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Investigation of some physicochemical properties of safflower oil blends

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SUMMARY: The current study aimed to explore the effects of blending safflower oil with terebinth and flaxseed oils at different ratios (5–20%) on its physicochemical properties, oxidative stability, fatty acid profile, and sensory quality. The blends included safflower oil enriched with 5, 10, and 20 terebinth oil; 5, 10, and 20% flaxseed oil; and combined mixtures containing 5% terebinth + 5% flaxseed or 10% terebinth + 10% flaxseed oils. Pure safflower oil showed the highest total phenolic content and radical scavenging activity, which slightly decreased after blending. Peroxide values were the lowest in pure safflower oil and the highest in flaxseed oil-containing blends. A mixture with 10% terebinth and 10% flaxseed oils exhibited the best oxidative stability. The oleic acid proportion peaked at 40.52% in the 10% terebinth blend, whereas linoleic acid decreased to 52.92% in the 20% flaxseed blend. Bitterness and pungency increased with higher terebinth levels, yet overall acceptability remained high. These results suggest that appropriate blending ratios can enhance the oxidative, nutritional, and sensory properties of safflower oil.

KEY-WORDS: *Flaxseed oil; Oil blends; Phenolics; Safflower oil; Terebinth oil.*

RESUMEN: ***Investigación de algunas propiedades fisicoquímicas de mezclas de aceite de cártamo.*** El presente estudio tuvo como objetivo explorar los efectos de la mezcla de aceite de cártamo con aceites de terebinto y linaza en diferentes proporciones (5-20 %) sobre sus propiedades fisicoquímicas, estabilidad oxidativa, perfil de ácidos grasos y calidad sensorial. Las mezclas incluyeron aceite de cártamo enriquecido con 5 %, 10 % y 20 % de aceite de terebinto; 5 %, 10 % y 20 % de aceite de linaza; y mezclas combinadas que contenían 5 % de terebinto + 5 % de linaza o 10 % de terebinto + 10 % de aceites de linaza. El aceite de cártamo puro mostró el mayor contenido fenólico total y actividad de eliminación de radicales, que disminuyó ligeramente después de la mezcla. Los valores de peróxido fueron más bajos en el aceite de cártamo puro y más altos en las mezclas que contenían aceite de linaza. Una mezcla con 10 % de aceites de terebinto y 10 % de linaza exhibió la mejor estabilidad oxidativa. La proporción de ácido oleico alcanzó un máximo del 40,52 % en la mezcla con 10 % de terebinto, mientras que el ácido linoleico disminuyó al 52,92 % en la mezcla con 20 % de linaza. El amargor y el picor aumentaron con mayores niveles de terebinto, aunque la aceptabilidad general se mantuvo alta. Estos resultados sugieren que unas proporciones de mezcla adecuadas pueden mejorar las propiedades oxidativas, nutricionales y sensoriales del aceite de cártamo.

PALABRAS CLAVE: *Aceite de cártamo; Aceite de linaza; Aceite de terebinto; Fenoles; Mezclas de aceites.*

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1. INTRODUCTION

In recent years, technological innovations and the increase in consumer demand have led to significant advances in the vegetable oil sector. Oils produced by cold pressing method preserve their natural taste and aroma and provide better preservation of antioxidants, vitamins, and minerals since they are not subjected to chemical processing and are not exposed to heat. These features make cold-pressed oils a healthier and higher quality option than traditional oils (Özkılıç and Arslan, 2022).

Although the use of blended oils in the food industry has been widespread for many years, blended oils for home use are very few in the consumer market. On the other hand, vegetable blended oils suitable for domestic use are abundant in foreign markets (Özkılıç *et al*., 2018). Studies show that better performing oils can be produced by combining oils with desired ratios and properties. Especially for heart health, blended oils containing enriched fatty acids have been shown to be more effective in terms of health compared to the use of a single type of oil. Blended oils are used not only in the food industry but also in various other fields.

Safflower (*Carthamus tinctorius* L.) is an important oilseed plant containing high ratios of unsaturated fatty acids, especially omega-6 linoleic acid varying between 73.58-88.46% (Kurt *et al*., 2017). The effects of linoleic acid on brain functions and heart health are very important. In addition, safflower oil shows antioxidant properties (Djuricic and Calder, 2021).

Flax *(Linum usitatissimum* L.) has gained importance in recent years due to its protective role in some diseases, especially due to its high levels of omega-3 fatty acids. It is high in lignans and regarded as a fiber source (Jihadi and Hameed, 2018). Terebinth (*Pistacia terebinthus*) is rich in omega-9 fatty acids with high antioxidant content. The high antioxidant content of terebinth oil provides an oxidation stability enhancing effect in frying oils. In addition, the fact that safflower oil is rich in omega-6 fatty acids and flaxseed oil is rich in omega-3 fatty acids is beneficial in providing an omega-6/omega-3 balance in blended oils (Özkılıç and Arslan, 2022).

Consumers expect vegetable oils not only to contain healthy fatty acids, but also to be a source of antioxidants and vitamins, to positively affect blood lipid levels, to be rich in omega-3 fatty acids and to offer a better flavor. Cold-pressed oils, on the other hand, offer natural taste and aroma as they do not undergo chemical processing, and the vitamins, minerals and antioxidants in these oils are better preserved as they do not come into contact with heat. With these features, cold-pressed oils offer a better quality and healthier alternative to oils produced by traditional methods.

In the present study, different ratios of terebinth and flaxseed oils were blended with safflower oil and analyses were carried out on their physicochemical and chemical properties. With the combination of these three oils, the fatty acid composition was altered, oxidative stability was increased and oil rich in functional content was obtained. Physico-chemical analyses, oxidation related analyses and sensory panel tests were carried out to evaluate the effects of the incorporation of terebinth and flaxseed oils into blends.

2. MATERIALS AND METHODS

2.1. Materials

Flaxseed (*Linum usitatissimum* L.) and terebinth (*Pistacia terebinthus* L.) seeds from the 2023 harvest period were obtained from a local store in Konya, Turkey. Oils were extracted by a screw cold-press machine (Karaerler NF 500, Karaerler Machinery, Turkiye). The extracted oil was filtered through Whatman No.1 filter paper (Cytiva, UK) and stored in dark amber glass bottles at room temperature in a cool, dark place. Commercial safflower oil was supplied by a local company. The oils were blended in various ratios by mass, as specified in Table 1. Each blend was stirred at 24 ± 1 °C, 120 rpm for 5 min in a beaker using a magnetic stirrer (IKA RT 15, IKA®-Werke GmbH, Staufen, Germany). All chemicals and solvents used in the assays were of analytical grade and purchased from Sigma-Aldrich (St. Louis, MO, USA) and Merck (Darmstadt, Germany).

TABLE 1. Safflower, terebinth and flaxseed oil ratios in the blends

Blend oil codes*	Ratios
S	safflower oil
S +10%T	safflower + 10% terebinth oil
S + 10%F	safflower + 10% flaxseed oil
S + 5%T + 5%F	safflower + 5% terebinth oil+ 5% flaxseed oil
S + 20%T	safflower + 20% terebinth oil
S + 20%F	safflower + 20% flaxseed oil
S+ 10%T + 10%F	safflower + 10% terebinth oil+ 10% flaxseed oil

*S (safflower oil), T (terebinth oil) and F (flaxseed oil).

TABLE 2. Total phenolic content, radical scavenging activity, and lipid oxidation in oil blends

Oil blend	peroxide number (meq O_2 kg/oil)	*p*-anisidine value	induction time (h)	TOTOX	INTOX	Total phenolics (mg/kg)	DPPH radical scavenging activity (%)
S	5.55 ±0.47 ^{e}	1.50 ±1.12 ^{c}	1.75 ± 0.02 ^{ab}	12.61^{e}	8.56^{f}	376 ± 47 ^{a}	28.70 ± 0.39 ^{a}
S + % 10T	6.27 ± 0.15 ^{e}	1.93 ± 1.03 ^{bc}	1.93 ± 0.02 ^{a}	14.48^{d}	10.15^{e}	364 ± 29 ^{a}	26.33 ± 2.30 ^{ab}
S + %10F	8.59 ± 0.39^{d}	2.87 ± 0.95 ^{abc}	1.55 ±0.05 ^{bc}	20.05^{c}	14.33^{c}	238 ± 12 ^{b}	25.19 ± 2.45 ^{ab}
S + % 5T +% 5F	9.60 ± 1.03 ^{a}	2.86 ±1.00 ^{abc}	1.68 ±0.02 ^{b}	22.06^{b}	15.32^{bc}	253 ± 17 ^{b}	26.04 ± 0.93 ^{ab}
S + % 20T	8.09 ± 0.74 ^{cd}	2.07 ± 1.01^{bc}	1.71 ± 0.04 ^{b}	18.25b^{c}	12.24^{d}	289 ± 24 ^{b}	24.85 ± 6.11 ^{ab}
S + % 20F	9.82 ±0.61 ^{bc}	3.77 ± 0.82 ^{a}	1.22 ± 0.04 ^{d}	23.41^{b}	17.37^{b}	226 ± 13 ^{b}	14.81 ± 2.18 ^{b}
S + % 10T + % 10F	10.74 ± 0.21 ^{ab}	3.66 ± 1.57 ^{a}	1.37 ± 0.05 ^{cd}	25.15^{a}	18.08^{a}	269 ± 15 ^{b}	20.70 ± 3.39 ^{c}

*S (safflower oil), T (terebinth oil) and F (flaxseed oil). The values are the mean ± standard deviation (n=3). Different superscripts in the same column represent significant differences ($P < 0.05$) as determined by Duncan's multiple range test within the analysis of variance (ANOVA).

TABLE 3. Fatty acid composition of oil blends consisting of safflower, terebinth and flaxseed oils

Fatty acids (%)	S	S+10%T	S+10%F	S+5%T+5%F	S+%20T	S+20F	S+10%T+10%F
Myristic acid (C14:0)	0.10±0.01	0.09±0.00	0.94±0.03	0.10±0.01	0.09±0	0.09±0.01	0.09±0.01
Palmitic acid (C16:0)	6.22±0.05	7.37±7.37	5.91±0.04	7.02±0.05	9.4±0.07	6.22±0.05	7.72±0.06
Palmitoleic acid (C16:1)	0.08±0.005	0.34±0.00	0.08±0.001	0.22±0.04	0.61±0.01	0.09±0.00	0.32±0.01
Stearic acid (C18:0)	2.25±0.04	1.84±0.03	2.14±0.03	2.33±0.04	2.21±0.04	2.59±0.05	2.42±0.04
Oleic acid (C18:1n9c)	28.03±0.22	40.52±0.32	34.32±0.27	28.29±0.22	31.75±0.25	26.55±0.21	29.09±0.23
Linoleic acid (C18:2n6c)	62.05±1.63	48.54±1.27	50.91±1.33	57.91±1.52	53.87±1.52	52.92±1.39	53.71±1.41
Linolenic acid (C18:3n3)	0.16±0.01	0.21±0.00	5.34±0.15	2.93±0.08	0.31±0.01	10.39±0.30	5.48±0.16
Arachidic acid (C20:0)	0.36±0.03	0.31±0.02	0.29±0.02	0.32±0.03	0.32±0.03	0.30±0.03	0.33±0.03
Cis-Eicosenoic acid (C20:1)	0.20±0.01	0.22±0.01	0.23±0.01	0.20±0.01	0.20±0.01	0.23±0.01	0.21±0.01
Behenic acid (C22:0)	0.26±0.01	0.23±0.00	0.23±0.02	-	0.22±0.01	0.23±0.01	0.23±0.01
Lignoceric acid (C24:0)	0.13±0.01	0.13±0.01	0.13±0.01	0.12±0.01	0.12±0.01	0.12±0.01	0.12±0.011
Nervonic acid (C24:1)	0.16±0.01	0.14±0.00	0.15±0.001	0.17±0.01	0.13±0.01	-	0.13±0.01
other	1.21	1.12	1.57	0.91	1.08	0.97	1.08
Total SFA	9.32	9.97	9.64	9.89	12.36	9.55	10.91
Total MUFA	28.47	41.22	34.78	28.88	32.69	26.87	29.74
Total PUFA	62.21	48.75	56.25	60.84	53.87	63.31	59.19

*S (safflower oil), T (terebinth oil) and F (flaxseed oil). Changes on the same lines are in different lowercase letters ($P < 0.05$) n:3

2.2. Color analysis (L*, a*, b*)

Color parameters were determined using a Minolta Chromameter CR-400 (Konica Minolta Co., Osaka, Japan), calibrated with a standard white calibration plate and adjusted according to the CIE Standard Illuminant C. Approximately 20 g of each oil sample were placed in a glass Petri dish (90 mm), and measurements were taken by placing the instrument head directly onto the surface (Pomeranz and Meloan, 1994).

2.3. Determination of free fatty acidity (FFA), peroxide value (PV), *p*-anisidine value (*p*-AV) and induction time

The FFA (as % oleic acid), PV, and *p*-AV were determined according to the official ISO 660:2016 and ISO 3960:2017 methods, respectively. Oxidative stability was assessed using a Rancimat apparatus (Model 892 Professional, Metrohm Co., Herisau, Switzerland) under the following conditions: temperature 100 °C, oil weight 3 g, air flow 20 L h^{-1}, and 60 mL ultrapure water as the absorbing medium (AOCS, 1992; Pawar *et al*., 2014).

2.4. Determination of total oxidation value (TOTOX value) and integral oxidation value (INTOX value)

The TOTOX Value is the sum of the PVs and AVs which represents the generation of primary and secondary oxidation products, focusing more on PVs. The formula is TOTOX = 2*PV + AV (Olmedo *et al*., 2019). Since this value assigns a crucial role to the generation of peroxides in the primary stage of oxidation. However, as the oxidation progresses, these peroxides decompose into secondary oxidation products, resulting in increases in AVs and a corresponding decrease in PVs. The INTOX Value prioritizes the formation of secondary oxidation compounds. The value is calculated as INTOX Value = PV + 2*AV (Juncos *et al*., 2024).

2.5. Determination of total phenolics and DPPH radical scavenging effect

The extraction of phenolics from the oil samples was performed: 1 mL n-hexane (≥ 99%) and 5 mL methanol-water (HPLC grade methanol, 70:30 v/v with distilled water) were added to 1 gram of the oil sample. The mixture was vortexed for 10 min and then centrifuged at 6000 rpm (centrifuge Nüve NF 800R refrigerated, Ankara, Turkiye). After separation of the hydroalcoholic phase, 1 mL of *n*-hexane and 5 mL of methanol-water were added to the oil phase and the mixture was centrifuged at 9000 rpm for 5 min. Finally, the extract was filtered using PTFE syringe tip filters (0.45 µm pore size, Sigma-Aldrich, Milan, Italy). The Folin-Ciocalteu's method was followed for total phenolics analysis. Phenolic content was expressed as gallic acid equivalents (mg/kg) (Paradiso *et al*., 2016). The radical scavenging effect of the oil samples was determined by testing the % inhibition effect of methanolic extracts of the oils against the DPPH radical **(**2,2-diphenyl-1-picrylhydrazyl, Sigma-Aldrich) following the method reported by Roginsky and Lissi (2005).

2.6. Determination of fatty acid composition

Fatty acids were analyzed using GLC, according to Ramadan *et al*. (2007). The fatty acid methyl esters (FAMEs) from the oil samples were prepared by saponification using 0.5 mol/L NaOH followed by methylation with a 50% BF3-methanol solution and 5 mL hexane along with a saturated NaCl solution for phase partitioning. FAMEs were identified on a Shimadzu GC-14A equipped with a flame ionization detector (FID) and C-R4AX chromatopac integrator (Shimadzu Corp., Kyoto, Japan) Kyoto, Japan). The flow rate of the carrier gas helium (99.999%) was 0.6 ml/min and the split value with a ratio of 1:40. A sample of 1 µL was injected onto a capillary column (30 m×0.25 mm×0.25 µm, Supelco SP™-2380, USA). The inlet and FID temperatures were set at 250 °C. The initial column temperature was 100 °C programmed at 5 °C/min until 175 °C and kept 10 min at 175 °C, then 8 °C/min until 220 °C and kept 10 min at 220 °C. Fatty acid methyl ester identification was performed by comparing the retention times of sample peaks with those of a 37-component FAME standard mixture (Supelco® 37 FAME Mix, Sigma-Aldrich, USA) analyzed under

identical chromatographic conditions. Peak areas were integrated using GCsolution software (Shimadzu Corp., Kyoto, Japan), and fatty acids were expressed as the percentage of total identified fatty acids (area normalization method).

2.7. Sensory analysis

30 mL of the samples were transferred to containers that were similar in color and appearance and did not damage the oil. In the sensory analysis, the color, odor, flavor, acceptability, seed-like, pungent, bitter, sweet and woody characteristics of the oils were evaluated. The acceptability of each oil blend was assessed through a nonstructured 10-cm length scale which was used for marking the intensity of the descriptors, where 0 represented "none" and 10 "extremely strong". Subsequently, the results were graphically represented by spiderwebs. The panel was formed by 32 untrained tasters (aged 20–48 years). Each panelist received 30 mL of each oil in a transparent glass cup encoded with three random digit codes. The samples were offered in a random order. Unsalted crackers and mineral water were used to clean the palate between samples (González-Gamallo *et al*., 2021; ISO, 2007).

The sensory evaluation was conducted in accordance with the principles of the Declaration of Helsinki. Since the study involved only harmless, edible oil samples and presented no risks to participants, no formal ethics committee approval was required according to institutional guidelines. All panelists were informed about the study objectives and procedures and provided informed consent prior to participation. The consent process included a statement confirming appropriate protocols for protecting participants' rights and privacy. Participation was entirely voluntary, with full disclosure of study requirements and potential risks, the right to withdraw at any time, and assurance that no personal data would be disclosed without consent. The authors confirm that no coercion was used and that all relevant ethical guidelines and regulations were followed throughout the research.

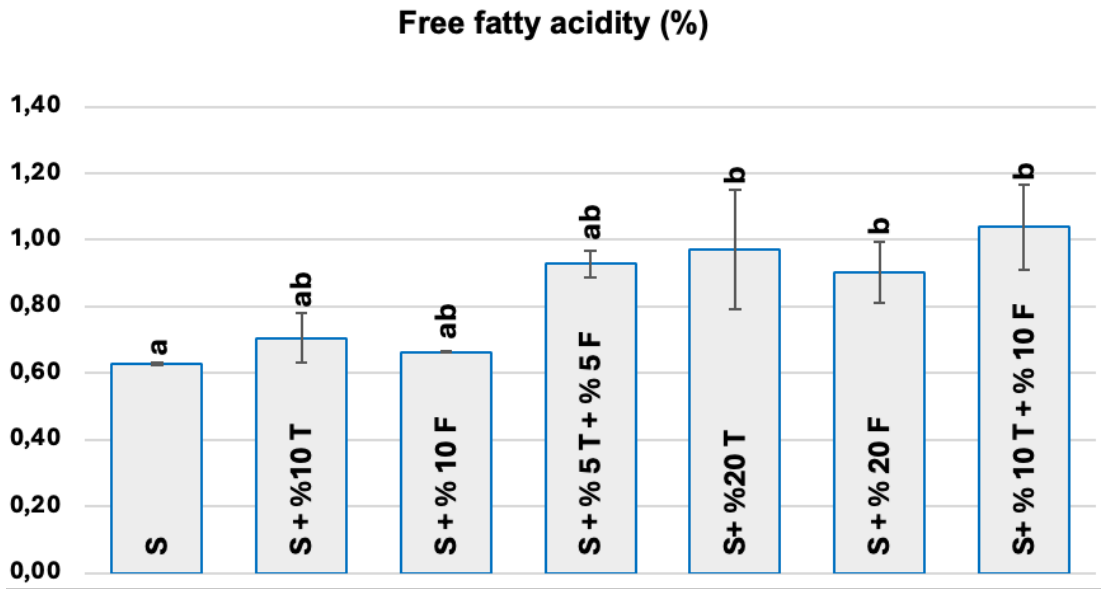

FIGURE 1. Free fatty acidity in safflower oil

*S (safflower oil), T (terebinth oil) and F (flaxseed oil).
Changes on the same lines are in different lowercase letters ($P < 0.05$).

The values are the mean ± standard deviation (n=3). Different superscripts in the same column represent significant differences ($P < 0.05$) as determined by Duncan's multiple range test within the analysis of variance (ANOVA).

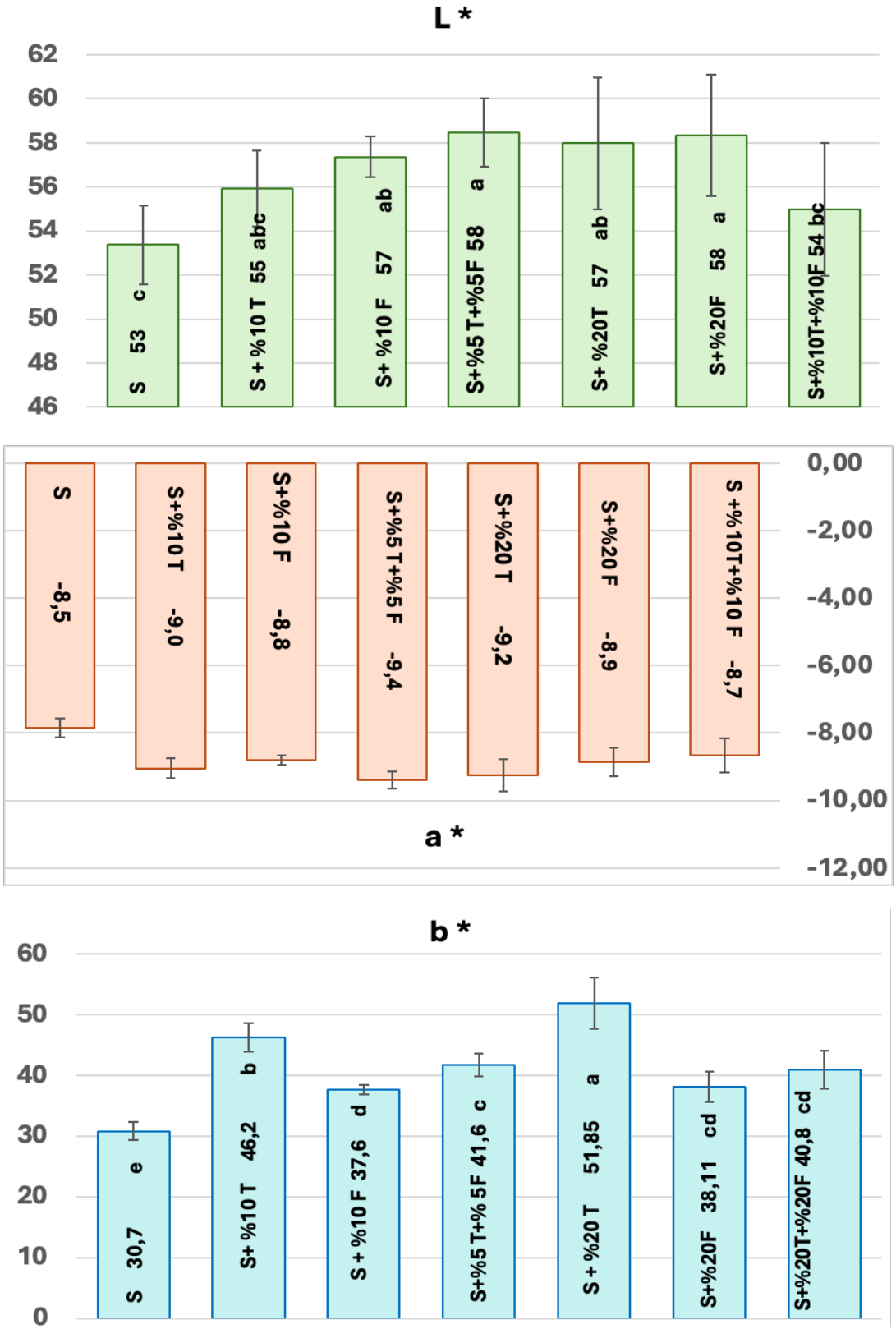

FIGURE 2. Color indices (L*, a*, b*) of oil blends.

*S (safflower oil), T (terebinth oil) and F (flaxseed oil). The values are the mean ± standard deviation (n=3). Different superscripts in the same column represent significant differences ($P < 0.05$) as determined by Duncan's multiple range test within the analysis of variance (ANOVA).

2.8. Statistical analysis

The results were given as the mean values of the three replicates and standard deviations. Analyses were performed using the statistical program SPSS for windows (v.16) and the significant differences between mean values were determined by Duncan's multiple range test ($P < 0.05$).

In this study, no human ethics committee or formal documentation process wase executed due to no risks presented to the participants and to the fact that the study does not involve sensitive topics. Panellists were given informed consent via the statement confirming the appropriate protocols for protecting their rights and privacy prior to the sensory analysis during the execution of the research. The authors confirm that no coercion to participate, full disclosure of study requirements and risks, written or verbal consent of participants, no release of participant data without their knowledge, ability to withdraw from the study at any time were provided.

3. RESULTS AND DISCUSSION

3.1. FFA contents in safflower blends

FFA content reflects the level of hydrolytic degradation in oils and is a key indicator of quality deterioration. Significant differences were observed in the FFA values of the oil blends. The FFA of pure safflower oil was 0.63 ± 0.02%, which increased slightly to 0.70% with the addition of 10% terebinth oil. The incorporation of terebinth and flaxseed oils led to a gradual rise in FFA, with higher blending ratios resulting in greater acidity. This increase can be attributed to the inherently higher FFA levels of the cold-pressed oils used in the blends. Similarly, Nykter *et al*. (2006) reported an FFA value of 0.21% for safflower oil. According to food regulations in most countries, the FFA content in cold-pressed oils should not exceed 2.0 g per 100 g, expressed as oleic acid. In the present study, all FFA values were well below 1%, indicating that the oils maintained acceptable quality levels.

3.2. Total phenolic content and antioxidant activity in safflower oil blend

Plain safflower oil contained the highest values of total phenolic content with 376 mg/kg and DPPH radical scavenging activity (28.7%) among the oils tested, while with the incorporation of 10% terebinth oil, the phenols decreased to 364 mg/kg and DPPH radical scavenging activity to 26.33%. 20% terebinth oil in safflower oil decreased the total phenolic content to 289 mg/kg. On the other hand, the addition of 20% flaxseed oil to safflower oil decreased the total phenolic content to 226 mg/kg and DPPH activity to 14.81. This result revealed that pure safflower oil stands out as a higher source of antioxidants compared to terebinth and flaxseed oils. With the addition of terebinth and flaxseed oils together at a 5% ratio to safflower oil, the DPPH radical scavenging activity was measured as 26.04, although the total phenolic content remained at the level of 253 mg/kg, indicating that the reducing effect of flaxseed oil can be eliminated by using it together with terebinth oil. The same applies to the triple blend at the 10% level. The blend obtained by adding 10% terebinth oil and 10% flax oil to safflower oil presented a moderate antioxidant capacity compared to the other blends with a total phenolic content of 269 mg/kg and a DPPH radical scavenging activity value of 20.70. These results indicate that terebinth and flaxseed oils can optimize the antioxidant capacity of safflower oil when mixed in the right proportions. The total phenolic content of plain safflower oil determined in the present study was higher than some reported previously by Güngören *et al*. (2024) (149.50 mg/kg) and Aydeniz *et al*. (2014) (26.16 mg/kg), which was dramatically lower than the total phenolic content obtained in the present study. Such variations may result from differences in safflower cultivar, cultivation conditions, harvest period, and climatic factors, as well as the analytical methods and environmental parameters used in each study.

3.3. Color indices of safflower oil blends

The L^* value of plain safflower oil with a value of 53.4 represented a medium level of lightness. The blend with 10% terebinth oil (S+10 % T) provided an increase in lightness by increasing the L^* value to 55.93. The

addition of 10% flaxseed oil (S+10% F) resulted in a more pronounced rise in lightness to a value of 57.4. The "S+5%T+5 F" blend exhibited the highest level of lightness by increasing the *L** value to 58.5. "S+20%T" and "S+20%F" blends increased the lightness with values of 57.9 and 58.3, respectively, although the difference was not statistically significant. On the other hand, the blend with 10% incorporation of flaxseed and terebinth oil each (S+10%T+10%F) was darker in color (54.9). In a study conducted by Safkan (2023), the *L**, *a**, and *b** color parameters of seven safflower varieties ranged between 49.72 and 65.59, and the *L** value measured in the present study (53.37) was consistent with those findings. These results indicate that terebinth oil contributes more effectively to lightening the color of safflower oil. Similarly, Özkılıç and Arslan (2022) reported that flaxseed oil exhibited higher *L** values than terebinth oil, supporting the present results.

The *a** values were negative in all oil samples, indicating a greenish color tendency. While plain safflower oil had the lowest greenness with a value of -7.84, these values reached more negative levels with the addition of flaxseed and terebinth oils. Particularly the blend containing 5% of both terebinth and flaxseed oils showed the most intense green color with a value of -9.38. The addition of terebinth oil and flaxseed oil to safflower oil increased the greenness of the blended oils, in particular, the addition of terebinth oil had a pronounced effect on the green hue. However, these differences were not statistically significant.

The positive *b** values of pure safflower oil showed its location in the yellow region. A significant increase in *b** value was observed when terebinth oil was incorporated. The addition of terebinth oil to safflower oil contributed more evidently in terms of an increase in the *b** value. The lowest *b** values were determined in 10% and 20% flaxseed oil-added samples. Terebinth oil made a significant contribution to the yellow tones, and when flaxseed oil was included to the blend the degree of yellowness was lower than that given by terebinth oil.

3.4. Analysis results of lipid oxidation in safflower oil blends

The lowest PV was measured in pure safflower oil, whereas the highest PVs were observed in the blends containing flaxseed oil. The greater susceptibility of flaxseed oil to oxidation compared to terebinth oil can be attributed to its higher linolenic acid content. The p-AVs followed a similar trend to the PVs, with higher values recorded in the samples containing both oils, particularly flaxseed oil. The negative influence of flaxseed oil on oxidative stability was also evident in the induction time results. While the induction time of the blend containing 20% terebinth oil (1.71 h) was comparable to that of plain safflower oil (1.75 h), the shortest induction time was observed in the blend containing 20% flaxseed oil (1.22 h). Consistent with the present findings, Özkılıç and Arslan (2022) reported that flaxseed oil exhibited a markedly shorter induction time (0.44 h) than terebinth oil (8.27 h).

Overall, lipid oxidation analyses demonstrated that pure safflower oil exhibited the highest resistance to oxidative degradation, whereas the blends containing higher proportions of flaxseed oil (10% and 20%) were the most susceptible to oxidation, as reflected by their elevated TOTOX (20.1–25.2) and INTOX (14.3–18.1) values. The INTOX value proposed by Juncos *et al*. (2024) integrates both primary and secondary oxidation products to provide a more comprehensive assessment of lipid oxidation. Shifting the emphasis toward secondary oxidation compounds (carbonyls) rather than primary peroxides is considered to represent the actual oxidation state more accurately. According to Juncos *et al*. (2024), oils with INTOX values exceeding 18 mEq/kg can be considered rancid.

3.5. Fatty acid composition of safflower oil blends

The fatty acid composition of the safflower oil blends is shown in Table 3. Abd El-Baset *et al*. (2024) reported that safflower oil contains a fatty acid profile characterized by high linoleic acid content and relatively low oleic acid content, making it a rich source of ω-6 polyunsaturated fatty acids. Oleic acid (C18:1n9c) stands out as an important component of all blends, reaching its highest level in the S+10 T blend (40.52%). This percentage decreased to 31.75% in the S+20%T blend and to 34.32% in the S+10%F blend. Oleic acid is a monounsaturated fatty acid and is known to have positive effects on cardiovascular health (Schwingshackl and Hoffmann, 2012). Therefore, an increase in oleic acid content can be considered as an important parameter in obtaining a healthy fatty acid profile.

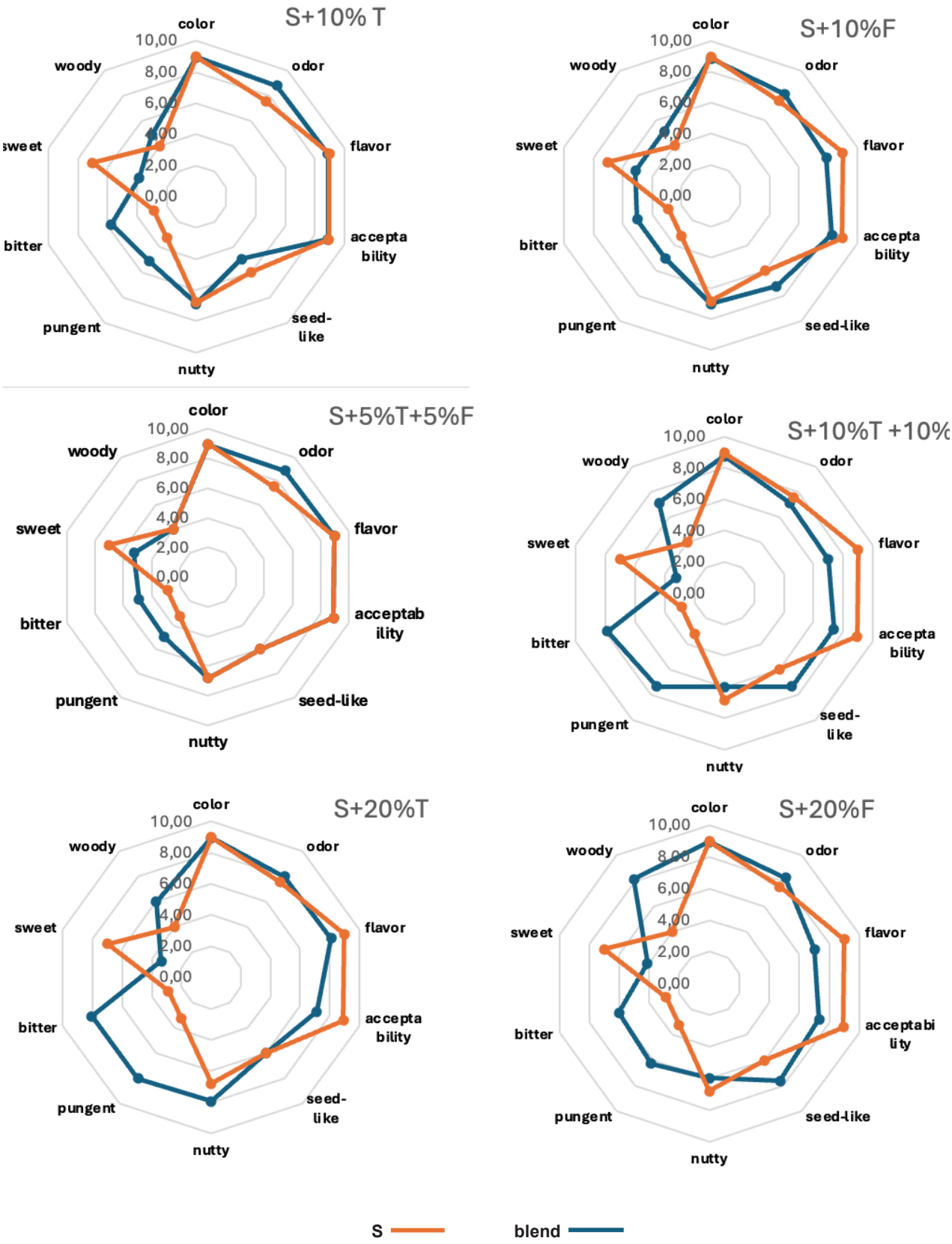

FIGURE 3. Sensory evaluation scores of safflower oil blends

*S (safflower oil), T (terebinth oil) and F (flaxseed oil). (The average scores given by 32 panelists)

Linoleic (C18:2n6c) and linolenic (C18:3n3) acids showed a remarkable increase with the addition of flaxseed oil. Linoleic acid content increased to 50.91% and 53.87% in the S+10%F and S+20%F blends, respectively. Linoleic acid has many important functions in the body as an omega-6 fatty acid and plays an important role in the prevention of cardiovascular diseases (Tortosa-Caparrós *et al*., 2017). The proportion of linolenic acid reached 5.34% with the addition of 10% and 10.39% with the addition of 20% flaxseed oil. Flaxseed oil, with its high linolenic acid content, was an important source of omega-3 fatty acid in these blends. S+10%F contained the highest percentage of PUFA (63.3%), followed by plain safflower oil (62.2%) and S+5%T+5%F (60.8%). The highest percentage of SFA (12.4%) was present in the S+20%T blend.

The PUFAs/SFAs ratios in the safflower oil blends were around 6, however in blends containing 10% and 20% terebinth oil, this ratio was 5 and 4, respectively. The lowest ratio in the MUFAs/SFAS ratios ranging from 2.5 to 3.5 occurred in the sample containing 20% terebinth.

The PUFAs/SFAs ratio is an index used to evaluate the impact of foods on cardiovascular health. A high PUFAs/SFAs ratio is associated with a reduced risk of CVDs, autoimmune, and other chronic diseases (Chen and Liu 2020; Simopoulos, 2002).

A balanced intake of dietary PUFA/SFA is thought to be important in regulating serum cholesterol (Kang *et al*. 2005). A PUFA/SFA ratio greater than 2 is recommended in the Mediterranean Diet (Gouaref *et al*., 2020). The SFAs:MUFAs:PUFAs ratios in the blends were around 1:3:6. Again, the ratios differed in blends containing 10% (1:4:5) and 20% (1:2.5:4.5) terebinth oil.

As a result, variations in the proportions of oleic, linoleic, linolenic, and palmitic acids determined the fatty acid profiles of the blends, depending on the types and ratios of oils incorporated. The addition of 10% flaxseed oil and 10% terebinth oil resulted in a more balanced fatty acid distribution, characterized by an increase in monounsaturated fatty acids (MUFAs) without a corresponding rise in saturated fatty acids (SFAs). These findings indicate that the selection and proportion of blending oils play a critical role in optimizing the fatty acid composition and that tailored formulations can be designed to achieve specific nutritional and functional benefits.

3.6. Sensorial evaluation of safflower oil blends

In the sensory analysis, the color, odor, flavor, seed-like, nutty, woody, pungent, bitter, sweet and acceptability characteristics of the oils were evaluated. Safflower oil generally exhibited a milder and more balanced flavor profile in the sensory analysis, achieving high sweetness scores. It also received low ratings for woody notes, while its seed-like and nutty characteristics remained moderate. Furthermore, pungency and bitterness were almost absent, indicating that plain safflower oil offers a mild and neutral flavor profile.

The incorporation of flaxseed and terebinth oils significantly enhanced the bitterness and pungency of the blends, and these effects became more pronounced as their proportions increased. Blends containing 20% of either oil, or their combination, showed slight reductions in flavor intensity and overall acceptability; however, these decreases were minimal and remained within acceptable sensory limits. At the 20% addition level, both flaxseed and terebinth oils increased woody notes, with flaxseed oil producing a more pronounced effect. Conversely, terebinth oil contributed greater pungency and bitterness than flaxseed oil at equivalent ratios. As a result, the panelists assigned lower sweetness scores to the blends, particularly to the 20% flaxseed (S+20%F) and 10% flaxseed + 10% terebinth (S+10%F+10%T) samples. Despite these changes, the overall acceptability scores remained high, indicating that all blends maintained a generally favorable and well-accepted taste profile.

There was also an improvement in woody and seed-like characteristics, which added a more pronounced flavor to the blend. No significant effect was noticed on nutty properties.

The addition of terebinth oil imparted significant pungency and bitterness, and both the samples S+10%T and S+20% provided high bitterness and pungency scores (which were higher for the latter). As a result, acceptability decreased slightly, suggesting that terebinth oil may create an intense odor and taste profile for some users. Sweet and woody characteristics remained at lower levels, revealing the sharper profile of the blend. In summary, the addition of 20% terebinth oil added richness and depth to the blend but also led to some pungent and bitter flavors becoming more pronounced. This change may be positive for consumers looking for a rich experience in terms of taste and smell, but it has a slightly negative impact on overall

acceptability.

Compared to plain safflower oil, the blend S+5%T+5%F was rated as slightly more odorous and pungent, while it was evaluated quite similarly with regards to other factors. The addition of 10% terebinth and 10% flaxseed oil produced a marked change in the overall profile of the blend, resulting in a more intense, complex flavor and odor. This blend may be of interest to consumers looking for rich and deep flavors, but for some, the stronger and more intense flavors may not be pleasing.

4. CONCLUSIONS

The results demonstrate that while blending these oils affects FFA content, antioxidant activity, and oxidative stability, strategic blending can enhance certain beneficial properties. The increase in PUFA content with flaxseed oil addition contributed to a healthier lipid profile, with PUFA levels reaching 63.3% in the 10% flaxseed oil blend. However, higher flaxseed oil content led to increased lipid oxidation, with INTOX values ranging from 14.3 to 18.1, indicating a potential risk of rancidity. Sensory analysis suggests that moderate incorporation of these oils can enrich flavor complexity without significantly compromising acceptability. While the 10% terebinth oil +10% flaxseed oil in the blend presented a more balanced sensory profile, higher terebinth oil ratios introduced stronger pungency and bitterness. Ultimately, this research underscores the importance of optimizing oil blends to achieve desirable health benefits and consumer preferences, paving the way for further studies on functional oil formulations.

DATA AVAILABILITY

The datasets during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

DECLARATION OF COMPETING INTEREST

The authors declare no conflicts of interest.

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AUTHORSHIP CONTRIBUTION STATEMENT

B.B. Doğan: Formal analysis, Investigation, Writing—original draft Preparation, Data curation, Project administration.

D. Arslan: Conceptualization, Methodology, Formal analysis, Investigation, Writing—review and editing, Validation, Visualization, Supervision, Project administration.

ETHICAL STATEMENT

The authors confirm all relevant ethical guidelines have been followed. All methods were used in accordance with relevant guidelines and regulations. There are no human or animal subjects in this article.

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