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Some Nutraceutical and Bioactive Compounds of Seed Oils Obtained from Seeds of Different Gundelia Varieties

Some Important Properties of Gundelia Seed Oils

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ABSTRACT

The goal of this research was aimed to investigate the nutraceutical and bioactive compounds of *Gundelia* seed and its seed oils. The contents of fatty acids, triglycerides, sterols, tocopherol, tocotrienol (tocols) and some physicochemical properties of the cold pressed *Gundelia* seed oils were analyzed by HPLC and GC devices. The main fatty acid was found to be linoleic acid (45.078-75.113%), which is a polyunsaturated fatty acid (PUFA), and the main triglyceride structure was LLL (trilinolein, 13.39-44.6%). The main sterol was β-sterol (37.65-72.62%) and the main tocol was α-tocopherol (31.10-77.95 µg/g). It was determined that the total phenolic content of the oils of *Gundelia* seeds varied between 974.55 and 3439.09 µg GAE/mg oil and their antioxidant capacity ranged between 113.56 and 287.26 mg trolox/L. The oils obtained from the seeds of different *Gundelia* have similar properties to some edible oils and have a rich content in terms of nutraceutical and bioactive compounds.

Keyword: *Gundelia* seed oil, Fatty acid, Triglyceride, Sterol, Tocopherol

INTRODUCTION

Gundelia is a genus of the *Asteraceae* family. *Gundelia tournefortii* is commonly known as tumble thistle, tumbleweed, and a′kub in Arabic [1]. Native to the Asian-temperate zones of Western Asia, including Cyprus, Egypt, Iran, Israel, Jordan, Turkey, Azerbaijan, and Turkmenistan, *Gundelia tournefortii* L. var. armata Freyn. and Sint. is a member of the Asteraceae (Compositae) family and used medicinally [2,3].

Gundelia tournefortii is a plant whose leaves and stems are used culinary dishes and food ingredients [4–6]. *Gundelia tournefortii*'s stems, flowers, leaves, and seeds are consumed as food. Before flowering, the flower buds of tender plants are harvested and cooked in Turkey, Palestine, Jordan, and Syria [1,4,7]. The late x obtained from *Gundelia* is used to make chewing gum (kenger chewing gum) in Turkey and its seeds are used to make coffee (kenger coffee). It is also used in the preparation of different dishes and soups [8].

Most of the studies on *Gundelia* have been done on *Gundelia tournefortii* L. These studies are related to the root, stems, leaves, fruits, and seeds of *Gundelia tournefortii* L. There are many phytochemical components in the roots, seeds, and flower buds of *Gundelia tournefortii* L. [1,8–11]. This plant has antibacterial, anti-inflammatory, and hypolipidemic properties. [1]. The researchers were primarily interested in flower buds, from which they isolated numerous components using analytical techniques. These include crude protein, water-insoluble fibers, minerals, fat acids, sterols, tocopherols, and minerals [1,7,12–18].

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In this study, the moisture, protein, and crude oil values of the seeds of 17 different *Gundelia* species collected from different regions in Turkey were determined. In addition, the refractive index, iodine number, free fatty acidity, fatty acid composition, triglyceride contents, sterol contents, tocopherol and tocotrienol contents (tocols), color values, total phenolic content and antioxidant activity of the oils obtained by cold pressing from *Gundelia* seeds were determined and compared in terms of nutraceutical and bioactive compounds. For the first time, this study looked at the physical and chemical properties of oils made from the seeds of many different *Gundelia* species.

MATERIAL AND METHODS

MATERIAL

Samples were taken by going to the places where the existing taxa of the genus were found in "Flora of Turkey and East Aegean Islands (volume 5)" [19], as well as the places where new species and new records were found, and the places where the existing taxa were found in herbariums and flora studies. The types and species codes of the samples collected are given in Table 1.

Table 1 *Gundelia* types and spice codes (t codes).

Sample Code	T Code	Species Name
G1	5050	*Gundelia armata*
G2	5064	*Gundelia asperrima*
G3	5073	*Gundelia armeniaca*
G4	8275	*Gundelia tournefortii*
G5	8282	*Gundelia cilicica*
G6	8288	*Gundelia komagenesis*
G7	8291	*Gundelia mesopotamica*
G8	8299	*Gundelia siirtica*
G9	8306	*Gundelia glabra*
G10	5089	*Gundelia glabra* (Bayburt)
G11	8307	*Gundelia munzuriensis*
G12	8308	*Gundelia dersim*
G13	8309	*Gundelia vitekil*
G14	8333	*Gundelia colemerikensis*
G15	8334	*Gundelia rosea*
G16	8325	*Gundelia purpurescens*
G17	17449	*Gundelia anatolica*

Extraction of crude oil from *Gundelia* seeds by the cold pressing method was carried out with a cold pressing oil machine (Karaerler brand NF500 model, Turkey). *Gundelia* seeds were pressed at a frequency of 15 Hz at 40-45°C in a cold press oil machine preheated to 100°C. It was ensured that the oil obtained was below 45°C. *Gundelia* seed oils were stored in amber glass bottles under refrigerator conditions until analysis. The following analyses were carried out to determine the physical and chemical composition of the seeds of *Gundelia* species and the oils obtained from them:

Moisture Content

The moisture content of seeds was determined according to AOAC Official Method 925.40-1925 [20]. Approximately 3 grams of ground seeds were weighed into an aluminum desiccant (precision 0.1 g). It was dried to a constant weight at 103ºC in a preheated oven (Memmert UF 110). The moisture content was determined with the help of the following formula:

Moisture (%) = $((W_1-W_2)/W1) \times 100$

where W_1= wet weight (g) of sample and W_2= dry weight (g) of sample (g).

Protein Content

The amount of protein was determined with the "Gerhardt Vapodest 45s" instrument using the Kjeldahl method according to the AACC Official Method 46-12.01 [21]. The conversion factor was used as 5.30 in the calculation of the protein amount and expressed as a percentage.

Crude Oil Content

The seeds were ground in an IKA brand grinder (A 11 basic analytical mill) until a uniform structure was obtained. Solvent extraction for oil extraction from ground seeds was carried out according to AOCS Am 2-93 [22] using petroleum ether (boiling point range 40-60°C) in a soxhlet extraction unit (Gerhardt SOX-416 Automatic Oil Analyzer).

Refractive Index

The refractive indexes of the seed oil samples obtained from the seeds were determined at 20°C using an Abbe refractometer (Krüss AR 2800).

Iodine Value

The iodine value of fatty acids was determined using the AOCS Official Method Tg 1a-64 [23], and it is expressed as the amount of iodine that was absorbed by one 100 grams of test sample (percentage of iodine absorbed).

Free Fatty Acids

Titrimetric analysis in accordance with AOCS Official Method Ca 5a-40 [24] was used to determine the percentage of free fatty acids (FFA), and the results were expressed in terms of oleic acid as follows:
FFA, oleic acid (%) = (mL of alkali x M x 28.2)/mass; g of test portion

Fatty Acid Composition

A gas chromatography instrument (GC/FID, Agilent 7890A) with an FID detector was used to analyse fatty acid methyl esters. All samples were injected into a 100 m × 0.25 mm ID, 0.2 µm HP-88 (J&W 112-88A7) column. Helium (1.5 mL/min) was used as the carrier gas. The detector temperature was set at 260°C and the oven temperature at 230 °C. The diluted samples (n-heptane 1/100 (v/v)) were injected automatically in split mode (1/100). The FAME percent was calculated according to the method specified in AOAC Method 996.06 [25].

Triacylglycerol (TAG) Composition

TAG profile analysis of *Gundelia* seed oil following solid phase extraction (SPE) using the protocol from Commission Regulation (EEC) No: 2472/97 [26]. The quantification of 17 distinct TAGs was made possible by isocratic reversed phase analysis and following refractive index (RI) detection. An exact quantity of 0.5 grams of gundelia seed oil was dissolved in a volume of 10 milliliters of acetone that was chromatographically pure. After passing some of this solution through a disposable filter unit with a pore size of 0.45 µm, it was placed in a vial for further processing. This solution was injected in 10 µL aliquots for HPLC analysis. The following equipment and conditions were used for the HPLC analysis: column: ACE 5 C18 250 x 4.6 mm; column temperature: 30°C; mobile phase: acetone: acetonitrile (60:40); flow rate: 1.00 mL/min; detector: refractive index (RID); detector temperature: 35°C.

Sterol Composition

The determination of sterol content was carried out according to "TS EN ISO 12228-1 Determination of individual and total sterol contents - Gas chromatographic method - Part 1: Animal and vegetable fats and oils" [27]. For this purpose, first, the oil samples were saponified with KOH, the unsaturated part was extracted, and the sterols in this part were separated by thin layer chromatography. The separated sterols were then analyzed using the Agilent 6850 GC with an FID detector and an HP-5 (30 m x 320 µm x 0.25 µm) column. Chromatographic conditions: injection at 280°C at 7.9 psi, column temperature of 260°C, detector temperature of 290°C, injection volume of 1.0 µL, split ratio of 10:1, flow of carrier gas of 36 cm/s of hydrogen gas were used.

Tocopherol and Tocotrienol (Tocols) Composition

Tocopherol and tocotrienol (tocols) analysis were performed using a Shimadzu 20A HPLC equipped with a UV-VIS (DAD) detector and a Phenomenex Kromasil 150 x 4.6 mm, 3.5 µm particle size column. A mixture of 0.2% IPA and 0.8% acetic acid in hexane was used as the mobile phase and analyzed for 40 minutes at 290 ± 8 nm at an isocratic elution with flow rate of 1.0 mL/minute. For sample preparation, 1 g of oil sample was weighed into a 20 mL test tube. 10 mL of hexane was added and mixed in a vortex for 2 minutes to dissolve the sample. It was then passed through a 0.45 µm nylon filter with a pore diameter and taken into 2 mL vials. 10 µL of sample was injected into the HPLC device at a column temperature of 35°C. The amounts of alpha, beta, gamma, and delta tocols (%) were calculated according to the peak areas of the standard (ChromaDex, CDXA-12-2980) calibration curves [28].

Colour

In the color measurement of oils obtained from seeds, L*, a*, b*, Chroma and hue values were determined by using the Konica Minolta CM-5 colorimeter using the L*, a* and b* systems accepted by the CIE (Commission Internationale de L. Eclairage).

Total Phenolic Compounds

Total phenolic content of seed oils was determined by measuring the color of phenolic compounds in Folin-Ciocalteu solution in alkaline medium with a UV-visible spectrophotometer (UV-1201; Shimadzu, Kyoto, Japan) [29]. Results are given in gallic acid equivalent (GAE) as µg GAE/mg oil.

Antioxidant Activity (DPPH method)

The assessment of antioxidant activity was conducted using DPPH (2, 2-diphenyl-1-picryl hydrazyl) assay [30]. This method is based on electron transfer, producing a violet solution with maximum absorption at 517 nm.
Seed oils (0.1 mL) were mixed with 3.9 mL of DPPH solution (2.36 mg/100 mL methanol) and vortexed vigorously. The solution was stored in the dark at room temperature for 15 minutes. Absorbance was monitored at 517 nm with a UV-visible spectrophotometer (UV-1201; Shimadzu, Kyoto, Japan the seed oil's antioxidant activity was determined using a Trolox calibration curve, and its antioxidant capacity was expressed as mg Trolox equivalent /L.

Statistical Analysis

The results were presented as the average of three different assessments. Statistical analysis was performed using Excel 2016 (Microsoft, Redmond, DC, USA).

RESULTS

As can be seen from Table 2; the moisture, protein, and crude oil yields of the seeds of *Gundelia* species vary between 3.62-4.68%, 6.48-12.78% and 2.96%-11.96%, respectively. It was determined that the lowest crude oil yield was in *Gundelia munzuriensis* (G11) and the highest crude oil yield was in *Gundelia armeniaca* (G3). In a study [16], the crude oil yield of *Gundelia tournefortii* L. seeds was found to be 22.8%. In another study [18], the crude oil yield of *Gundelia tehranica* seeds was found to be 26.4%. A group of researchers reported that the crude oil yield of *Gundelia* seeds varied between 11.35-39.17% [7].
The crude protein content of *Gundelia* species seeds was 6.48-12.78%, which was found to be similar (11.2%) to a study, but different from the data (%16.6) reported by other researchers [12,13].
The differences in crude oil and crude protein contents of *Gundelia* seeds in this study and other studies may be caused by characteristic differences of the varieties as well as temperature, water, light, chemical, mechanical factors, etc. factors. In addition to ecological conditions, they may change depending on many factors, such as climatic, topographic, edaphic, and biotic factors. In addition, it was concluded that the most important reason for the differences in crude oil content may be due to the difference in the extraction method, the seeds having been spilled by physical factors, or the lack of development.

Fatty Acid Contents of *Gundelia* Seed Oils

Fatty acid methyl ester composition (FAME) is a key part of figuring out what kind of oil it is and how pure it is. Saturated and unsaturated fatty acids are the two categories of fatty acids. Furthermore, there are two categories of unsaturated fatty acids: healthy fats like omega-3s and omega-6s, also known as monounsaturated and polyunsaturated [32].

Average values of the fatty acid composition of Gundelia seed oil samples obtained by cold pressing are given in Figure 1 and Table 3.

The main saturated fatty acids (SFA) in *Gundelia* seed oils are palmitic acid (16:0) and stearic acid (18:0), while the unsaturated fatty acids (UFA) are oleic acid (18:1n9) and linoleic acid (18:2n6). These fatty acids are found in the seed between 5.029 and 10.413%, 2.199 and 3.953%, 15.385 and 38.982%, and 45.078 and 75.113%, respectively. It was determined that the main polyunsaturated fatty acid (PUFA) was linoleic acid (45.078-75.113%) (Table 3).

In the oils obtained from the seeds of *Gundelia* varieties by cold pressing, the highest linoleic acid content was obtained from the seeds of the *Gundelia glabra* (Bayburt) (G10) variety (75.113%), and the lowest linoleic acid content was obtained from the seeds of the *Gundelia rosea* variety (G15) (45.078%) (Table 1, Table 3).

When the total saturated fatty acid (SFA), monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), and total unsaturated fatty acid (UFA) contents of the oils obtained from the seeds of *Gundelia* species are examined, it was determined that the seed oils of *Gundelia* species were rich in unsaturated fatty acids and the total unsaturated fatty acid (UFA) content varied between 84.363-90.839%. It was determined that the total saturated fatty acid (SFA) content of the oils obtained from the seeds of *Gundelia* species was 7.739-14.994% and the main saturated fatty acid was palmitic acid (5.029-10.413%) (Table 3).

The average values in our study are similar to those found by a group of researchers who examined the physical properties of *Gundelia tournefortii* seed oils. They found that the oleic acid and linoleic acid contents of *Gundelia* seed oil were 27.99% and 54.59%, respectively, and the total unsaturated fatty acid content was 82.58%. Both values are comparable to what you would find in soybean and sunflower oils in terms of oleic and linoleic acid concentrations. It was reported that the oleic and linoleic acid content of soybean oil was 26.4% and 50.8%, respectively, while the oleic and linoleic acid content of sunflower oil was 30.2% and 55.4%, respectively [14,33].

Triglyceride Content of *Gundelia* Seed Oils

Average values of triglyceride composition (TAG) and distribution of oils obtained by cold pressing seeds of *Gundelia* species during the study are given in Table 4 and Figure 2.

It was determined that the triglyceride structures in the oils of *Gundelia* seeds were LLnLn, LLL, OLL, PLL, OOL+LnPP, POL+SLL, OOO and SOL+POO. These triglycerides are found in the range of 1.15-5.03%, 13.39-44.37%, 0.00-26.06%, 0.00-12.98%, 6.73-17.58%, 8.48-12.83%, 0.77-9.18% and 2.07-9.64%, respectively, in the structure of the oil (Table 4).

It was determined that the main triglyceride structure in *Gundelia* seed oils is LLL (trilinolein, 13.39-44.6%), followed by OLL (oleodilinolein, 0.00-26.06%) and POLn (palmitooleolinolein, 0.00-22.89%) respectively (Table 4). It was determined that LLL (trilinolein), which is the main triglyceride structure, was the lowest in *Gundelia rosea* (13.39%) (G15), while the highest LLL (trilinolein) was in *Gundelia glabra* (Bayburt) (44.36%) (G10). In addition, the OOL+LnPP, POL+SLL, PPL, OOO, SOL+POO, POP, SOO, and SOP contents of *Gundelia glabra* (Bayburt) were found to be higher than those of other *Gundelia* species. *Gundelia munzuriensis* (G11) and *Gundelia purpurescens* (G16) characteristically contain POLn (palmitooleolinolenin) (22.89% and 9.51%, respectively), while other *Gundelia* species do not contain POLn. No studies were found on triglyceride composition and distribution in *Gundelia* species.

Sterol Content of *Gundelia* Seed Oils

Sterols are found in the unsaponifiable part of oils in free form or esterified with fatty acids (waxes) in nature [32]. Table 5 and Figure 3 show the average amounts of plant sterols and where they are found in *Gundelia* seed oils made by cold pressing.

As can be seen in Table 5, the total sterol content of the oils obtained from *Gundelia* seeds by cold pressing varied between 1679-5229 mg/kg. The lowest total sterol content was in *Gundelia comagenesis* (1679 mg/kg) variety (G6) and the highest total sterol content was in *Gundelia mesopotamica* (5229 mg/kg) (G7).

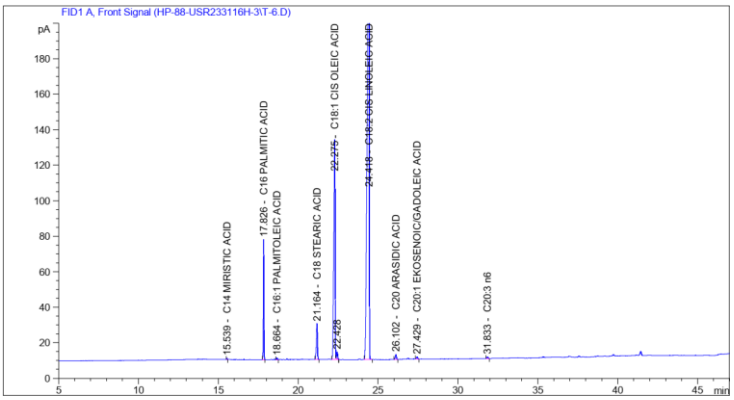

Fig. 1 GC chromatogram of fatty acid content of oils obtained from seeds of *Gundelia* species.

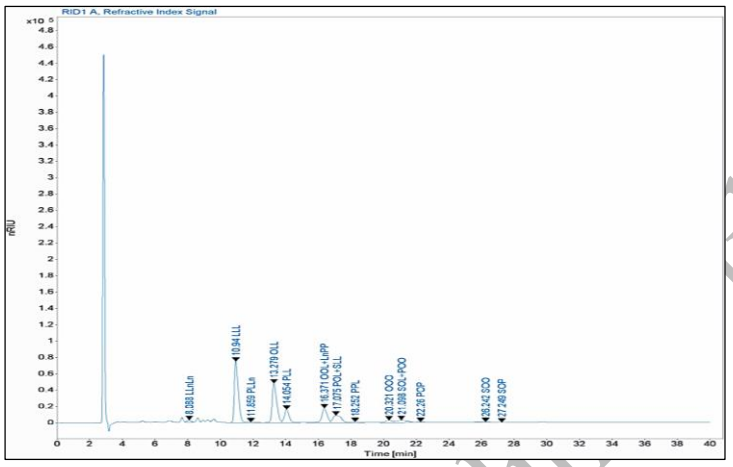

Fig. 2 HPLC chromatogram of the amount of triglycerides in oils made from *Gundelia* species seeds.

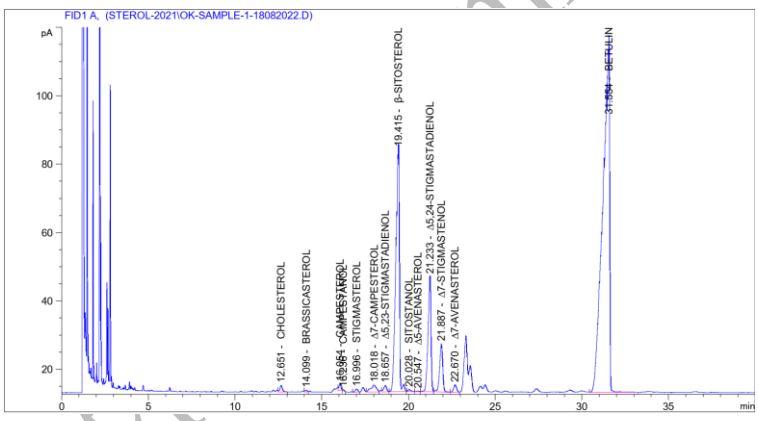

Fig. 3 GC chromatogram of sterol content of oils obtained from seeds of *Gundelia* species.

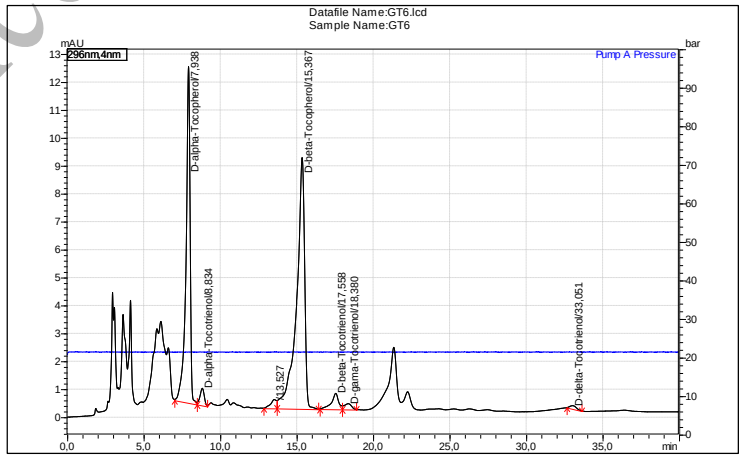

Fig. 4 HPLC chromatogram of tocopherol and tocotrienol (tocols) content of oils made from the seeds of *Gundelia* species.

Table 2 Moisture, protein and crude oil yield of seeds of *Gundelia* species and refractive index, iodine and free fatty acidity values of oils obtained from *Gundelia* seeds.

Properties	*Gundelia* species																
	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17
Moisture (%)	3.64	4.12	3.12	4.48	3.72	4.22	4.02	3.86	4.12	4.00	4.45	4.52	3.89	4.42	4.22	4.68	3.86
Protein (%)*	11.285	6.886	7.982	7.860	6.802	7.708	7.826	12.739	10.524	10.224	6.480	12.778	6.962	7.411	9.816	9.481	8.124
Crude oil (%)	8.982	10.123	11.956	7.682	8.566	9.448	10.120	2.962	8.968	3.246	2.147	7.588	8.684	5.688	6.982	8.012	7.648
Refractive index (nD_{20})	1.4756	1.4766	1.4752	1.4752	1.4751	1.4787	1.4766	1.4759	1.4775	1.4786	1.4787	1.4758	1.4765	1.4763	1.4721	1.4769	1.4768
Iodine value	140.67	146.03	137.57	137.29	137.72	143.94	131.36	134.84	145.42	150.23	145.79	140.17	145.00	140.16	116.76	127.78	148.07
Free fatty acidity (%, as oleic acid)	1.082	1.090	1.092	1.078	1.086	1.097	1.088	1.086	1.098	1.092	1.078	1.082	1.082	1.094	1.088	1.082	1.084

* N factor was used as 5.30 as in oil seeds.

Table 3 The amount of fatty acids in the oils made from the seeds of *Gundelia* species.

Fatty acid (%)	*Gundelia* species																
	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17
Myristic acid	0.058	0.100	0.068	0.058	0.053	0.047	0.104	0.085	0.065	0.039	0.052	0.064	0.079	0.088	0.053	0.097	0.046
Palmitic acid	7.242	6.094	8.059	7.380	7.238	5.469	8.860	7.458	5.498	5.067	6.417	8.315	6.457	7.975	10.413	8.536	5.029
Palmitoleic acid	0.108	0.086	0.125	0.152	0.143	0.088	0.181	0.123	0.071	0.073	0.092	0.123	0.101	0.130	0.160	0.220	0.077
Stearic acid	3.036	2.966	3.023	2.900	2.838	2.864	2.299	2.409	2.670	3.055	3.433	3.150	3.124	3.226	3.953	2.577	2.199
Cis Oleic acid	21.755	18.163	23.300	25.302	25.269	21.652	29.608	28.564	20.242	15.385	17.132	19.826	18.401	20.030	38.982	33.228	15.393
Trans Linoleic acid	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cis Linoleic acid	66.710	71.575	64.362	63.041	63.331	68.678	57.575	60.231	70.180	75.113	71.674	67.388	70.674	67.420	45.078	53.630	73.891
Arachidic acid	0.331	0.373	0.297	0.321	0.320	0.420	0.312	0.300	0.447	0.419	0.364	0.301	0.374	0.376	0.575	0.415	0.465
Linolenic acid	0.087	0.000	0.000	0.117	0.091	0.000	0.147	0.000	0.000	0.102	0.190	0.092	0.145	0.000	0.000	0.254	0.118
Gadoleic acid	0.134	0.151	0.137	0.119	0.126	0.181	0.139	0.161	0.217	0.166	0.143	0.130	0.144	0.129	0.143	0.159	0.173
Σ SFA	10.667	9.533	11.447	10.659	10.449	8.800	11.575	10.252	8.680	8.580	10.266	11.830	10.034	11.665	14.994	11.625	7.739
Σ MUFA	21.997	18.400	23.562	25.573	25.538	21.921	29.928	28.848	20.530	15.624	17.367	20.079	18.646	20.289	39.285	33.607	15.643
Σ PUFA	66.797	71.575	64.362	63.158	63.422	68.678	57.722	60.231	70.180	75.215	71.864	67.480	70.819	67.420	45.078	53.884	74.009
Σ UFA	88.794	89.975	87.924	88.731	88.960	90.599	87.650	89.079	90.710	90.839	89.231	87.559	89.465	87.709	84.363	87.491	89.652

SFA: Saturated fatty acid, MUFA: Mono unsaturated fatty acid, PUFA: Poly unsaturated fatty acid and UFA: Unsaturated fatty acid

Table 4 Triglyceride content of oils obtained from seeds of *Gundelia* species (%).

Triglycerides	*Gundelia* species																
(%)*	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17
LLnLn	2.207	1.513	1.307	2.463	1.678	1.4083	4.064	5.029	1.253	1.743	2.186	1.795	1.643	2.415	1.622	1.151	1.642
LLL	33.325	38.806	29.868	28.237	28.951	35.649	23.033	25.095	37.734	44.363	39.160	33.373	37.667	33.409	13.388	21.825	34.075
PLLn	0.316	0.342	0.327	0.292	0.271	0.329	0.381	0.259	0.306	0.373	0.495	0.395	0.411	0.473	0.342	0.453	0.272
POLn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	22.892	0.000	0.000	0.000	0.000	9.507	0.000
OLL	23.908	24.603	24.691	25.268	25.455	26.056	23.823	25.016	25.949	22.918	0.000	22.933	23.671	22.872	20.178	23.030	23.478
PLL	11.158	10.454	11.741	10.317	10.233	8.872	10.614	9.438	9.210	9.413	10.870	12.979	11.041	12.372	8.737	0.000	9.657
OOL+LnPP	9.934	8.207	11.194	12.652	12.843	10.929	14.593	14.565	10.009	6.731	7.339	8.748	8.382	8.995	17.579	16.089	8.442
POL+SLL	10.089	9.268	10.993	10.570	10.409	8.772	10.695	9.565	8.483	8.629	9.812	10.974	9.699	10.559	12.831	10.790	9.622
PPL	0.887	0.696	1.073	0.882	0.855	0.543	1.099	0.823	0.551	0.493	0.722	1.174	0.759	1.126	1.588	1.002	0.883
OOO	2.426	1.172	2.530	3.025	3.070	2.094	4.712	4.127	1.710	0.771	1.105	1.785	1.419	1.757	9.184	7.099	1.458
SOL+POO	4.112	3.506	4.604	4.666	4.607	3.769	5.291	2.066	3.478	3.207	3.603	4.105	3.596	4.202	9.636	6.348	3.888
POP	0.647	0.623	0.718	0.595	0.576	0.509	0.462	0.453	0.472	0.689	0.927	0.822	0.848	0.849	1.043	0.492	0.512
SOO	0.924	0.728	0.953	0.986	1.004	1.002	1.210	1.036	0.776	0.565	0.781	0.824	0.767	0.874	2.991	1.841	1.006
SOP	0.067	0.085	0.000	0.050	0.048	0.068	0.025	0.031	0.068	0.107	0.108	0.096	0.099	0.097	0.881	0.374	0.275

* P: palmitic acid; S: stearic acid, O: oleic acid, L: linoleic acid, Ln: linolenic acid

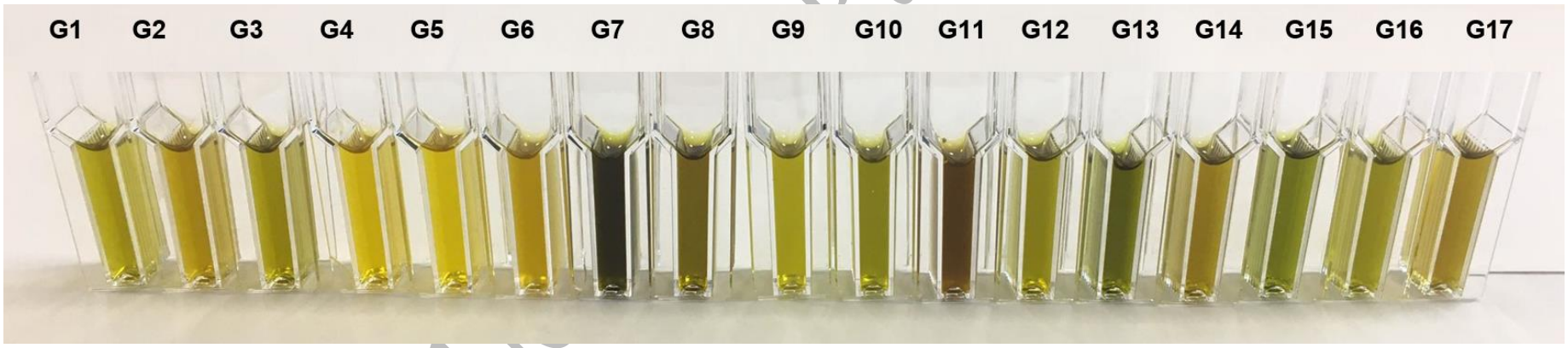

Fig. 5 Colors of oils obtained from the seeds of *Gundelia* species.

Table 5 Sterol content of oils obtained from seeds of *Gundelia* species (%).

Sterols (%)	*Gundelia* species																
	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17
Cholesterol	7.29	1.58	3.64	3.65	2.66	3.55	6.85	3.91	3.22	0.85	1.90	2.35	5.03	1.31	14.15	6.11	3.42
Cholestanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Brassicasterol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24-metien cholesterol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Campesterol	5.73	10.11	6.37	6.56	6.69	14.73	7.40	6.36	6.18	5.90	7.82	7.16	7.09	6.58	5.46	6.24	7.64
Campestanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stigmasterol	13.95	14.56	16.74	16.06	15.88	19.55	12.95	16.72	12.14	10.92	12.36	14.89	11.81	14.56	11.21	17.75	15.92
Δ7-campesterol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
β-sterol	65.15	65.87	65.25	65.48	64.90	37.65	68.52	62.64	65.86	64.73	72.62	67.82	71.12	67.14	62.38	61.06	63.51
Δ5-23 stigmastadianol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Clerosterol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
β-sitosterol	51.06	46.39	52.15	50.94	49.77	8.43	55.71	49.86	44.17	44.14	53.17	53.35	52.69	47.57	43.10	48.51	48.24
Sitostanol	10.12	16.17	9.96	11.91	11.66	20.86	9.12	9.01	16.84	14.75	13.90	9.64	15.42	16.12	17.42	8.56	12.01
Δ5-avenastenol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Δ5-D24 stigmastadionol	3.97	3.31	3.14	2.63	3.47	8.36	3.69	3.77	4.85	5.84	5.55	4.83	3.01	3.45	1.86	3.99	3.26
Δ7 stigmastenol	4.77	3.51	4.19	4.26	5.12	11.63	2.46	6.37	5.74	6.50	2.42	4.44	2.05	4.82	3.02	5.21	5.24
Δ7-avenasterol	3.12	4.37	3.81	4.00	4.77	12.90	1.83	4.00	6.86	11.10	2.89	3.35	2.90	5.58	3.77	3.62	4.42
Total Sterol (mg/kg)	4210	3079	3245	3226	2572	1679	5229	4337	2982	3559	3765	3800	3240	2855	3955	3996	3448

Table 6 Tocopherol and tocotrienol (µg/g) content of oils obtained from seeds of *Gundelia* species (µg/g).

Tocols (µg/g)	*Gundelia* species																
	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17
D-α-tocopherol	66.937	70.880	66.802	73.008	72.524	73.805	63.711	77.945	73.479	66.978	66.909	72.965	71.638	60.300	81.099	74.176	88.273
D-α-tocotrienol	1.129	1.542	1.430	1.902	1.955	2.312	4.846	4.072	2.242	3.446	3.977	3.481	3.595	3.515	0.426	0.768	0.204
D-β-tocopherol	0.000	1.861	0.594	8.896	8.520	31.413	32.074	38.712	8.449	3.910	50.305	3.915	6.860	6.746	3.989	32.128	21.538
D-β-tocotrienol	3.252	0.286	3.361	7.922	7.889	1.211	1.780	20.312	7.944	7.817	20.578	3.690	3.265	3.169	7.648	8.514	0.336
D-γ-tocopherol	21.951	42.613	15.313	5.332	5.482	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	5.750	28.747	0.000	4.442
D-γ-tocotrienol	0.000	5.092	0.000	0.000	0.000	7.384	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	5.190
D-δ-tocopherol	0.537	0.000	0.000	0.000	0.000	0.000	1.179	2.479	0.000	0.715	0.000	0.448	0.696	1.023	0.000	1.218	4.023
D-δ-tocotrienol	0.000	0.000	3.847	0.000	0.000	4.287	3.972	3.999	0.000	0.000	20.386	3.961	0.000	3.733	0.000	3.976	0.000
Total tocopherol	18.806	52.274	26.347	18.06	17.37	200.412	47.562	77.519	12.114	07.866	272.155	28.46	16.054	25.236	91.909	60.78	214.006

The main sterols in *Gundelia* seed oils were found to be β-sterol (37.65-72.62%), Stigmasterol (10.92-19.55%) and Campesterol (5.46-14.73%), respectively. It was determined that β-sterol, which is the main sterol in the seed oils of *Gundelia* species, consisted of β-sitosterol, Sitostanol, and Δ5-D24 stigmastadionol and varied between 8.43-55.71%, 8.56-20.86% and 1.86%-8.36%, respectively (Table 5).

As can be seen in Table 5, the lowest β-sterol content was found in *Gundelia comagenesis* (37.65%) (G6) and the highest β-sterol content was found in *Gundelia munzuriensis* (72.62%) (G11). The lowest β-sitosterol content was found in *Gundelia comagenesis* (8.43%) (G6) and the highest β-sitosterol content was found in *Gundelia mesopotamica* (55.71%) (G7).

In an investigation of *Gundelia tournefortii* L. seed as a source of edible oil [16], seed oil was extracted using the dipping method and diethyl ether as the solvent. The extracted oil was evaluated for acidity, saponification number, esters, iodine, peroxide and refractive index, fatty acid composition, unsaponifiable matter, viscosity, color, and density. It is determined that the principal unsaponifiable components of *Gundelia tournefortii* L. seed oil are β-sitosterol (35.25%), stigmasterol (11.70%), and 5-avenasterol (11.5%) [16].

In another study, the total sterol content of *Gundelia* seed oil was found to be 3766.60 mg/kg, similar to the average values in our study, and determined that β-sitosterol constituted 51.76% of the total sterol content. Other sterols were found to be stigmasterol (18.52%), 5-avenasterol (9.82%), campesterol (6.02%), 7-stigmastenol (3.68%) and 7-avenasterol (2.63%), respectively [15].

The β-sitosterol content (76-87.1% and 50-70%, respectively) in cotton and sunflower oils used as edible oil [33,34] is higher than the β-sitosterol content (8.4-55.7%) in the seed oils of *Gundelia* species. The content of β-sitosterol (47-60% and 45.1-57.9%, respectively) in soybean and rapeseed oils [33] appears to be similar to that of oils obtained from *Gundelia* seeds.

Tocopherol and Tocotrienol (Tocols) Contents of *Gundelia* Seed Oils

Average values of tocol (tocopherol and tocotrienol) composition and distribution of cold pressed *Gundelia* seed oils are given in Table 6 and Figure 4.

It was determined that the total tocol (tocopherol and tocotrienol) content of *Gundelia* seed oils varied between 91.91-272.16 µg/g. The lowest total tocol (tocopherol and tocotrienol) content was in *Gundelia rosea* (91.91 µg/g) variety (G15), and the highest total tocopherol (tocopherol and tocotrienol) content was in *Gundelia munzuriensis* (272.16 µg/g) (G11) (Table 6).

The main tocols found in *Gundelia* seed oils were found to be β-tocopherol (0.00-150.31 µg/g), α-tocopherol (31.10-77.95 µg/g) and γ-tocopherol (0.00-42.61 µg/g), respectively (Table 6). In *Gundelia* seed oils, the lowest β-tocopherol content was found in *Gundelia armata* (0.00 µg/g) (G1), and the highest β-tocopherol content was found in *Gundelia munzuriensis* (150.31 µg/g) (G11).

It is reported that *Gundelia tehranica* seed oil can be considered a rich source of tocols (tocopherol and tocotrienol) and α-tocopherol (649.0 mg/kg±1.6 mg/kg) was the major tocopherol, followed by γ-tocopherol (47.0 mg/kg±1.0 mg/kg) and β-tocopherol (39.0 mg/kg±0.9 mg/kg), respectively [18].

In other studies, it was reported that the main tocopherols in the oils obtained from *Gundelia tournefortii* L. were α-tocopherol (489 mg/kg) and γ-tocopherol (10 mg/kg), and the total tocopherol content was 519 mg/kg [15,17]. The β-tocopherol (39.0 mg/kg) content in *Gundelia tehranica* seed oil was found to be within the mean value range (0.00-150.31 mg/kg) in *Gundelia* seed oils determined in our study [18]. In some *Gundelia* species in our study, these values were found to be much higher than *Gundelia tehranica*. The α-tocopherol (489 mg/kg) content in other studies [15] was found to be much higher than the α-tocopherol content (31.10-77.95 mg/kg) in our study. The differences in tocol content between the findings in our study and other studies [15,17,18] may be due to the characteristic differences specific to the cultivars, as well as temperature, water, light, chemical and mechanical factors, ecological conditions, etc.

Color Values of *Gundelia* Seed Oils

Average color values (L*, a*, b*, Chrome, Hue) of cold pressed *Gundelia* seed oils are given in Table 7 and Figure 5. In the measurement of CIE L*a*b* color values, L* indicates lightness (L*=0 is black and L*=100 is white), a* shows the red/green balance and +a* indicates red and -a* indicates green. b* shows the yellow/blue balance and +b* indicates yellow and -b* indicates blue. Chroma (C) refers to the vividness or dullness of the

color. C indicates how close the color is to gray or pure color. The hue value, that is, the angle of the color, changes according to the redness, greenness, and blueness of the color. If the hue angle is 0, the color is red; if it is 90, it is yellow; if it is 180, it is green; and if it is 270, it is blue. It is an indicator of the intensity of the color. When the color values of *Gundelia* seed oils were examined, it was determined that the dominant color was yellow or green (light or dark) depending on the cultivars (Figure 1). It is thought that this difference in color (yellow or green) may vary depending on the characteristic differences specific to *Gundelia* varieties or the maturity period of the bracts (capitula) in which the seeds are.

In a study about *Gundelia tournefortii* L. seeds as a source of edible oil [16], the dominant color was found to be yellow (Lovibond, 0.8 red, 14 yellow).

Total Phenolic Content and Total Antioxidant Capacities of *Gundelia* Seed Oils

Average values of total phenolic content (µg GAE/mg oil) and antioxidant capacity (mg Trolox/L) of cold pressed *Gundelia* seed oils are given in Table 8.

The total phenolic content of *Gundelia* seed oils varies between 974.55 and 3439.09 µg GAE/mg oil. The lowest total phenolic content is in *Gundelia anatolica* (974.55 µg GAE/mg oil) (G17), and the highest total phenolic content is in *Gundelia siirtica* (3439.09 µg GAE/mg oil) (G8) (Table 8).

The antioxidant capacity of the oils of *Gundelia* seeds varies between 113.56 and 287.26 mg Trolox/L. The lowest antioxidant capacity is in *Gundelia colemerikensis* (113.56 mg Trolox/L) (G14) and the highest antioxidant capacity is in *Gundelia siirtica* (287.26 mg Trolox/L). (G8) as well (Table 8).

It was determined that both the total phenolic content (3439.09 µg GAE/mg oil) and the antioxidant capacity (287.26 mg Trolox/L) of *Gundelia siirtica* (G8) were higher than those of other *Gundelia* species (Table 8).

The antioxidant capacity of the aerial parts and seeds of *Gundelia tournefortii* was investigated using both 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging and lipid peroxidation inhibition methods. In this study, it was determined that the seeds of G. tournefortii had high antioxidant potential, with IC50 values of 0.073 mg/mL and 0.146 mg/mL for lipid peroxidation inhibition capacity in the DPPH method. In addition, it was reported that the total phenolic content of *Gundelia tournefortii* L. extracts, especially seed extracts, was determined to be 105.1±8.7 µg gallic acid equivalent (GAE) per mg of seed extract and showed high antioxidant activity [3].

In a study in which the antioxidant capacities and total phenolic content of the aqueous and methanolic extracts of a total of 51 plant species originating in Jordan were determined using the improved ABTS+ method and the Folin-Ciocalteu colorimetric method [35]; the antioxidant capacities of the aqueous and methanolic extracts of *Gundelia tournefortii* L. were determined to be 57.3±2.7 and 63.9±2.0 µmol TE/g, respectively, on a dry matter basis. The total amount of phenolic matter was determined to be 13.2±5.0 and 14.7±0.2 mg GAE/g in aqueous and methanolic extracts, respectively, on a dry matter basis [35].

In a study investigating the biopharmaceutical potential and bioactive compounds of *Gundelia rosea* seed [36], the ethanol extract contained high levels of total phenolic substances (55.3 mg gallic acid equivalent/g extract) and had high reducing capacities (1683 µmol Fe^{2+} and 214.1 mg Trolox equivalent/g extract for FRAP and CUPRAC, respectively). In addition, it was determined that the oxygen radical absorbance capacity (ORAC: 2241.9 µmol, DPPH: 91.7 mg, ABTS: 141.2 mg, Trolox equivalent/g extract) and total antioxidant (Phosphomolybdenum: 1.39 mmol Trolox equivalent/g extract) capacities were high. [36].

Cold-pressed *Gundelia* seed oils are important oilseed varieties due to their high levels of unsaturated fatty acids (linoleic and oleic fatty acids), sterols (β-sitosterol, etc.) and tocopherols (β-tocopherol and α-tocopherol). These seeds can be cultivated, especially in arid areas. Our research findings revealed that the physical and chemical compositions of *Gundelia* seeds are very different from each other. For this reason, it was concluded that *Gundelia* species can be used as raw materials in the food industry, as well as in the cosmetics industry and pharmaceutical industry, due to their nutritional properties, either by choosing the appropriate ones among the *Gundelia* varieties, either in whole or grinding the seeds.

Table 7 Color values of oils obtained from the seeds of *Gundelia* species.

Colour values	*Gundelia* species																
	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17
L*	65.87	66.00	61.79	76.34	75.17	67.21	9.98	87.66	68.54	87.71	87.79	57.87	42.70	55.79	50.29	87.77	72.26
a*	2.49	8.40	2.92	4.73	6.46	12.40	-6.09	-0.33	2.25	-0.35	-0.34	4.17	0.25	9.45	-7.00	-0.34	5.42
b*	103.01	104.05	98.68	109.41	109.49	105.89	16.95	-0.11	103.43	-0.08	0.07	95.14	71.91	91.28	82.16	-0.01	102.42
Chrome (C*)	103.04	104.39	98.72	109.51	109.68	106.61	18.01	0.35	103.46	0.36	0.35	95.23	71.91	91.77	82.46	0.34	102.56
Hue (h)	88.61	85.38	88.31	87.52	86.62	83.32	70.24	198.76	88.76	193.02	168.90	87.49	89.80	84.09	94.87	180.86	85.92

Table 8 Total phenolic compounds (µg GAE/mg oil) and total antioxidant activities (mg Trolox/L) of oils obtained from seeds of *Gundelia* species.

Properties	*Gundelia* species																
	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17
Total phenolic compounds (µg GAE/mg oil)	)71.82	522.73	558.18	)54.55	700.91	)05.00	193.64	439.09	109.09	402.73	279.09	337.73	511.82	)78.18	)10.45	)37.27	74.55
Antioxidant activity (mg Trolox/L)	)1.13	30.34	56.62	34.24	)4.12	34.15	78.34	37.26	)4.48	)0.90	32.24	75.40	95.22	33.55	70.12	)8.86	13.56

RESULTS AND DISCUSSION

The physicochemical characteristics of oils extracted from the seeds of 17 different *Gundelia* species were assessed in this research. The compositions of fatty acids, triglycerides, sterols, tocopherols and tocotrienols (tocols), antioxidant activity, total phenolic compounds, and some physicochemical properties of 17 distinct *Gundelia* species were determined and compared for the first time in this work. Our research demonstrates the significant potential for nutraceutical and bioactive compounds in the oils extracted from the seeds of *Gundelia* species for the food, cosmetic, and pharmaceutical sectors. Oils extracted from the seeds of various G*undelia* species had some physicochemical and bioactive characteristics that indicated they were of good quality and could be used as edible oils in the food industry. When assessed in terms of fatty acid content, it was discovered that *Gundelia* seed oils were comparable to the oleic and linoleic acid contents of soybean and sunflower oils. Our research also revealed that *Gundelia* seed oils were rich in unsaturated fatty acids, vitamin E (α-tocopherol), and β-sterol content.

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