



Systematic Review

Evaluation of Polycyclic Aromatic Hydrocarbons in Vegetable Oils: A Review and Meta-analysis and Health Risk Assessment

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Abstract

Individuals' daily diets include a wide variety of vegetable oils worldwide. Our study assessed the concentrations of polycyclic aromatic hydrocarbons (PAHs) in several vegetable oils (corn, sunflower, olive, soybean, sesame, and canola). A search of major international databases was conducted to find published studies on PAHs in vegetable oils between May 12, 1986, and June 20, 2021. Based on the results of 13 research articles, out of 713 retrieved studies, the most common PAHs found in corn, sunflower, olive, sesame, soybean, and canola were fluoranthene (33.6 µg/kg), dibenz[a,h]anthracene (7.13 µg/kg), phenanthrene (22.45 µg/kg), benz[a]anthracene (16.49 µg/kg), naphthalene (3.92 µg/kg), and pyrene (8.01 µg/kg), respectively. However, the lowest concentrations of PAHs in the mentioned oils were associated with benzo[b]fluoranthene (11 µg/kg), benzo[b]fluoranthene (0.28 µg/kg), dibenz[a,h]anthracene (0.13 µg/kg), benzo [b] fluoranthene (0.22 µg/kg), acenaphthene (0.05 µg/kg), and benzo(g,h,i)perylene (0.150 µg/kg), respectively. According to the continent type, PAHs in vegetable oils were detected in countries of the European Region, Eastern Mediterranean Region, and Western Pacific Region. Based on the findings, there is a country-to-country variation in the carcinogenic and mutagenic risks of PAHs. As a result, vegetable oils pose no threat to human health.

Keywords: Vegetable oils, PAHs, Health risk assessment, Systematic review, Meta-analysis

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1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) have long been recognized as a large collection of organic compounds containing hundreds of lipophilic organic compounds varying in the number of aromatic rings (1). Food matrices may contain PAHs due to incomplete combustion from both environmental contamination and certain processes during food manufacturing that are lipophilic and have an affinity for long importunity and transportation (2). A variety of preparation methods contribute to PAH production in food (3). The fat content of the food, fuel type (coal tar, coke, or asphalt), processing temperature, distance, and duration of cooking affect PAH levels in food (4). Several anthropogenic emissions play a role in PAH contamination in the environment, such as those produced by vehicles, heat and power plants, tobacco smoke, urbanization, and industrialization (5, 6). Overall,

16 PAHs were classified as potent carcinogens to humans and annals (7). Environmental compartment and ecotoxicological characteristics affect the fate and transfer of PAHs (8). PAHs are categorized into two groups based on the number of aromatic rings; those having 2–3 rings are light PAHs, while the ones with 4–6 rings are called heavy PAHs, which are more stable and toxic (9). The European Union reported a level of 2 µg/kg for benzo[a]pyrene in oils and fats safe for health.

Many factors can influence the toxic effects of PAHs, including concentration, duration, and exposure route (10). As highlighted by animal studies, animals exposed to PAHs, especially benzo[a]pyrene, have shown multiple toxicological effects, including hematotoxicity, immunotoxicity, reproductive toxicity, developmental toxicity, and mutagenic and carcinogenic adverse effects (11). Another study indicated that exposure to PAHs



and their derivatives may increase the risk of cancer in the skin and lungs (2). Many studies have approved the health risks associated with PAHs for animals and humans (12, 13). Food is the primary source of human exposure to PAHs, and vegetable oils and fats are among the most significant sources. These oils are generally composed of triacylglycerol, a complex of minerals and natural chemicals (14-16). The tendency to use oils has increased due to the presence of fit-sterols, essential fatty acids, tocopherol, and low cholesterol (17). Previous studies reported that cereals and vegetable oils or fats not only had the highest dietary PAH load but also the concentration of heavy PAHs in this group was higher than that in fruits, sugar, some vegetables, and meat (18). Considering that oils are edible in the diet and both oils and fats are susceptible to PAH contamination due to the lipophilic nature of PAHs, many studies evaluated the level of PAHs in these types of foods (19-20). A meta-analytic review of food safety risk perception has recently conducted to condense the results obtained from preliminary investigations (21). Hence, using a systematic review and meta-analysis, this study seeks to evaluate the concentrations of PAHs in various vegetable oils (corn, sunflower, olive, soybean, sesame, and canola). Further, the risk of cancer or mutation of PAHs through the consumption of vegetable oils will be assessed in adults.

2. Methods and Materials

2.1. Search Scheme

Documents relating to the concentration of PAHs in various vegetable oils (corn, sunflower, olive, soybean, sesame, and canola) were assessed based on the Cochrane protocol (Fig. 1). First, several databases, such as ScienceDirect, Web of Science, Scopus, PubMed, and Google Scholar, were searched for published original studies from 1986 to 2021. Keywords used for this purpose included “polycyclic aromatic hydrocarbons” OR “PAHs” AND “food” OR “sunflower” OR “peanut” OR “corn” OR “olive” OR “soybean” OR “sesame” OR (contaminants, residual, and concentration). Moreover, the reference lists of similar studies provided additional articles. Then, the articles were screened for eligibility by screening their titles, abstracts, and full texts.

2.2. Inclusion and Exclusion Criteria

Two authors (S. K. and F. M.) independently selected the articles based on our research criteria after screening the databases using the same keywords and procedures. To select the articles that met the inclusion criteria, each author had to review all papers (titles, abstracts, and full texts). The inclusion criteria were (a) papers written in the English language, (b) original studies, (c) cross-sectional studies, and (d) readings reporting the mean and standard deviation. On the other hand, the exclusion criteria included papers published as (a) book studies, (b) workshops, and (c) clinical trials and reviews. Furthermore, articles without raw data, mean values, or

standard deviations were excluded from the investigation (22-24). To keep the units consistent, all toxic metal measurement units were changed to ng/g (including µg/L, ppb, mg/L, and µg/kg).

2.3. Meta-analysis and Statistical Analysis

A mean ± standard error (SE) was used to evaluate the concentrations of PAHs in vegetable oils (corn, sunflower, olive, soybean, sesame, and canola). Equation (1) was utilized to calculate the SE of PAH levels (25):

$$SE = SD/\sqrt{n} \quad (1)$$

where SD and N represent the standard deviation and the sample size, respectively. Based on the PAH type and country, the study was divided into subgroups. The I² and Q tests were employed to measure heterogeneity. The Cochran Q tests and I² statistics indicate statistical significance and a large degree of heterogeneity, respectively. Moreover, meta-regression was applied to determine whether the year of the study might contribute to heterogeneity. Finally, Stata software (version 14; Stata Corporation, USA) was used to survey the records, and the value of 0.05 was considered statistically significant.

2.4. Risk Assessment

The carcinogenic risks of 7 PAH compounds were determined using the BaP equivalent dose of mutagenic PAHs (BaPEQ) (26).

BaPEQ is dependent on TEQBaP or MEQBaP planned by the amount of mutagenic equivalent factor (MEF) or toxicity equivalent factor (TEF) × each PAH concentration. Eqs. (2) and (3) can be utilized to estimate the TEQBaP or MEQBaP and BaPEQ:

$$TEQBaP = \sum (TEFi \times Ci) \quad (2)$$

$$MEQBaP = \sum (MEFi \times Ci) \quad (3)$$

where Ci is the amount of each PAH with its associated TEFi or MEFi value, whereas the values of TEFi for BaA, BaP, BbFlu, BkFlu, Chr, DahA, and IndP are 0.1, 1, 0.1, 0.01, 0.001, 1, and 0.1, respectively (27). MEFi values for BaA, BaP, BbFlu, BkFlu, Chr, DahA, and IndP are 0.082, 1, 0.25, 0.11, 0.017, 0.290, and 0.310, respectively (28). The BaP equivalent dose can be calculated using Eq. (4):

$$BaPEQ = (TEQ \text{ or } MEQ) \times IR \times EF \times ED/BW \times AT \quad (4)$$

where IR and EF (350 days/year) denote the ingestion rate of the vegetable oil (kg/day) and the exposure frequency, respectively. In addition, ED (adults=30 years) and BW (adults=70 kg) indicate the exposure duration and body weight EPA, respectively (29), and ATn (EF×ED) represents (average life time (that for adults equals to 10950 days)) (25, 30). The risk of cancer or mutagenicity is shown by:

The SFBaP × BaP is the equivalent dose of a mixture of PAHs (5), and SFBaP shows the oral carcinogenic slope

factor for benzo[a]pyrene (7.3 per mg/kg/day). Further, the USEPA command implies that CR values greater than 10^{-4} indicate risk. Furthermore, CR values between 10^{-6} and 10^{-4} are acceptable, and CR values less than 10^{-6} denote safety (30).

3. Results and Discussion

3.1. Structure and Process of the Systematic Review

The PRISMA flow chart of the process of the present study is depicted in Fig. 1. A total of 713 articles were obtained from international databases. Initially, 367 articles were excluded because of duplication. Only 346 articles were considered relevant based on their titles. Thus, 117 articles were eliminated from the research because of their unrelated titles. The abstracts of 229 articles were analyzed, and 197 articles were excluded from the analysis. In addition, 19 articles were excluded from the review due to inadequate full texts. Eventually, a total of 13 full texts were reviewed in this study.

3.2. Amounts of Various Polycyclic Aromatic Hydrocarbons in Vegetable Oils

The results revealed a significant heterogeneity based on Cochran's Q test and I² statistics (Q=3289.3, df.=480,

$P<0.001$, and $I^2=85.4\%$). Tables 1 and 2 present subgroup results based on PAH types and countries in order to reduce heterogeneity. According to the data in Table 1, a variety of PAH subgroups can be detected in vegetable oils. Among the vegetable oils (Table 1), corn, sunflower, olive, sesame, soybean, and canola had the highest concentrations of PAHs (33.6 µg/kg, 7.13 µg/kg, 22.45 µg/kg, 16.49 µg/kg, 3.92 µg/kg, and 8.01 µg/kg, which belonged to fluoranthene, dibenz[a,h]anthracene, phenanthrene, benzo[a]anthracene, naphthalene, and pyrene, respectively). On the other hand, the lowest PAH concentration was found in the corn, sunflower, olive, sesame, soybean, and canola (0.11 µg/kg, 0.28 µg/kg, 0.13 µg/kg, 0.22 µg/kg, 0.05 µg/kg, and 0.150 µg/kg for benzo[b]fluoranthene, benzo[b]fluoranthene, dibenz[a,h]anthracene, benzo[b]fluoranthene, acenaphthene, and benzo(g,h,i)perylene, respectively). Our findings showed that levels of PAHs in vegetable oils varied significantly ($P<0.05$). The results are consistent with those of previous studies. According to Dost and İdeli, the mean concentrations of fluorine, phenanthrene, anthracene, fluoranthene, and pyrene identified in corn samples in Turkey were 16.84 µg/kg, 7.4 µg/kg, 10.84 µg/kg, 76.08 µg/kg, and 12.04 µg/kg, while they were 7.44

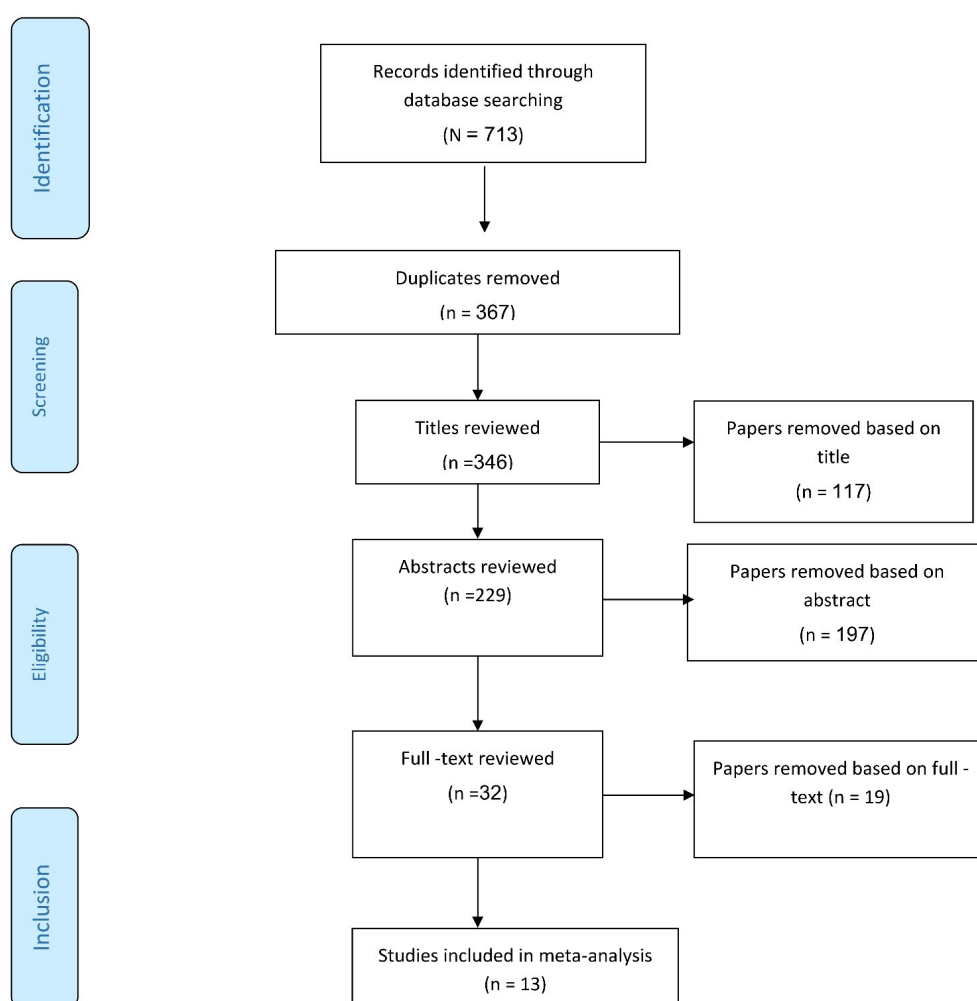


Fig. 1. Flow diagram of study selection process

Table 1. Meta-analysis of the Concentration of Polycyclic Aromatic Hydrocarbons in Vegetable Oils Based on Type of Oil

Metal	Meat	Number of Studies	ES (95% CI)	Heterogeneity				
				Weight (%)	Statistics	df	P Value	I ² (%)
Acenaphthene	Corn	1	2.470 (2.270, 2.670)	11.19	-	-	-	-
	Sunflower	2	1.546 (-1.302, 4.435)	22.63	3998.44	1	<0.001	100.0
	Olive	3	2.670 (1.589, 3.751)	32.82	140.77	2	<0.001	98.6
	Seasame	1	0.450 (0.372, 0.528)	11.31	-	-	-	-
	Soybean	1	0.055 (0.050, 0.060)	11.33	-	-	-	-
	Canola	1	6.170 (5.751, 6.589)	10.72	-	-	-	-
	Total	9	2.224 (1.633, 2.816)	100.0	1.2e+05	8	<0.001	100.0
Acenaphthylene	Sunflower	2	2.450 (2.080, 2.820)	35.87	0.0	1	1.00	0.0
	Olive	5	8.252 (5.849, 10.655)	64.13	233.91	4	<0.001	98.3
	Total	7	5.104 (3.643, 6.565)	100.0	234.67	6	<0.001	97.4
Anthracene	Corn	1	6.277 (-0.021, 12.574)	11.69	553.81	2	<0.001	99.6
	Sunflower	2	2.157 (1.051, 3.263)	33.23	705.02	5	<0.001	99.3
	Olive	1	2.711 (1.287, 4.134)	27.67	564	4	<0.001	99.3
	Seasame	1	0.650 (0.537, 0.763)	9.23	-	-	-	-
	Soybean	1	0.116 (0.109, 0.123)	9.97	-	-	-	-
	Canola	1	4.810 (4.626, 4.994)	8.21	-	-	-	-
	Total	9	2.022 (1.897, 2.148)	100.0	6671.97	16	<0.001	99.8
Benzo[a]anthracene	Corn	3	5.672 (1.030, 10.313)	13.08	3855.04	2	<0.001	99.9
	Sunflower	5	0.693 (0.312, 1.074)	31.70	667.15	4	<0.001	99.4
	Olive	6	1.506 (1.115, 1.897)	29.61	617.72	5	<0.001	99.2
	Seasame	2	16.499 (-13.802, 46.80)	6.54	376.34	1	<0.001	99.7
	Soybean	2	0.377 (-0.035, 0.788)	12.98	62.46	1	<0.001	98.4
	Canola	1	1.020 (0.812, 1.228)	6.09	16397.73	-	-	-
	Total	19	1.426 (1.232, 1.620)	100.0	6671.97	18	<0.001	99.9
Benzo[a]pyrene	Corn	2	0.379 (0.164, 0.595)	13.97	33.93	1	<0.001	97.1
	Sunflower	4	0.695 (0.131, 1.259)	21.16	19.64	3	<0.001	98.4
	Olive	7	0.716 (0.522, 0.909)	34.70	445.17	6	<0.001	98.7
	Seasame	3	1.290 (0.606, 1.974)	13.45	69.50	2	<0.001	97.1
	Soybean	2	0.413 (-0.169, 0.995)	14.49	6529.76	1	<0.001	100.0
	Canola	2	3.626 (2.695, 4.557)	2.24	2.56	1	0.110	60.9
	Total	20	0.677 (0.605, 0.749)	100.0	10759.79	19	<0.001	99.8
Benzo[b]fluoranthene	Corn	1	0.110 (0.086, 0.134)	14.39	-	-	-	-
	Sunflower	2	0.285 (0.063, 0.508)	28.41	86.89	1	<0.001	98.8
	Olive	2	0.207 (-0.082, 0.497)	29.05	1120.49	1	<0.001	99.9
	Soybean	1	0.226 (0.216, 0.236)	14.54	-	-	-	-
	Canola	1	0.300 (0.245, 0.355)	13.62	-	-	-	-
	Total	7	0.230 (0.151, 0.309)	100.0	1322.12	6	<0.001	99.5
Benzo[b]fluorene	Corn	2	10.082 (9.882, 10.282)	12.33	0.07	1	0.787	0.0
	Sunflower	3	0.973 (0.363, 1.583)	32.12	71.24	2	<0.001	97.2
	Olive	5	1.386 (0.776, 1.997)	44.66	371.14	4	<0.001	98.9
	Seasame	1	0.770 (0.637, 0.903)	10.89	-	-	-	-
	Total	11	2.309 (1.866, 2.752)	100.0	11412.64	10	<0.001	99.9
Benzo[e]pyrene	Corn	4	7.291 (5.244, 9.338)	43.92	4885.18	3	<0.001	99.9
	Sunflower	2	0.793 (0.156, 1.430)	28.01	89.06	1	<0.001	98.9
	Olive	1	0.240 (0.181, 0.299)	14.03	-	-	-	-
	Canola	1	0.340 (0.277, 0.403)	14.03	-	-	-	-
	Total	8	3.221 (2.565, 3.877)	100.0	5101.67	7	<0.001	99.9

Table 1. Continued.

Metal	Meat	Number of Studies	ES (95% CI)	Heterogeneity				
				Weight (%)	Statistics	df	P Value	I ² (%)
Benzo(g,h,i)perylene	Corn	2	3.136 (-2.578, 8.850)	9.61	36.17	1	<0.001	97.2
	Sunflower	4	0.492 (0.368, 0.615)	29.92	193.60	3	<0.001	98.5
	Olive	5	0.705 (0.476, 0.935)	34.79	466.50	4	<0.001	99.1
	Seasame	1	0.960 (0.794, 1.126)	6.71	-	-	-	-
	Soybean	1	0.356 (0.326, 0.386)	9.45	-	-	-	-
	Canola	1	0.150 (0.130, 0.173)	9.53	-	-	-	-
	Total	14	0.508 (0.430, 0.587)	100.0	1114.06	13	<0.001	98.8
Benzo[k]fluoranthene	Corn	3	14.168 (-12.793, 41.130)	9.95	10227.24	2	<0.001	100.0
	Sunflower	5	0.541 (0.238, 0.843)	34.23	948.87	4	<0.001	99.6
	Olive	6	1.083 (0.617, 1.549)	34.35	22118.52	5	<0.001	100.0
	Seasame	1	0.420 (0.347, 0.493)	7.05	-	-	-	-
	Soybean	1	0.066 (0.064, 0.068)	7.22	-	-	-	-
	Canola	1	0.210 (0.183, 0.237)	7.20	-	-	-	-
	Total	17	1.333 (1.206, 1.460)	100.0	1.1e+05	16	<0.001	100.0
Chrysene	Corn	2	57.875 (-55.041, 170.79)	6.72	38.83	1	<0.001	97.4
	Sunflower	4	0.934 (0.251, 1.617)	26.10	149.18	3	<0.001	98.0
	Olive	6	0.873 (0.679, 1.067)	30.74	1182.72	5	<0.001	99.6
	Seasame	2	0.962 (0.139, 1.785)	16.03	42.39	1	<0.001	97.6
	Soybean	1	0.183 (0.173, 0.193)	10.77	-	-	-	-
	Canola	1	0.630 (0.534, 0.724)	9.64	-	-	-	-
	Total	16	0.760 (0.670, 0.849)	100.0	2016.78	15	<0.001	100.0
Dibenz[a,h]anthracene	Corn	2	1.204 (-0.941, 3.349)	11.26	35.33	1	<0.001	97.2
	Sunflower	6	7.137 (2.503, 11.771)	32.72	6.2e+05	5	<0.001	100.0
	Olive	5	0.137 (0.085, 0.189)	26.13	205.21	4	<0.001	98.1
	Seasame	2	6.044 (-3.668, 15.756)	11.80	2422.98	1	<0.001	100.0
	Soybean	1	0.073 (0.068, 0.078)	6.03	-	-	-	-
	Canola	2	0.314 (-0.009, 0.638)	12.06	137.99	1	<0.001	99.3
	Total	18	2.933 (2.483, 3.383)	100.0	6.3e+05	17	<0.001	100.0
Fluoranthene	Corn	3	33.683 (-24.717, 92.083)	13.16	16763.67	2	<0.001	100.0
	Sunflower	4	1.975 (1.231, 2.720)	24.10	630.34	3	<0.001	99.5
	Olive	8	6.295 (4.653, 7.938)	44.92	11309.88	7	<0.001	99.9
	Seasame	1	5.380 (4.448, 6.312)	5.76	-	-	-	-
	Soybean	1	0.923 (0.885, 0.961)	6.08	-	-	-	-
	Canola	1	6.020 (5.514, 6.526)	5.98	-	-	-	-
	Total	18	8.779 (7.812, 9.746)	100.0	31552.30	17	<0.001	99.9
Fluorene	Corn	2	9.401 (-5.181, 23.983)	14.46	4676.72	1	<0.001	100.0
	Sunflower	4	3.148 (1.240, 5.055)	28.95	9798.76	3	<0.001	100.0
	Olive	5	3.576 (2.830, 4.322)	34.87	217.83	4	<0.001	98.2
	Seasame	1	1.120 (0.926, 1.314)	7.26	-	-	-	-
	Soybean	1	0.677 (0.628, 0.726)	7.28	-	-	-	-
	Canola	1	4.810 (4.394, 5.226)	7.18	-	-	-	-
	Total	14	4.129 (3.181, 5.077)	100.0	32422.25	13	<0.001	100.0
Indeno (1,2,3-c,d)pyrene	Corn	1	7.260 (5.010, 9.510)	0.24	-	-	-	-
	Sunflower	3	0.780 (0.200, 1.215)	36.26	81.43	2	<0.001	97.5
	Olive	4	1.504 (0.900, 2.108)	37.15	134.82	3	<0.001	97.8
	Seasame	1	1.030 (0.852, 1.208)	11.0	-	-	-	-
	Soybean	1	0.280 (0.260, 0.300)	15.35	-	-	-	-
	Total	10	0.712 (0.602, 0.823)	100.0	518.49	9	<0.001	98.3

Table 1. Continued.

Metal	Meat	Number of Studies	ES (95% CI)	Heterogeneity				
				Weight (%)	Statistics	df	P Value	I ² (%)
Naphthalene	Corn	2	1.420 (1.295, 1.545)	9.74	-	-	-	-
	Sunflower	4	4.556 (3.384, 5.727)	25.79	46.48	2	<0.001	95.7
	Olive	5	11.264 (8.837, 13.691)	35.74	2816.15	4	<0.001	99.9
	Seasame	1	4.190 (3.464, 4.916)	9.38	-	-	-	-
	Soybean	1	3.920 (3.659, 4.181)	9.70	-	-	-	-
	Canola	1	4.650 (4.289, 5.011)	9.65	-	-	-	-
	Total	14	6.489 (5.336, 7.643)	100.0	3669.72	11	<0.001	99.8
Phenanthrene	Corn	2	4.291 (-1.795, 10.377)	13.44	595.09	1	<0.001	100.0
	Sunflower	4	3.103 (1.577, 4.629)	26.90	1189.07	3	<0.001	99.7
	Olive	6	22.451 (15.911, 28.990)	39.57	34492.22	5	<0.001	100.0
	Seasame	1	5.220 (4.316, 6.124)	6.64	-	-	-	-
	Soybean	1	1.680 (1.616, 1.744)	6.73	-	-	-	-
	Canola	1	3.970 (3.551, 4.389)	6.71	-	-	-	-
	Total	15	10.994 (8.967, 13.021)	100.0	39136.22	14	<0.001	100.0
Pyrene	Corn	3	10.443 (1.688, 19.199)	12.81	12938.13	2	<0.001	100.0
	Sunflower	5	2.187 (1.435, 2.939)	28.16	1090.61	4	<0.001	99.6
	Olive	8	3.755 (2.714, 4.795)	42.45	8765.13	7	<0.001	99.9
	Seasame	1	5.740 (4.746, 6.734)	5.26	-	-	-	-
	Soybean	1	1.080 (0.991, 1.169)	7.28	-	-	-	-
	Canola	1	8.010 (7.708, 8.312)	5.65	-	-	-	-
	Total	19	4.107 (3.280, 4.934)	100.0	32952.81	18	<0.001	99.9

Note. ES: Effect size; CI: Confidence interval; df: Degree of freedom.

µg/kg, 4.96 µg/kg, 3.36 µg/kg, not detection (ND), and 1.44 µg/kg, respectively, in sunflower samples in Turkey (31). Ma et al found that the mean concentrations of acenaphthene, anthracene, chrysene, fluoranthene, fluorine, naphthalene, and pyrene in Korean corns were 2.47 µg/kg, 2.46 µg/kg, 1.72 µg/kg, 2.32 µg/kg, 1.96 µg/kg, 1.42 µg/kg, and 1.36 µg/kg, respectively. However, in Korean olive samples, they were 2.54 µg/kg, 2.31 µg/kg, 0.12 µg/kg, 0.34 µg/kg, 1.62 µg/kg, 1.58 µg/kg, and 2.03 µg/kg, respectively (32). Based on the results of Teixeira et al, the amounts of naphthalene, acenaphthene, fluorine, phenanthrene, anthracene, fluoranthene, and pyrene were 3.19 µg/kg, 0.10 µg/kg, 0.71 µg/kg, 1.92 µg/kg, 0.12 µg/kg, 0.93 µg/kg, and 1.29 µg/kg in the sunflower oil samples, whereas the corresponding amounts were 4.90 µg/kg, 1.57 µg/kg, 1.63 µg/kg, 7.07 µg/kg, 0.29 µg/kg, 2.15 µg/kg, and 1.63 µg/kg in olive oil samples, respectively (33). The high levels of PAHs in our study were significantly different from those found in previous studies, which can be attributed to the physical-chemical properties of PAHs in food preparation, drying processes of oil seeds, solvent extraction, packaging, soil burn, the residue of mineral oils, and raw material of vegetable oils (34-36). Drying the plant before oiling with direct combustion gases can affect the high amounts of PAHs in the final product (34). Olatunji concluded that poor combustion of organic material has important role in the PAHs levels of the final product. At high temperatures, organic compounds can

produce dangerous free radicals that combine to form stable polycyclic aromatic compounds (pyrosynthesis) (1). According to Veyrand et al, the heating process used in oil preparation is also an important factor that can affect the concentration of PAHs in edible oils, which is dependent on several factors, such as the distance and source of heating, and the type of fuel (37). In this regard, in a study performed in India, it was revealed that 80% of the edible oil samples were contaminated with PAHs, and the average level of contamination tended to be between 40.2 µg/kg and 624 µg/kg. High levels of PAH may be attributed to the unrefined form of crude oils used during the preparation step based on kiln drying assisted by combustion gas and direct air heating (38). Additionally, Srivastava et al reported that the consumption of repeatedly heated oils was associated with high mean levels of 16 PAHs, which ranged from 30.91 µg/kg in the coconut oil after single heating to 66.25 µg/kg after repeated heating (39). The oil refinement process, however, has been mentioned by some researchers as an important factor in the observed differences in this study. Moret et al demonstrated that PAH levels were low in refined edible oils in the range of a few µg/kg versus the crude oil contaminated by environmental factors (40). Based on the findings obtained by Teixeira et al, the contamination levels of 15 PAHs in various commercially refined oils (e.g., virgin olive, sunflower, and soybean) were generally lower than those of the crude oil (33).

Table 2. Meta-Analysis of the Concentration of Polycyclic Aromatic Hydrocarbons in Vegetable Oils Based on the Type of WHO Regions

Metal	Meat	Number of studies	ES (95% CI)	Heterogeneity				
				Weight (%)	Statistics	df	P Value	I ² (%)
Acenaphthene	EURO	4	0.545 (-0.319, 1.409)	45.30	1.1e+05	3	<0.001	100.0
	EMRO	4	3.527 (2.600, 4.455)	44.33	260.60	3	<0.001	98.8
	WPRO	1	4.000 (3.467, 4.533)	10.37	-	-	-	-
Acenaphthylene	EURO	4	2.474 (2.210, 2.739)	71.71	0.03	3	0.998	0.0
	WPRO	3	26.654 (4.135, 49.173)	28.29	231.57	2	<0.001	99.1
Anthracene	EURO	11	0.881 (0.776, 0.986)	63.59	2416.35	10	<0.001	99.6
	EMRO	4	3.312 (1.993, 4.632)	29.06	429.15	3	<0.001	99.3
	WPRO	2	4.405 (0.211, 8.598)	7.35	51.97	1	<0.001	98.1
Benzo[a]anthracene	EURO	13	1.678 (1.440, 1.917)	67.0	16019.84	12	<0.001	99.9
	EMRO	4	0.614 (0.296, 0.932)	25.44	139.49	3	<0.001	97.8
	WPRO	2	5.106 (-3.821, 14.033)	7.56	115.97	1	<0.001	99.1
Benzo(a)pyrene	EURO	11	0.395 (0.348, 0.442)	62.66	1915.59	10	<0.001	99.5
	EMRO	8	1.135 (0.903, 1.367)	37.12	593.94	7	<0.001	98.8
	WPRO	1	8.900 (7.382, 10.418)	0.22	-	-	-	-
Benzo[b]fluoranthene	EURO	3	0.251 (0.153, 0.349)	43.61	563.97	2	<0.001	99.6
	EMRO	4	0.215 (0.091, 0.339)	56.39	250.54	3	<0.001	98.8
Benzo[b]fluorene	EURO	9	2.185 (1.709, 2.661)	87.02	11215.11	8	<0.001	99.9
	WPRO	2	8.446 (-6.920, 23.811)	12.98	121.24	1	<0.001	99.2
Benzo[e]pyrene	EURO	2	15.130 (6.836, 23.424)	15.86	24.28	1	<0.001	95.9
	EMRO	5	0.464 (0.263, 0.665)	70.12	282.06	4	<0.001	98.6
	WPRO	1	0.740 (0.665, 0.815)	14.02	-	-	-	-
Benzo(g,h,i)perylene	EURO	9	0.646 (0.537, 0.755)	58.84	268.83	8	<0.001	97.0
	EMRO	4	0.176 (0.107, 0.245)	38.07	183.84	3	<0.001	98.4
	WPRO	1	2.160 (1.792, 2.528)	3.09	-	-	-	-
Benzo[k]fluoranthene	EURO	11	1.835 (1.674, 1.996)	63.50	1.1e+05	10	<0.001	100.0
	EMRO	4	0.257 (0.109, 0.405)	28.77	394.79	3	<0.001	99.2
	WPRO	2	4.520 (-3.133, 12.174)	7.74	112.19	1	<0.001	99.1
Chrysene	EURO	12	0.711 (0.605, 0.817)	58.79	1068.79	9	<0.001	99.2
	EMRO	4	0.890 (0.319, 1.461)	30.92	356.51	3	<0.001	99.2
	WPRO	2	4.942 (-3.740, 13.625)	10.28	116.75	1	<0.001	99.1
Dibenz[a,h]anthracene	EURO	12	3.927 (3.303, 4.551)	67.76	6.3e+05	11	<0.001	100.0
	EMRO	4	0.139 (0.092, 0.185)	24.13	123.78	3	<0.001	97.6
	WPRO	2	7.602 (-6.470, 21.674)	8.10	123.55	1	<0.001	99.2
Fluoranthene	EURO	12	11.173 (9.776, 12.569)	65.28	28948.67	11	<0.001	100.0
	EMRO	4	2.625 (1.373, 3.877)	24.20	1818.97	3	<0.001	99.8
	WPRO	2	9.231 (2.746, 15.717)	10.51	31.91	1	<0.001	96.9
Fluorene	EURO	8	4.175 (2.813, 5.537)	57.86	30944.68	7	<0.001	100.0
	EMRO	4	2.560 (1.841, 3.279)	28.93	199.50	3	<0.001	98.5
	WPRO	2	7.211 (6.453, 7.969)	13.21	0.58	1	0.448	0.0
Indeno[1,2,3-c,d]pyrene	EURO	9	0.637 (0.537, 0.737)	98.82	400.59	8	<0.001	98.0
	WPRO	1	5.730 (4.753, 6.707)	1.18	-	-	-	-
Naphthalene	EURO	6	5.442 (4.469, 6.415)	51.29	206.10	5	<0.001	97.6
	EMRO	4	2.764 (1.718, 3.810)	38.85	560.28	3	<0.001	99.5
	WPRO	2	24.631 (13.145, 36.117)	9.86	15.59	1	<0.001	93.6
Phenanthrene	EURO	9	14.601 (10.986, 18.216)	52.72	37733.77	8	<0.001	100.0
	EMRO	4	2.599 (1.821, 3.378)	26.91	363.35	3	<0.001	99.2
	WPRO	2	11.991 (4.221, 19.762)	12.80	37.46	1	<0.001	97.3
Pyrene	EURO	13	3.748 (2.708, 4.788)	67.04	26874.31	12	<0.001	100.0
	EMRO	4	3.617 (2.149, 5.084)	22.70	2356.22	3	<0.001	99.9
	WPRO	2	7.662 (5.065, 10.259)	10.26	10.32	1	0.001	90.3

Note. ES: Effect size; CI: Confidence interval; df: Degree of freedom; WHO: World Health Organization. EURO, European Region; EMRO, Eastern Mediterranean Region; WPRO, Western Pacific Region.

Hossain and Salehuddin examined the effect of refining on the decrease of low molecular weight PAHs and found that different oils contained low amounts of these compounds (2). Several other studies have confirmed the impact of packaging on the production of PAHs in foods. Chen et al concluded that PAHs can diffuse into packaging prepared using low-density polyethylene and polytetrafluorethylene; thus, they believed packaging is a potent method for reducing the presence of PAH in rapeseed oil (41).

3.3. Levels of Polycyclic Aromatic Hydrocarbons in Vegetable Oils According to the World Health Organization Region

The concentration of PAHs in vegetable oils (corn, sunflower, olive, sesame, soybean, and canola) varied by country (Table 2). Among vegetable oils, the highest PAH concentrations in the European Region (EURO), Eastern Mediterranean Region (EMRO), and Western Pacific Region (WPRO) concerning vegetable oils (corn, sunflower, olive, sesame, soybean, and canola) were 15.13 µg/kg, 3.617 µg/kg, and 26.65 µg/kg, which were attributed to benzo[e]pyrene, pyrene, and acenaphthylene, respectively. In the EURO, EMRO, and WPRO regions, the lowest amounts of PAHs in vegetable oils (corn, sunflower, olive, sesame, soybean, and canola) were 0.25 µg/kg, 0.139 µg/kg, and 0.74 µg/kg, respectively, which belonged to benzo[b]fluoranthene, dibenz[a,h]anthracene, and benzo(g,h,i)perylene, respectively. The results of the present meta-analysis revealed that there were noteworthy alterations ($P < 0.05$) between PAH concentrations in countries from the WHO. Various countries have surveyed the level of PAHs in vegetable oil samples. In Italy, Vichi et al investigated the content of PAHs in olives. According to their analysis, the amounts of phenanthrene, anthracene, and fluoranthene were 16.00 µg/kg, 2.3 µg/kg, and 6.00 µg/kg, respectively (42). The results of another study conducted by Martorell et al showed that naphthalene, acenaphthylene, acenaphthene, fluorine, phenanthrene, anthracene, and fluoranthene levels in the corn oil were 12.5 µg/kg, 2.45 µg/kg, 2.45 µg/kg, 2.45 µg/kg, 2.45 µg/kg, 2.45 µg/kg, and 2.45 µg/kg, respectively (43). According to Wu et al, in olive samples collected from China, fluorine, benzo[k]fluoranthene, acenaphthylene, chrysene, indeno[1,2,3-cd]pyrene, and anthracene were present at mean concentrations of 3.81 µg/kg, 4.23 µg/kg, 11.31 µg/kg, 4.70 µg/kg, 2.86 µg/kg, and 3.29 µg/kg, respectively (44). Alomirah et al reported that the mean concentrations of benzo[a]pyrene in the soybean, corn, sesame, canola, and sunflower were 0.71 µg/kg, 0.27 µg/kg, 2.05 µg/kg, 4.26 µg/kg, and 0.71 µg/kg, respectively (45). As a result, there are significant differences in PAH contamination between various regions. According to the results of this study (Table 2), this difference is likely caused by environmental contamination from the region of the cultivation, pollution from active industries and mines, pollution in urban and rural areas, and cooking

techniques. Various studies have examined the presence of PAHs in food samples, and many publications discuss differences in the contamination of PAHs in different vegetable oils. Emissions from traffic, vehicular exhausts, and industrial sources may be mainly responsible for the PAH contamination of edible oils. In this regard, Corradetti et al found that vegetable oils from plants exposed to vehicular exhausts were highly contaminated with PAHs compared to vegetable oils from plants exposed to pitch condensate emissions (46). According to another study, plants that grow in industrial areas and high-traffic environments have higher levels of PAH pollution than other regions (47). Bishnoi et al concluded that soil layers in busy traffic areas were more contaminated with PAHs (48). Further, Srogi reported that high concentrations of atmospheric PAHs are caused by increased vehicular traffic and the limited dispersion of pollutants in the urban environment, which has an effect on the production of plant oil (49). The environmental contamination of the region also influences different levels of PAHs in various oils. In this respect, Wennrich et al demonstrated that the concentration of PAHs in vegetables was affected by distance from sources and atmospheric conditions, including pollution of water, soil, and exogenous compounds present in the plant (50). Studies have shown that contamination can enter the plant's roots, leaves, and stems. A direct relationship between soil PAH concentrations and plants was reported by Srogi, who found that plants grown on polluted sediment soils had the highest concentration of PAHs. Moreover, the main routes of entry for PAHs into surface waters were atmospheric fallout, urban runoff, municipal effluents, industrial effluents, and oil spills or leaks (49). The results of a review study indicated that vegetable oil producers irrigated with wastewater had higher levels of PAHs than those from rural areas (51). Several factors influence the content of PAHs in food, including the type, county of origin, ecological and . PAHs can be released by natural processes, such as volcanic eruptions or forest fires, or by human activities, such as industry, mining, vehicles, or household processes (52).

3.4. Health Risk Assessment

Vegetable oils made from agricultural products (e.g., fruits and seeds) are extensively used throughout the world (53). PAHs can pose a risk to human health. The responsible and relevant organizations list PAHs as carcinogenic. The European Union reported 2 µg/kg of benzo[a]pyrene in oils and fats safe for health (54). Cancers of the lung, respiratory system, and stomach caused by PAHs have been established by several studies (55). Tables 3 and 4 present data on the risks of carcinogenic or mutagenic PAHs in different countries. Among countries with the highest carcinogenic risk, the Netherlands ranked first, followed by Turkey, Spain, China, Poland, Portugal, Egypt, Korea, Greece, and Kuwait. In addition, from the viewpoint of mutagenic risk, the Netherlands ranked

Table 3. Carcinogenic Risk Assessment Based on BaP Equivalency for Vegetable Oils

Country	IR (kg)	BaA	BaP	BbFlu	BkFlu	Chr	DahA	IndP	Total
Greece	26.5	3.09E-09	1.42E-09	4.79E-11	6.39E-12	3.09E-11			4.60E-09
Turkey	24.9	2.71E-09	4.43E-09	3.59E-09	2.54E-09				1.33E-08
China	8.1	2.15E-09	1.98E-08	3.63E-09	1.88E-10	2.09E-11	3.29E-08	1.27E-09	5.99E-08
Egypt	6.1	1.04E-10	2.55E-09	3.63E-11	4.30E-12	1.51E-12	2.34E-10		2.93E-09
Korea	18.6	3.01E-10		3.41E-10	3.31E-11	2.80E-12	2.45E-09		3.12E-09
Kuwait	20.2		8.85E-09						8.85E-09
Netherlands	14.3	1.62E-09	3.58E-09	1.76E-09	8.36E-11	1.59E-10	3.57E-09	1.14E-09	1.19E-08
Poland	13.4	6.07E-09	4.59E-09	2.83E-10	1.54E-11	5.10E-12	4.96E-08	3.78E-10	6.10E-08
Portugal	20.5	1.90E-10	7.06E-10	1.41E-10	1.89E-11	1.30E-12	3.39E-10	1.95E-10	1.59E-09
Spain	33.3	8.94E-10	8.23E-09	8.94E-10	8.94E-11	8.94E-12	8.94E-09	8.94E-10	2.00E-08
Total	---	1.71E-08	5.41E-08	1.07E-08	2.97E-09	2.30E-10	9.81E-08	3.88E-09	1.87E-07

Note. Chr: Chrysen; BaA: Benzo[a]anthracene; BaP: Benzo[a]pyrene; BkF: Benzo[k]fluoranthene; BbF: Benzo[b]fluoranthene; BghiP: Benzo[g,h,i]perylene; DahA: Dibenzo[a,h]anthracene; IndP: Indeno[1,2,3,c,d]pyrene.

Table 4. Mutagenic Risk Assessment Based on BaP Equivalency for Vegetable Oils

Country	IR (kg)	BaA	BaP	BbFlu	BkFlu	Chr	DahA	IndP	Total
Greece	26.5	2.53E-09	1.42E-09	1.20E-10	7.03E-11	5.25E-10			4.67E-09
Turkey	24.9	2.22E-09	4.43E-09	8.97E-09	2.79E-08				4.35E-08
China	8.1	1.77E-09	1.98E-08	9.07E-09	2.07E-09	3.55E-10	9.55E-09	3.94E-09	4.65E-08
Egypt	6.1	8.57E-11	2.55E-09	9.09E-11	4.73E-11	2.56E-11	6.79E-11		2.87E-09
Korea	18.6	2.47E-10		8.54E-10	3.64E-10	4.76E-11	7.09E-10		2.22E-09
Kuwait	20.2		8.85E-09						8.85E-09
Netherlands	14.3	1.33E-09	3.58E-09	4.40E-09	9.19E-10	2.70E-09	1.03E-09	3.54E-09	1.75E-08
Poland	13.4	4.98E-09	4.59E-09	7.07E-10	1.70E-10	8.68E-11	1.44E-08	1.17E-09	2.61E-08
Portugal	20.5	1.56E-10	7.06E-10	3.53E-10	2.08E-10	2.22E-11	9.83E-11	6.04E-10	2.15E-09
Spain	33.3	7.33E-10	8.23E-09	2.24E-09	9.83E-10	1.52E-10	2.59E-09	2.77E-09	1.77E-08
Total	---	1.41E-08	5.41E-08	2.68E-08	3.27E-08	3.91E-09	2.84E-08	1.20E-08	1.72E-07

Note. Chr: Chrysen; BaA: Benzo[a]anthracene; BaP: Benzo[a]pyrene; BkF: Benzo[k]fluoranthene; BbF: Benzo[b]fluoranthene; BghiP: Benzo[g,h,i]perylene; DahA: Dibenzo[a,h]anthracene; IndP: Indeno[1,2,3,c,d]pyrene.

first, followed by Spain, Portugal, Poland, Turkey, China, Korea, Egypt, Greece, and Kuwait. There has been research on the carcinogenicity and metastasis risk of different products, the results of which are in line with ours. Based on a typical Indian diet, the cancer risk of PAHs depends on consumption patterns, preparation methods, contamination sources, the body weight of people, gender, and age (56). To reduce the contamination, transfer, and formation of PAHs in foods, food safety and regulatory authorities must develop guidelines for food and packaging providers. Governmental regulators should be responsible for conducting periodic food testing, including testing the oils that go through refining and deodorization processes. The findings of this study indicated that consumers can prevent PAH contamination in food during cooking by preventing the frequent use of cooking oils, removing burnt parts of food, choosing suitable fuel and heat sources, and the like (57).

4. Conclusion

This research evaluated the PAH content in various vegetable oils, depending on the kind of PAH and

country of origin. Further, the health risk was investigated according to the oil consumption pattern in different countries. Thirteen studies reported that the levels of PAHs in different countries varied based on the inclusion and exclusion criteria. Additionally, the physicochemical characteristics of PAHs, the drying processes of the oil seeds, packaging material, soil burning, and the source of the vegetable oil were considered critical factors in determining the levels of PAHs in vegetable oils. In different countries, PAHs were found to pose risks to health. Therefore, vegetable oils should be monitored by different agencies to reduce contaminants.

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Competing Interests

The authors declared no conflict of interests regarding this paper.

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