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Exploring Oxidative Stability, Transepidermal Water Loss, and Hydration Levels of Selected Oils for Applications in Cosmetics

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Abstract

The study investigates various oils, revealing their diverse compositions and implications for cosmetic applications. Analysis elucidates the fatty acid composition, with pumpkin seed oil and safflower carrier oil exhibiting high levels of saturated fats, while fish oil and flaxseed oil emerge as rich sources of beneficial polyunsaturated fatty acids. Notably, Evening prime rose oil demonstrates superior stability with the lowest peroxide value (11.97 meq/1000g). Correlation analysis unveil strong positive correlations between oils like algal oil and flaxseed oil (0.958) and hemp seed oil and watermelon seed oil (0.990), indicating similar compositions. Induction times and kinetic parameters highlight oil's susceptibility to oxidation, with fish oil showing long induction times and relatively low activation energies, suggesting moderate stability. Hydration values underscore oil's moisturizing potential, with sea buckthorn oil and soyabean oil exhibiting consistently high hydration values, indicative of water absorption. Transepidermal Water Loss (TEWL) assessments unveil oil's effects on skin barrier function, with algal oil and watermelon seed oil demonstrating lower TEWL values, suggesting enhanced moisturizing properties. This comprehensive analysis enhances our understanding of oil's roles in skincare and guides the development of tailored formulations for optimal health and wellness.

Keywords: Oxidative stability, hydration, skin barrier, peroxide value, induction time, kinetic parameters

Introduction

In cosmetic applications, oils containing unsaturated fatty acids, such as omega-3, omega-6, and omega-9 acids, serve vital functions. Fatty acid compositions vary among oils; polyunsaturated (PUFA), monounsaturated (SFA), and saturated (SFA) fatty acids are all present [1]. Fatty acids are of paramount importance in the regulation of gene expression, transcription factor activity, and membrane structure and function within the human body [2]. They also have an impact on the stability and combustion characteristics of oils [3]. Oils with

high contents of linoleic and α-linolenic acid are used for skin care, as they reduce the formation of eczemas and regenerate damaged lipid barriers [4].

Omega-3 fatty acids, such as alpha-linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA), are considered essential membrane components and have various biological functions. These fatty acids can be found in oils derived from plant sources, fish, fish products, seeds, nuts, green leafy vegetables, and beans. The presence of these unsaturated fatty acids in cosmetic formulations can provide benefits such as skin regeneration, protection against aging, and anti-inflammatory effects [5]. For example, algal oil is a promising source for various applications, including structured antioxidant oils, biodiesel production, and edible oils. Studies have shown that algal oil powders can be used to stabilize emulsion templates, resulting in improved physical storage stability and oxidation stability [6]. Microalgae lipids have the potential to replace vegetable oils in food and cosmetic applications, as well as serve as a source of biofuels [7]. Chia seed oil has also been reported to have anti-inflammatory and antioxidant activities, making it beneficial for skincare products [8]. Additionally, the oil's high omega-3 fatty acid content can contribute to its anti-aging properties [9]. Evening primrose oil is known for its benefits in managing dry skin, aging skin, juvenile skin, atopic dermatitis, and scalp conditions. It has been used for centuries for the treatment of various skin ailments [10]. Fish oil has been found to have potential benefits in skin care products and cosmetics to resist skin wrinkles, xerosis cutis, dermectasia, skin aging, and photodamage [11]. Flaxseed oil has been extensively studied for its potential applications due to its antioxidant and anti-inflammatory properties, making it beneficial for skin health [12]. Flaxseed oil, along with mucilage, has been used in the formulation of moisturizers and multipurpose skin creams. These products have been found to reduce fine wrinkles, provide hydration for up to 8-10 hours, and have appropriate physiochemical parameters for safe and nourishing skincare [13]. Additionally, hempseed, pumpkin seed, and watermelon seed have shown promising antioxidant activity, making them suitable for use in cosmetic applications [14]. Seed oils, including rapeseed oil, are traditionally used in cosmetic products as moisturizers and emollients [15]. Safflower oil has also been used in the formulation of herbal nutritive skin creams, which showed clinical effects in protecting the skin from oxidative damage and reducing the symptoms of skin aging [16]. The active substances in sea buckthorn, such as polyphenols, have antimicrobial, antiviral, antifungal, and anti-inflammatory properties, making it a valuable component in dermocosmetics for protecting the skin from UV radiation, dryness, and signs of aging [17]. Soybean extract has been found to promote ceramide biosynthesis and strengthen the skin barrier, leading to improved skin moisturization and alleviation of itching [18]. Walnut oil also contains antioxidants, phenolic compounds, and vitamins, which contribute to its antioxidant capacity and health-promoting effects [19]. These bioactive compounds protect the skin against oxidative stress, UVB-induced damage, and inflammation, making walnut oil a promising ingredient for sunscreen and anti-aging cosmetic formulations [20].

The oxidative stability of oils has a significant impact on their shelf life and quality. Lipid oxidation can lead to functional and sensory deterioration of oils, causing economic losses. Factors such as temperature, packaging, and exposure to light can affect the oxidative stability of oils. Studies have shown that oils stored at lower temperatures, such as 4°C, have better oxidative stability and can preserve their initial quality for longer periods of time [21]. On the other hand, oils stored at higher temperatures, such as 40°C, experience intense lipid oxidation after a shorter period of storage [22]. Adulteration of oils can also affect their oxidative stability, and detection of adulteration can be done by analyzing the fatty acid composition of the oils. The oxidative stability of oils can be evaluated using various methods, such as the oxidation stability index and peroxide value.

Trans-Epidermal Water Loss (TEWL) plays a crucial role in determining the effectiveness of cosmetic products containing oils. Research indicates that TEWL measurements are essential in evaluating the moisturizing efficacy of cosmetic formulations [23]. Studies have shown that formulations containing specific ingredients like flavonoids or linoleic acid can significantly impact TEWL levels, leading to improvements in skin hydration and barrier function [24]. TEWL is influenced by factors like eccrine gland activity [25], skin hydration levels [26,27], and environmental conditions like pollution [28]. TEWL values are typically lower in healthy skin with intact barriers, while increased TEWL signifies barrier disruption. Skin hydration, measured through metrics like stratum corneum hydration (SCH) and hydration index, plays a significant role in TEWL levels, with a positive correlation observed between SCH and TEWL in certain skin areas [29]. Understanding these relationships is vital for skincare practices and assessing skin health, paralleling the importance of oxidative stability in oils for ensuring product quality and longevity. Therefore, this research aims to explore oxidative stability, TEWL, and hydration of selected oils for cosmetics applications.

Materials and methods

Raw material

The research material consisted of eleven cold-pressed, unrefined oils: Algal oil (ALO), chia seed oil (CSO), evening prime rose oil (EPO), fish oil (FO), flaxseed oil (FSO), hemp seed oil (HSO), pumpkin seed oil (PSO), rapeseed oil (RO), safflower carrier oil (SCO), sea burkthorn oil (SBO), soyabean oil (SO), walnut oil (WAO) and watermelon seed oil (WSO). The oils utilized in the study were procured from the producer of cold-pressed oils. Purchases of all reagents and compounds used in the analysis were made at Merck Millipore (Darmstadt, Germany) and SD Fine compounds (India). All compounds and reagents employed in the preparation of the sample and analysis via gas chromatography (GC) were of high-performance liquid chromatography (HPLC)/GC purity.

Fatty acid composition analysis

The fatty acid profiling of the oils was conducted following a rigorous methodological approach. Initially, representative samples of each oil were meticulously collected and labeled to ensure accurate identification throughout the analysis. 204.1 mg of each oil sample was weighed and then placed into a suitable flask. Methanolic NaOH was subsequently added to the flask, initiating a reaction process. A condenser was affixed to the flask, and the resulting mixture was subjected to reflux for a duration of 10 minutes, ensuring thorough reaction conditions. Following refluxing, a solution containing BF_3 was introduced into the flask, and the mixture was boiled for 2 minutes to facilitate further chemical transformations. Next, 5 mL of heptane was carefully added to the boiling mixture, and the entire concoction was allowed to boil for an additional minute. After cooling the flask to ambient temperature, 15 mL of saturated NaCl solution was introduced, and the resulting mixture was vigorously shaken to ensure homogeneous distribution. Subsequent to shaking, the organic layer was separated from the aqueous layer via filtration, utilizing appropriate equipment. The organic layer was then transferred to a fresh flask for further processing. To remove any residual water content, an appropriate quantity of Na_2SO_4 was added to the organic layer, followed by agitation to aid in drying. Afterward, the mixture was once again filtered to eliminate the Na_2SO_4, resulting in a purified organic layer ready for subsequent analyses or manipulations.

Following neutralization and extraction with hexane, GC analysis was performed using a flame ionization detector (FID) and a carefully selected capillary column with specific temperature programming and carrier gas parameters. The GC method employed in this analysis utilizes an oven with a temperature setpoint starting at 50°C, held for 4 minutes, followed by a post-run temperature of 500°C. Three temperature programs were applied subsequently: the first with a ramp rate of 45°C/min up to 750°C, held for 6 minutes; the second with a ramp rate of 8°C/min up to 200°C, held for 6 minutes; and the third with a

ramp rate of 10°C/min up to 230°C, held for 10 minutes. By comparing the retention periods of the standard fatty acid ester mixture, the individual acids were identified. Duplicate determinations were conducted.

Oxidative stability determination

In order to assess the correlation between the oxidizability value (COX) and the oxidative stability of the oils, the fatty acid composition was analyzed. The COX index was computed in accordance with the formula suggested by Fatemi and Hammond [30].

$$COX = \frac{1 \times (C16:1 + C17:1 + C18:1 + C20:1) + 10.3 \times (C18:2) + 21.6 \times (C18:3 + C20:3)}{100}$$

The investigation involved the utilization of the 892 Rancimat apparatus manufactured by Metrohm in conjunction with the AOCS method Cd 12b-92 [31]. A constant airflow was applied to a 2.5 g oil sample at five distinct temperatures (ranging from 90 to 150 °C) for five iterations (five for each oil). Twenty litres per hour was the ventilation velocity.

The rate constant (k), activation energy (Ea), and the pre-exponential factor (Z) were calculated using the Arrhenius equation:

$$k = Z \times e^{-\frac{E_a}{RT}}$$

Where:

R is the gas constant (8.314 J/mol*K)

T is the absolute temperature in Kelvin

Ea was further calculated using the natural logarithm of the ratio of the rate constants:

$$E_a = -\frac{ln\frac{k_{120}}{k_{90}}}{\frac{1}{R} \times \frac{1}{T_{120}} - \frac{1}{T_{90}}}$$

Z was calculated by substituting Ea into one of the original equations:

$$Z = \frac{k_{90}}{e^{\frac{-Ea}{RT_{90}}}}$$

ΔH, enthalpy of activation was calculated using Ea and Van't Hoff equation:

$$\Delta H = E_a - RT$$

ΔS was calculated by using following equation:

$$\Delta S = \frac{E_a - \Delta H}{R}$$

Analysis of hydration levels in various oils over time

In this hydration study, we utilized the MoistureMeterEpiD to gauge skin hydration levels and assess skin barrier integrity. Before measurements commenced, participants' skin was carefully prepped, ensuring cleanliness and allowing ample time for acclimatization to ambient conditions. The MoistureMeterEpiD was meticulously calibrated in accordance with the manufacturer's specifications, guaranteeing accurate readings. The device's sensor was gently placed against the skin surface to establish optimal contact. Subsequently, hydration measurements were initiated, and the MoistureMeterEpiD commenced recording moisture levels within the epidermal layers. Initial hydration measurements were recorded at the 2-hour mark using gravimetric analysis. Subsequent measurements were taken at 4-hour and 8-hour intervals. Duplicate determinations were conducted.

Analysis of TEWL in various oils over time

In this experiment, TEWL was measured using the Delfin VapoMeter® to assess skin barrier function, as shown in Figure 1. Prior to measurements, participants' skin was prepared by cleansing and allowing it to acclimatize to ambient conditions. The Delfin VapoMeter® was calibrated as per the manufacturer's instructions, and its probe was firmly placed against the

skin surface to ensure good contact. Measurements were initiated, and the instrument recorded the rate of water vapor passing through the skin for a specified duration. TEWL measurements were conducted at three time points: 2 hours, 4 hours, and 8 hours. Initially, TEWL levels were recorded for each oil sample at the 2-hour mark. Subsequent TEWL measurements were taken at 4-hour and 8-hour intervals. Duplicate determinations were conducted.

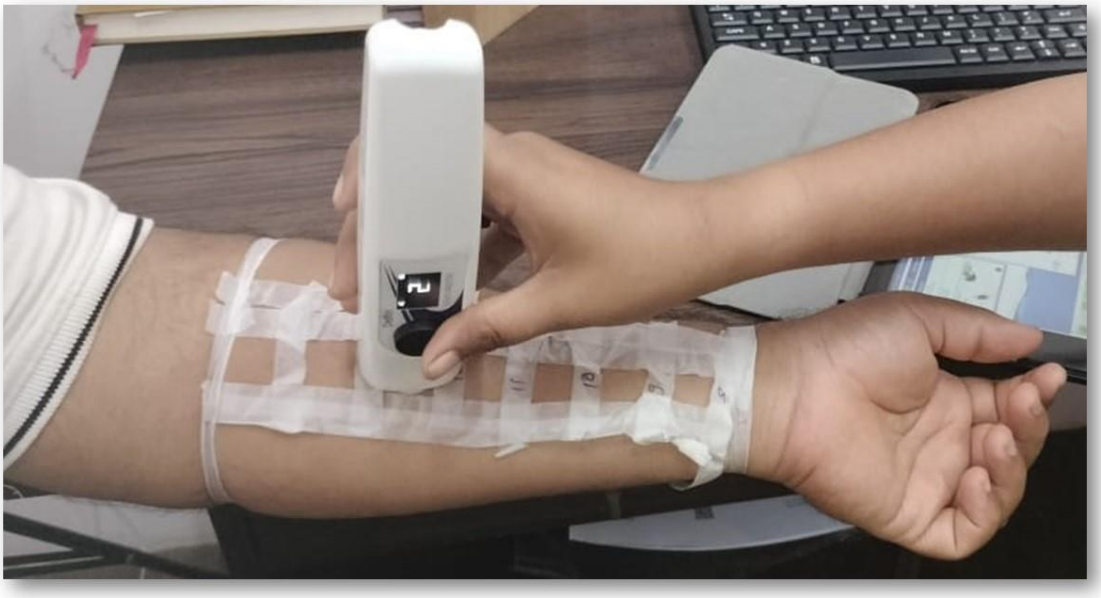

Figure 1: Analysis of TEWL in various oils over time

Statistical analysis

The statistical analysis of the findings was conducted utilising the Statistical Package for the Social Sciences (SPSS). At a significance level of $p \leq 0.05$, the homogeneous groups were partitioned utilising a one-way analysis of variance (ANOVA) and the Tukey HSD test. Additionally, a Pearson's linear correlation analysis was conducted.

Results

Fatty acid profiling

Analyzing the data provided in Table 1, we observe the fatty acid compositions of various oils along with additional parameters such as color, peroxide value, and concentrations of saturated, polyunsaturated, monounsaturated, and trans fatty acids. Notable variations exist among the oils in terms of their fatty acid profiles. ALO exhibits a high content of C16 fatty acids (10.771 g/100g), while CSO is rich in C18:1 (27.85 g/100g), and EPO contains significant levels of C18:3 (7.4 g/100g). FO is distinguished by its high concentration of C20:5 (0.273 g/100g) and C22:6 (0.171 g/100g) fatty acids. FSO stands out for its exceptionally high polyunsaturated fatty acid content (62.01 g/100g), primarily composed of C18:2 (59.98 g/100g). HSO and SO also show considerable levels of polyunsaturated fatty acids. SCO and SBO are notable for their high monounsaturated fatty acid content, particularly C18:1. Additionally, trans fatty acids are detected in most oils, albeit in minimal amounts, except for RO, which contains 1.15 g/100g. The oils also exhibit variations in color, with EPO being dark yellow, while most others are clear oils with varying shades of yellow or green. Peroxide values range from 11.97 to 75.81 meq/1000g, indicating different levels of oxidation among the oils.

Table 1: Fatty acid composition, peroxide value, and COX value of selected oils

Fatty acid	ALO	CSO	EPO	FO	FSO	HSO	PSO	RO	SCO	SBO

C6	-	-	-	-	-	-	-	-	-	0.09
C8	0.118	-	-	-	-	-	-	-	-	-
C10	0.131	0.18	0.113	0.16	0.05	-	0.355	-	-	-
C12	-	-	-	-	-	-	0.268	-	-	0.27
C13	0.146	0.15	0.083	0.23	0.1	0.24	0.253	0.5	0.47	0.24
C14	0.387	-	-	-	-	-	-	-	-	-
C15	0.247	-	0.17	-	0.08	0.11	-	0.2	-	0.2
C16	10.77	10	12.08	11.1	8.58	10.4	14.89	9.4	11.8	10.1
C17	-	-	-	-	-	-	-	-	-	-
C17:1	-	-	0.391	-	0.1	-	-	0.4	-	0.18
C18	3.871	21	17.82	23.5	6.45	19.6	24.75	28	23.1	28.7
C18:1	-	-	-	-	-	-	-	-	-	-
CI18:1	22.92	27.3	48.6	43.4	16.6	54.4	51.76	38	55.2	53.8
C 18:2	0.94	0.72	0.509	0.99	0.18	0.89	0.976	-	1.15	0.43
C18:2	41.46	0.33	10.17	3.35	60	9.78	3.672	17	5.46	4.87
C20:0	1.089	0.82	0.604	1.16	0.12	0.17	0.856	1.2	1.4	0.15
C18:3	3.085	1.51	-	7.4	0.93	0.33	-	-	-	-
C20:1	0.379	0.3	0.712	0.35	0.31	0.41	0.337	0.9	0.3	0.21
C18:3	6.727	-	0.935	-	0.22	-	-	2	-	0.13
C21:0	0.211	0.13	0.198	0.2	0.07	0.35	0.848	0.2	-	-
C20:2	0.284	0.32	0.204	0.3	0.2	-	-	-	-	-
C22	-	-	-	-	0.36	-	-	-	-	-
C20:3	-	0.29	0.663	0.47	0.19	0.31	-	0.4	-	0.42
C22:1	-	0.31	-	-	0.41	-	-	-	-	-
C23:0	-	0.51	-	-	0.61	-	-	-	-	-
C20: 3	0.445	0.36	-	-	0.34	-	-	-	-	-
C20: 4	1.518	0.32	-	1.69	0.19	0.35	-	-	-	-
C22:2	0.462	-	-	0.49	-	-	-	-	-	-
C20:5	0.141	-	0.273	-	0.16	-	-	0.2	-	-
C22:6	0.171	-	-	-	-	-	-	0.2	-	-
Color	Green color clear oil	Dark yellow color clear oil	Yellow color clear oil	Dark yellow color clear oil	Dark yellow color clear oil	Yellow color clear oil	Yellow color clear oil	Yellow color clear oil	Yellow color clear oil	Orange color clear oil
Peroxide Value (meq/1000g)	27.98	38	11.97	24	33.9	32	35.89	Nil	40	16
Saturated fatty acid (g/100g)	16.97	32.8	31.07	36.3	16.2	30.9	42.22	40	36.8	39.9
Poly unsaturated fatty acid (g/100g)	54.3	31.1	12.25	13.7	62	10.8	3.67	20	5.5	5.42
Mono unsaturated fatty acid (g/100g)	23.3	27.9	49.71	43.8	17.3	54.8	52.1	39	55.5	54

Total trans fatty acid (g/100g)	0.94	0.72	0.51	0.99	0.18	0.89	0.98	Not detected	1.15	0.43
COX	12.25	25.66	36.98	39.94	21.06	35.46	51.27	49.99	43.41	58.01

The correlation data reveals significant relationships between various variables, as shown in Table 2. Several strong positive correlations stand out, notably between FSO and ALO (r = 0.96), HSO and EPO (r = 1.00), and PSO and EPO (r = 0.99). These associations suggest high levels of interdependence among these variables. Conversely, weaker correlations are evident between certain pairs, such as CSO and FSO (r = 0.24) and FSO and FO (r = 0.30), indicating less consistent relationships. Interestingly, while most correlations are positive, indicating that as one variable increases, the other tends to increase as well, there are also a few negative correlations, such as between FSO and CSO (r = -0.24) and FSO and SO (r = -0.34). These negative associations imply an inverse relationship between the variables. Significant positive correlations exist between variables such as SCO and SBO (r = 0.994), SCO and SO (r = 0.999), and SO and WAO (r = 0.994), all with p-values less than 0.001, suggesting highly interdependent relationships. Additionally, variables like HSO and PSO (r = 0.996) and EPO and HSO (r = 0.995) also exhibit extremely strong correlations, underlining consistent associations among them. However, some variables, such as FSO, show weaker correlations with other variables, indicating less consistent relationships. For instance, FSO demonstrates relatively modest correlations with most other variables, notably with WSO (r = 0.928), suggesting a less robust association.

Table 2: Correlation analysis of selected oils

Oil	**ALO**	**CSO**	**EPO**	**FO**	**FSO**	**HSO**	**PSO**	**RO**	**SCO**	**SBO**	**SO**	**WAO**	**WSO**
ALO	1	.402*	.609**	.480**	.958**	.584**	.491**	.673**	.517**	.489**	.525**	.479**	.981**
CSO	.402*	1	.932**	.976**	.238	.931**	.974**	.933**	.957**	.974**	.958**	.942**	.481**
EPO	.609**	.932**	1	.968**	.429*	.998**	.986**	.947**	.993**	.981**	.993**	.982**	.703**
FO	.480**	.976**	.968**	1	.298	.971**	.986**	.935**	.983**	.987**	.983**	.975**	.566**
FSO	.958**	.238	.429*	.298	1	.404*	.306	.550**	.331	.316	.344	.293	.928**
HSO	.584**	.931**	.998**	.971**	.404*	1	.986**	.942**	.995**	.985**	.995**	.990**	.684**
PSO	.491**	.974**	.986**	.986**	.306	.986**	1	.938**	.996**	.994**	.996**	.986**	.587**
RO	.673**	.933**	.947**	.935**	.550**	.942**	.938**	1	.937**	.952**	.944**	.920**	.736**
SCO	.517**	.957**	.993**	.983**	.331	.995**	.996**	.937**	1	.994**	.999**	.995**	.618**
SBO	.489**	.974**	.981**	.987**	.316	.985**	.994**	.952**	.994**	1	.996**	.991**	.588**
SO	.525**	.958**	.993**	.983**	.344	.995**	.996**	.944**	.999**	.996**	1	.994**	.626**
WAO	.479**	.942**	.982**	.975**	.293	.990**	.986**	.920**	.995**	.991**	.994**	1	.589**
WS	.981	.481	.703	.566	.928	.684	.587	.736	.618	.588	.626	.589	1

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*. Correlation is significant at the 0.05 level (2-tailed).													
**. Correlation is significant at the 0.01 level (2-tailed).													

Oxidative stability of analyzed oils

Table 3 presents induction times in hours at two different temperatures for various oils. Induction time is a measure of a substance's resistance to oxidation, with longer induction times indicating greater stability. At 90°C, ALO demonstrates a moderate induction time of 5.25 hours, suggesting relatively good stability. However, at 120°C, its induction time significantly decreases to 0.42 hours, indicating increased susceptibility to oxidation at higher temperatures. CSO exhibits a high induction time of 7.31 hours at 90°C, indicating excellent stability. At 120°C, its induction time decreases to 0.88 hours, indicating reduced stability compared to the lower temperature. FSO shows a moderate induction time of 5.07 hours at 90°C, reflecting reasonable stability. However, at 120°C, its induction time decreases to 0.88 hours, suggesting increased vulnerability to oxidation at higher temperatures. EPO demonstrates a very high induction time of 26.18 hours at 90°C, indicating exceptional stability. However, at 120°C, its induction time decreases to 2.89 hours, suggesting reduced stability compared to the lower temperature. PSO displays a very low induction time of 0.05 hours at both 90°C and 120°C, indicating poor stability at both temperatures. RO shows an extremely high induction time of 51.16 hours at 90°C, indicating exceptional stability. At 120°C, its induction time decreases to 7.34 hours, still reflecting relatively good stability compared to other oils. SBO exhibits very low induction times of 0.07 hours at 90°C and 0.08 hours at 120°C, indicating poor stability at both temperatures. SO shows moderate induction times of 15.87 hours at 90°C and 1.82 hours at 120°C, reflecting moderate stability at both temperatures. SBO demonstrates moderate induction times of 17.12 hours at 90°C and 1.9 hours at 120°C, indicating moderate stability at both temperatures. WAO shows moderate induction times of 12.62 hours at 90°C and 1.29 hours at 120°C, reflecting moderate stability at both temperatures. WSO exhibits moderate induction times of 12.53 hours at 90°C and 1.21 hours at 120°C, indicating moderate stability at both temperatures.

Table 3: Induction time of selected oils

Oil	**Induction time (h)**	
	90ºC	**120 ºC**
ALO	5.25	0.42
CSO	7.31	0.88
FSO	5.07	0.88
FO	26.18	2.89
PSO	0.05	0.04
RO	51.16	7.34
SBO	0.07	0.08
SO	15.87	1.82
SCO	17.12	1.9
EPO	6.24	0.87
HSO	6.46	0.86
WAO	12.62	1.29
WSO	12.53	1.21

Kinetics parameters of analysed oils

Various kinetic parameters of selected oil for application in cosmetics are tabulated in Table 4. ALO demonstrates a moderate pre-exponential factor of 2.07×10^{10}, with relatively low activation energies at both temperatures, suggesting its susceptibility to oxidation.

Conversely, WAO exhibits a high pre-exponential factor of 6.64×10^{10}, indicating a higher probability of molecular collisions leading to oxidation. FO shows a relatively high activation energy, implying greater resistance to oxidation compared to other oils. PSO and SBO stand out with exceptionally high pre-exponential factors, signifying a high rate of collision between reactive species. A moderate pre-exponential factor of 1.31×10^{10} by chia seed oil exhibits relatively lower activation energy compared to some oils, suggesting moderate susceptibility to oxidation. However, its enthalpy of activation and entropy of activation are comparable to other oils, indicating typical kinetic behavior. FSO demonstrates a high pre-exponential factor of 4.32×10^{10}, suggesting a high frequency of molecular collisions conducive to oxidation. Despite this, its activation energy is relatively high, indicating significant resistance to oxidation compared to oils with lower activation energies. SCO shows a relatively high pre-exponential factor of 3.61×10^{10}, indicating a propensity for rapid oxidation kinetics. However, its activation energy is moderate, suggesting a balance between susceptibility to oxidation and resistance. SBO exhibits a moderate pre-exponential factor of 3.11×10^{10}, along with relatively low activation energies at both temperatures. This suggests that soybean oil is moderately susceptible to oxidation, with its kinetic behavior influenced by factors such as fatty acid composition and antioxidant content. WSO demonstrates a relatively high pre-exponential factor of 2.36×10^{10}, indicating a higher probability of molecular collisions leading to oxidation. Its activation energy is also high, suggesting substantial resistance to oxidation compared to oils with lower activation energies.

Table 4: Kinetic parameters of selected oils

Oil	**Pre-exponential Factor (Z) $\times 10^{10}$**	**k90 °C**	**k120 °C**	**Activation Energy (Ea) (kJ/mol)**	**Enthalpy of Activation (ΔH) (kJ/mol)**	**Entropy of Activation (ΔS) (J/mol*K)**
ALO	2.07	0.1905	2.3809	80.82	77.51	0.398
CSO	1.31	1.1364	0.1366	76.13	73.12	0.362
FSO	4.32	0.1973	1.1364	83.26	80.95	0.278
FO	4.36	0.0382	0.3461	97.45	94.14	0.398
PSO	1.78	20.00	25.00	87.03	83.71	83.71
RO	1.74	0.136	0.0195	135.67	132.36	0.398
SBO	3.61	14.29	12.50	86.75	83.44	0.398
SO	3.11	0.063	0.549	109.82	106.51	0.398
SCO	2.45	0.058	0.526	106.51	103.20	0.398
EPO	2.80	0.060	0.540	108.00	105.00	0.395
HSO	2.20	0.055	0.520	106.00	103.00	0.395
WAO	6.64	0.0792	0.7752	87.35	84.34	0.362
WSO	2.36	0.0797	0.826	120.64	117.62	0.363

Hydration assessments

The hydration levels of various oils over time were analyzed based on data collected at 2 hours, 4 hours, and 8 hours (Figure 2 and Table 5). Notable changes in hydration levels were observed among the oils during the specified time intervals. HSO exhibited substantial hydration, starting at 11.18% at 2 hours, increasing to 65.61% at 4 hours, and reaching 85.03% at 8 hours, indicating a significant increase in hydration over time. FO showed a similar trend, starting at 19.54% at 2 hours, increasing to 76.55% at 4 hours, and slightly decreasing to 80.09% at 8 hours. WCO displayed a steady increase in hydration from 9.65% at 2 hours to 61.78% at 4 hours and 65.29% at 8 hours. PSO demonstrated notable hydration changes, increasing from 9.72% at 2 hours to 59.06% at 4 hours and further to 72.08% at 8

hours. ALO showed a similar pattern, with hydration levels rising from 10.20% at 2 hours to 54.85% at 4 hours and 63.51% at 8 hours. SO exhibited consistent hydration increases, starting at 11.31% at 2 hours, rising to 47.35% at 4 hours, and reaching 58.72% at 8 hours. EPO demonstrated significant hydration, increasing from 7.74% at 2 hours to 44.20% at 4 hours and 59.48% at 8 hours. WSO displayed high hydration initially at 15.08% at 2 hours, peaking at 86.84% at 4 hours, and then decreasing to 76.48% at 8 hours. SBO showed consistent hydration levels, starting at 20.37% at 2 hours, rising to 74.40% at 4 hours, and 85.01% at 8 hours. CSO demonstrated a decrease in hydration from 14.26% at 2 hours to 76.23% at 4 hours and then to 66.18% at 8 hours. SCO displayed hydration changes from 23.97% at 2 hours to 72.21% at 4 hours and 79.83% at 8 hours. FSO showed an increase in hydration from 8.76% at 2 hours to 56.95% at 4 hours and 65.87% at 8 hours. RO exhibited notable hydration increases from 2.39% at 2 hours to 45.46% at 4 hours and 58.80% at 8 hours.

Table 5: Hydration values of selected oils

Oils	2hr	4 hr	8 hr
HSO	11.18	65.61	85.03
FO	19.54	76.55	80.09
WCO	9.65	61.78	65.29
PSO	9.72	59.06	72.08
ALO	10.20	54.85	63.51
SO	11.31	47.35	58.72
EPO	7.74	44.20	59.48
WSO	15.08	86.84	76.48
SBO	20.37	74.40	85.01
CSO	14.26	76.23	66.18
SCO	23.97	72.21	79.83
FSO	8.76	56.95	65.87
RO	2.39	45.46	58.80

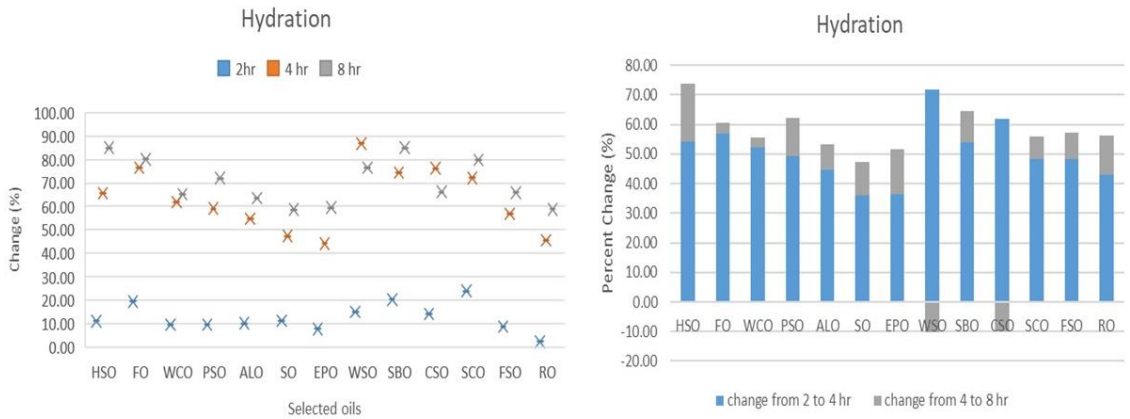

Figure 2: Change in hydration value of the selected oils

Rate of TEWL change analysis

The provided data presents TEWL measurements in various oils over time, recorded at 2-hour, 4-hour, and 8-hour intervals (Figure 3 and Table 6). TEWL is a crucial parameter in

skincare and dermatology, reflecting the skin's barrier function and hydration levels. HSO shows an initial TEWL of 29.95 g/m²/h at 2 hours, which notably increases to 118.39 g/m²/h by the 4-hour mark, indicating a potential disruption in skin barrier function. However, there is a substantial decrease in TEWL to 81.50 g/m²/h by the 8-hour mark, suggesting a potential recovery or improvement in hydration levels over time. FO exhibits a similar trend with an initial TEWL of 30.58 g/m²/h at 2 hours, sharply increasing to 118.39 g/m²/h by 4 hours, indicating a significant negative impact on skin barrier function. However, like HSO, FO shows a notable decrease in TEWL to 81.39 g/m²/h by 8 hours, suggesting potential recovery or hydration improvement over time. WCO demonstrates an initial TEWL of 19.10 g/m²/h at 2 hours, which increases to 86.92 g/m²/h by 4 hours and further to 37.60 g/m²/h by 8 hours. This suggests a mixed pattern of disruption and potential recovery in skin barrier function over the measured period. PSO displays an initial TEWL of 56.42 g/m²/h at 2 hours, decreasing to 107.19 g/m²/h by 4 hours, indicating potential improvement in skin barrier function. However, the TEWL further decreases to 68.50 g/m²/h by 8 hours, suggesting sustained improvement or hydration maintenance. SO demonstrates an initial TEWL of 26.23 g/m²/h at 2 hours, which decreases to 56.22 g/m²/h by 4 hours and further to 53.57 g/m²/h by 8 hours. This indicates a steady improvement in skin barrier function and hydration levels over the measured period. EPO exhibits an initial TEWL of 41.17 g/m²/h at 2 hours, which increases to 116.26 g/m²/h by 4 hours, suggesting a notable negative impact on skin barrier function. However, there is a significant decrease in TEWL to 83.89 g/m²/h by 8 hours, indicating potential recovery or hydration improvement over time. WSO shows an initial TEWL of 32.79 g/m²/h at 2 hours, which decreases to 59.43 g/m²/h by 4 hours, indicating potential improvement in skin barrier function. However, there is a subsequent increase in TEWL to 77.55 g/m²/h by 8 hours, suggesting potential fluctuation or limitation in long-term efficacy. SBO demonstrates an initial TEWL of 74.01 g/m²/h at 2 hours, which decreases to 95.30 g/m²/h by 4 hours and further to 101.30 g/m²/h by 8 hours. This suggests a mixed pattern of disruption and potential recovery in skin barrier function over the measured period. CSO displays an initial TEWL of 46.05 g/m²/h at 2 hours, which decreases to 96.53 g/m²/h by 4 hours, indicating potential improvement in skin barrier function. However, there is a subsequent decrease in TEWL to 45.97 g/m²/h by 8 hours, suggesting sustained improvement or hydration maintenance. SCO exhibits an initial TEWL of 59.12 g/m²/h at 2 hours, which decreases to 101.93 g/m²/h by 4 hours and further to 95.93 g/m²/h by 8 hours. This suggests a steady improvement in skin barrier function and hydration levels over the measured period. FSO demonstrates an initial TEWL of 116.24 g/m²/h at 2 hours, which decreases to 86.17 g/m²/h by 4 hours and further to 84.38 g/m²/h by 8 hours. This indicates a significant improvement in skin barrier function and hydration levels over the measured period. RO shows an initial TEWL of 120.38 g/m²/h at 2 hours, which increases to 163.32 g/m²/h by 4 hours, suggesting a notable negative impact on skin barrier function. However, there is a subsequent decrease in TEWL to 142.04 g/m²/h by 8 hours, indicating potential recovery or hydration improvement over time.

Table 6: TEWL values of selected oils

	2hr	**4 hr**	**8 hr**
HSO	29.95	118.39	81.50
FO	30.58	118.39	81.39
WCO	19.10	86.92	37.60
PSO	56.42	107.19	68.50
ALO	18.97	65.97	58.37
SO	26.23	56.22	53.57

EPO	41.17	116.26	83.89
WSO	32.79	59.43	77.55
SBO	74.01	95.30	101.30
CSO	46.05	96.53	45.97
SCO	59.12	101.93	95.93
FSO	116.24	86.17	84.38
RO	120.38	163.32	142.04

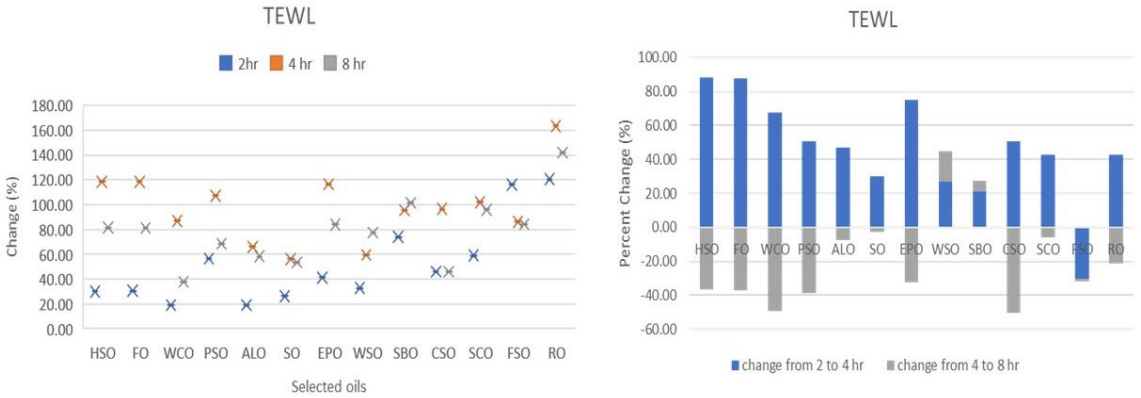

Figure 3: Change in TEWL values of selected oils

Discussion

The fatty acid composition of oils plays a crucial role in their profile and suitability for application in cosmetics. The fatty acid composition is presented in Table 1, along with additional information such as color, peroxide value, and COX value. Oils with higher saturated fat content may have a more stable shelf life [32]. Here, PSO and SCO have relatively high levels of SFAs. PUFAs, particularly omega-3 and omega-6 fatty acids, are essential for optimal skin health and nourishment [33]. Oils like FO [34] and FSO [35] are rich sources of PUFAs, making them beneficial for moisturization, improving skin elasticity, and reducing inflammation, contributing to a healthier and more radiant complexion. Oils like ALO and HSO [36] have higher levels of MUFAs. Trans fats, typically found in partially hydrogenated oils, are associated with detrimental effects on skin health. In the provided data, trans fats are mostly negligible, except for PSO and SBO. COX values provide information about the extent of conjugated fatty acids in oils. Higher COX values may indicate greater oxidative stability and resistance to rancidity. In this dataset, WSO shows the highest COX value (1005.18), indicating a potentially higher resistance to oxidation.

The color of oils can provide valuable information about their quality and processing. Generally, clear oils with a green or yellow color are indicative of freshness and purity. However, the presence of a darker yellow or orange color might suggest the presence of impurities or oxidation products, which could affect the oil's flavor and nutritional value. The peroxide value indicates the degree of oxidation in oils, with higher values suggesting increased levels of oxidation. Oils with lower peroxide values are typically fresher and more stable [37]. In the provided data, EPO exhibits the lowest peroxide value (11.97 meq/1000g), indicating better stability and freshness. On the other hand, WAO shows the highest peroxide value (75.8 meq/1000g), suggesting a higher degree of oxidation.

Table 2 presents a correlation matrix indicating the correlation coefficients between different types of oils. Each cell in the matrix represents the strength and direction of the relationship between two oils, with correlation coefficients ranging from -1 to 1. Positive correlations indicate that the two oils tend to change in the same direction. For instance, there are strong

positive correlations between oils like ALO and FSO (0.958), HSO and WSO (0.990), and PSO and SO (0.996), among others. These strong positive correlations suggest that the compositions of these oils tend to change similarly, indicating potential similarities in their fatty acid profiles or processing methods. Several pairs of oils exhibit correlation coefficients close to or equal to 1, indicating very strong correlations. For example, there is a very high correlation between CSO and PSO (0.974), EPO and SBO (0.993), and SCO and SO (0.999). These high correlations suggest that the compositions of these oils are highly similar or closely related. While some oils exhibit strong correlations with each other, others show weaker or even negative correlations. For example, there is a relatively weaker correlation between CSO and FSO (0.238), suggesting that their compositions may vary independently of each other.

The provided data in Table 3 shows the induction times of various oils at different temperatures (90°C and 120°C). Induction time refers to the duration until the onset of oxidation or degradation of the oil when subjected to heat, with longer induction times indicating greater resistance to oxidation. At 90°C, FO demonstrates the longest induction time of 26.18 hours, indicating high resistance to oxidation even at elevated temperatures. This suggests that FO is suitable for applications requiring high-temperature stability, such as deep frying or food processing. Other oils with relatively long induction times at 90°C include RO with 51.16 hours and SO with 15.87 hours, suggesting good resistance to oxidation. PSO and SBO exhibit the shortest induction times at 90°C, with values of 0.05 and 0.07 hours, respectively. This indicates lower resistance to oxidation at this temperature. Similarly, FO continues to show the longest induction time at 120°C, with a value of 2.89 hours, although significantly reduced compared to 90°C. This suggests that while FO is highly stable at high temperatures, its resistance to oxidation decreases as the temperature increases. RO also maintains a relatively long induction time at 120°C, with a value of 7.34 hours, indicating good stability at elevated temperatures. PSO and SBO again exhibit the shortest induction times at 120°C, with values of 0.04 and 0.08 hours, respectively. Generally, oils with higher levels of PUFAs tend to have shorter induction times due to their susceptibility to oxidation [38]. This is evident in oils like PSO, SBO, and SO. Oils with higher levels of MUFAs or SFAs tend to have longer induction times due to their greater stability [39]. This is observed in oils like ALO, CSO, and FO.

Table 4 presents the kinetic parameters of selected oils, including the Z, k at 90°C and 120°C, Ea, ΔH, and ΔS. These parameters provide insights into the kinetics of oxidation reactions in oils, helping to understand their stability and behavior under different conditions. The pre-exponential factor represents the frequency of molecular collisions and the likelihood of reaction occurrence [40]. Higher Z values indicate a higher frequency of reactions. Oils like FSO and WAO have relatively higher Z values (4.32 and 6.64 × 10^{10}, respectively), suggesting a higher tendency for reaction occurrence compared to other oils. The rate constants represent the speed of the reaction at different temperatures [41]. Higher k values indicate faster reaction rates. For instance, PSO exhibits exceptionally high rate constants at both 90°C and 120°C (20.00 and 25.00, respectively), indicating rapid oxidation kinetics compared to other oils. The activation energy represents the energy barrier that molecules must overcome to react. Higher Ea values indicate a higher energy barrier and slower reaction rates. RO shows the highest activation energy (135.67 kJ/mol), suggesting that it requires the most energy for oxidation to occur, indicating relatively higher stability compared to other oils. Findings indicate that FO exhibits relatively low activation energies at both temperatures, indicating lower stability and faster oxidation kinetics. Oils like RO and PSO show high activation energies, suggesting greater stability and slower oxidation rates. FSO and WAO have high pre-exponential factors and relatively high activation energies,

indicating a higher likelihood of reaction occurrence and a higher energy barrier for oxidation.

Table 5 and Figure 1 show the hydration values of selected oils at different time intervals (2 hours, 4 hours, and 8 hours). Hydration values indicate the amount of water absorbed by the oils over time, which can be indicative of their ability to undergo hydrolysis or interact with water [27]. Across the board, hydration values generally exhibit an increasing trend over time, indicating progressive water absorption by the oils. For instance, FO demonstrates a consistent upward trend in hydration values from 19.54% at 2 hours to 76.55% at 4 hours and then to 80.09% at 8 hours. There is considerable variation in hydration values among different oils at each time interval. For example, at 2 hours, RO shows the lowest hydration value of 2.39%, while SO exhibits a higher value of 11.31%. At 8 hours, SBO and FO have the highest hydration values at 85.01% and 80.09%, respectively, whereas RO maintains a relatively low hydration value of 58.80%. Some oils consistently demonstrate higher hydration values across all time intervals, suggesting a greater propensity for water absorption. SO and SBO are notable examples, exhibiting relatively high hydration values at all time points. Conversely, oils like RO consistently exhibit lower hydration values compared to others, indicating lower water absorption or hydrolysis susceptibility. FSO and PSO fall in between, showing intermediate hydration values compared to other oils, implying moderate water absorption characteristics. The hydration behavior of oils can significantly impact their stability, shelf life, and suitability for various applications. Oils with higher hydration values may be more prone to hydrolytic degradation, leading to rancidity and off-flavors over time. Understanding the hydration characteristics of oils is crucial for optimizing storage conditions and packaging to prevent moisture ingress and maintain oil quality throughout its shelf life. FSO and PSO show intermediate hydration values compared to other oils, indicating moderate water absorption characteristics. The hydration values of oils can impact their stability, shelf life, and suitability for various applications. Oils with higher hydration values may be more prone to hydrolytic degradation, leading to rancidity and off-flavors over time. Understanding the hydration behavior of oils is essential for optimizing storage conditions and packaging to prevent moisture ingress and maintain oil quality.

Table 6 and Figure 2 provide the TEWL values of selected oils at different time intervals (2 hours, 4 hours, and 8 hours). TEWL values indicate the rate of water loss through the skin when exposed to these oils, which can be indicative of their moisturizing or occlusive properties [25]. HSO exhibits moderate TEWL values across different time intervals, suggesting a potential balance between occlusive and moisturizing properties. The TEWL reduction over time indicates its ability to provide a protective barrier on the skin while also helping to maintain hydration levels. FO shows similar TEWL values to HSO, indicating its potential as a skin moisturizer and barrier enhancer. The gradual decrease in TEWL over time suggests its effectiveness in reducing water loss from the skin and maintaining hydration levels. WCO demonstrates relatively lower TEWL values, especially at 8 hours, indicating its potential as an effective moisturizer. The fluctuation in TEWL values over time may suggest variations in its occlusive and moisturizing effects. PSO exhibits moderate to high TEWL values, indicating potential limitations in its ability to maintain skin hydration. The fluctuations in TEWL values over time may suggest variability in its occlusive and moisturizing properties. ALO demonstrates relatively low TEWL values, especially at later time intervals, suggesting its efficacy in maintaining skin hydration. The consistent decrease in TEWL values over time indicates its potential as a long-lasting moisturizer. SO shows moderate TEWL values, indicating its potential as a skin moisturizer. The gradual decrease in TEWL values over time suggests its effectiveness in reducing water loss from the skin. EPO exhibits moderate to high TEWL values, indicating potential limitations in its ability to maintain skin hydration. The fluctuations in TEWL values over time may suggest variability

in its occlusive and moisturizing effects. WSO demonstrates relatively low TEWL values, especially at later time intervals, indicating its efficacy as a skin moisturizer. The fluctuation in TEWL values over time may suggest variations in its occlusive and moisturizing effects. SBO exhibits high TEWL values across all time intervals, suggesting potential limitations in its ability to maintain skin hydration. The consistent high TEWL values indicate its limited effectiveness in reducing water loss from the skin. CSO demonstrates moderate to high TEWL values, indicating potential limitations in its ability to maintain skin hydration. The fluctuations in TEWL values over time may suggest variability in its occlusive and moisturizing effects. SCO exhibits high TEWL values, suggesting potential limitations in its ability to maintain skin hydration. The consistent high TEWL values indicate its limited effectiveness in reducing water loss from the skin. FSO demonstrates high TEWL values, suggesting potential limitations in its ability to maintain skin hydration. The fluctuations in TEWL values over time may suggest variability in its occlusive and moisturizing effects. RO exhibits high TEWL values across all time intervals, suggesting potential limitations in its ability to maintain skin hydration. The consistent high TEWL values indicate its limited effectiveness in reducing water loss from the skin. Findings indicate that oils with lower TEWL values, such as ALO and WSO, may be more effective in maintaining skin hydration, while oils with higher TEWL values, such as SBO and RO, may have limitations in this regard. Understanding the TEWL properties of oils is crucial for formulators and dermatologists to select appropriate ingredients for skincare products and address specific skin concerns effectively.

Conclusion

The study conducted a comprehensive analysis of various oils to elucidate their effects on skin hydration and barrier function. Key findings included the assessment of fatty acid composition, peroxide values, induction times, TEWL values, kinetic parameters, hydration values, and TEWL values for selected oils. These analyses revealed significant variations in the properties and performance of different oils, with some demonstrating higher efficacy in maintaining skin hydration and barrier integrity than others. Such insights are crucial in advancing our understanding of moisturizer effects on skin health, as they enable formulators to identify and utilize oils with optimal properties for skincare formulations. By incorporating oils with favorable characteristics, such as ALO, WSO, and WCO, into moisturizer formulations, skincare products can be tailored to address specific skin concerns effectively. Moreover, recommendations for the optimization of formulation ingredients, consideration of kinetic parameters, and validation through clinical trials underscore the importance of continuous research and development in the skincare industry. Overall, this research significantly contributes to the development of effective moisturizer formulations that enhance skin hydration, strengthen the skin barrier, and promote overall skin health and wellness.

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