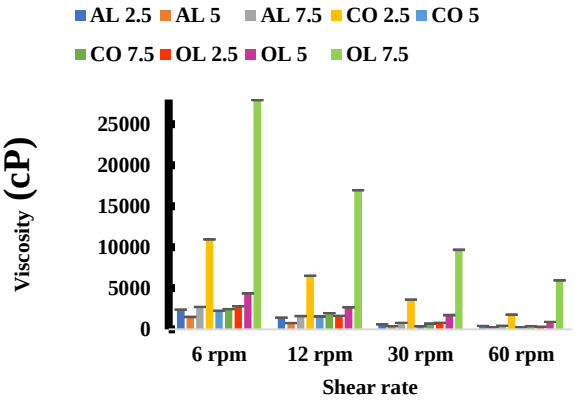

Figure 1: Shear-dependent rheological profiles of almond oil, coconut oil, and olive oil emulgels

Conclusion

Almond oil, coconut oil, and olive oil-based emulgels were successfully prepared. Emulgels containing low concentrations of the carrier oils appeared as hydrogel and it may be suitable to solubilise hydrophilic drugs. On the other hand, emulgels containing 5-7.5 % olive oil, almond oil, or coconut oil exhibited satisfactory organoleptic, physicochemical, and stability profiles and they could be used to formulate hydrophobic therapeutic agents. Olive oil emulgels were the most promising formulations in terms of their rheological and intrinsic antimicrobial properties. Nevertheless, almond oil and coconut oil-based emulgels could be used to deliver varieties of therapeutic agents as they exhibited acceptable physicochemical properties and stability profiles. Future work will explore the incorporation of antimicrobials into the emulgels

so that the resultant drug products can be used to treat superficial and invasive dermal diseases.

Conflict of interest

The authors declare no conflict of interest

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

Table 3: Physicochemical profile of emulgels

Sample	pH	Spreadability (cm)	Viscosity (cP)			
			6 rpm	12 rpm	30 rpm	60 rpm
OL2.5	5.27±0.02	1.1±0.1	2811±10	1648±5	798±4	316±10
AL2.5	5.36±0.13	1.0±0.1	2401±21	1423±13	607±33	420±5
CO2.5	5.36±0.13	1.0±0.1	10957±21	6534±36	3620±13	1792±8
OL5	5.23±0.01	1.2±0.1	4380±50	2686±46	1731±55	913±15
AL5	5.24±0.03	1.2±0.1	1511±43	763±26	384±13	253±11
CO5	5.21±0.01	1.2±0.2	2260±34	1566±44	371±2	250±4
OL7.5	5.20±0.01	1.1±0.1	27930±32	16947±37	9697±53	5967±51
AL7.5	5.21±0.01	1.0±0.1	2730±25	1612±41	794±6	436±4
CO7.5	5.23±0.01	1.1±0.1	2470±25	1968±20	701±9	406±12

Key: OL2.5/AL2.5/CO2.5: emulgels containing 2.5% of olive oil/almond oil/coconut oil; OL5/AL5/CO5: emulgels containing 5% of olive oil almond oil/coconut oil; OL7.5/AL7.5/CO7.5: emulgels containing 7.5% of olive oil/ almond oil/coconut oil

Table 4: Zones of microbial inhibition for different emulgels (mm)

Micro-organisms	OL 2.5	AL 2.5	CO 2.5	OL 5	AL 5	CO 5	OL 7.5	AL 7.5	CO 7.5
Escherichia coli	10 ± 1	10±2	10±1	7±1	0	7±1	0	0	0
Staphylococcus aureus	0	0	0	0	0	0	0	0	0
Pseudomonas aeruginosa	0	0	0	0	0	0	0	0	0
Gardnerella vaginalis	0	0	0	0	0	0	0	0	0

Key: OL2.5/AL2.5/CO2.5: emulgels containing 2.5% of olive oil/almond oil/coconut oil; OL5/AL5/CO5: emulgels containing 5% of olive oil almond oil/coconut oil; OL7.5/AL7.5/CO7.5: emulgels containing 7.5% of olive oil/ almond oil/coconut oil

Table 5: Stability profile of emulgels stored at 25 ± 2ºC/75±5 % and 40 ± 2ºC/75±5 % for 90 days

Days	Temperature: 25±2ºC/75±5%									40 ± 2ºC/75±5 %								
	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
90	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

= absence of phase separation after a predetermined period

Key: Samples 1-3: OL2.5/OL5/OL7.5 (olive oil-based emulgels); Samples 4-6: AL2.5/AL5/AL7.5 (almond oil-based emulgels); Samples 7-9: CO2.5/CO5/CO7.5 (coconut oil-based emulgels).

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