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Health Risk Assessment and Determination of Heavy Metals in Sesame Oil

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ABSTRACT

Introduction: The present study aimed to evaluate the fatty acid (FA) profile and level of heavy metals and determine the potential health risks of heavy metals (cumulative carcinogenic and non-carcinogenic risks) in the sesame oil consumed in Iran.

Methods: In total, 30 sesame oil samples were collected from factories (n=20; industrial) and traditional mills (n=10; non-industrial). The heavy metal content and FA profile of the examined samples were determined by ICP-OES and gas chromatography, respectively. The human health risk assessment model developed by the States Environment Protection Agency (U.S.EPA) was used to assess the human health risk (non-carcinogenic and carcinogenic risk) of heavy metals in the sesame oil samples based on Monte Carlo Simulation (MCS).

Results: No significant differences were observed between the industrial and non-industrial sesame oil samples in terms of the FA profile and toxic heavy metal contamination. Meanwhile, the FA profile of the industrial and non-industrial sesame oil samples indicated high levels of unsaturated fatty acids (84.5% and 83.49%, respectively), with the main fatty acids determined to be oleic acid and linoleic acid. The FA profile of the sesame oil samples indicated no adulteration with other vegetable oils. The concentration of lead, cadmium, and iron in the industrial sesame oil samples was estimated at 0.008-1.33, 0.001-0.04, and 0.11-6.74 mg/kg, while it was 0.00-0.199, 0.01-0.04, and 0.8-4.3 mg/kg in the non-industrial sesame oil samples, respectively. In general, lead content was higher than the legislation limit of Iran and the European Union (0.1 mg/kg). Mercury and arsenic were not detected in any of the sesame oil samples. The obtained mean values of iron were lower than the maximum values recommended by the FAO/WHO (1-1.5 μg/g). as for cadmium, these values were in line with international requirements (0.05 μg/g) (1). Carcinogenic health risk (ILCRs) and non-carcinogenic health risk (HI or THQ) highly exceeded the threshold value of one in both adult and children consumer groups.

Conclusion: According to the results, adults and children are at the risk of consuming contaminated sesame oil through ingestion. Therefore, it is essential to monitor heavy metal contaminants and the quality of imported sesame seeds prior to oil production.

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Introduction

Sesame belongs to the Pedaliaceae family and genus Sesamum (2), which contains approximately 36 species, 19 of which are vernacular to Africa (3). It is believed that the sesame plant originates in Africa (4), while many other countries produce and export sesame seeds, such as China, Japan, India, Egypt, Cameroon, Brasilia, Senegal, and Iran (5).

Sesame oil has therapeutic applications and is widely used for pharmaceutical purposes (6). Sesame oil contains vitamin E and various important antioxidants, such as sesaminol and sesamolinol, which protect the body tissues against oxidizing agents (7). Furthermore, sesame seeds have been shown to contain gamma-tocopherol, which enhances the beneficial health effects of sesame seeds by significantly elevating the concentration of this element in the human serum. In addition, gamma-tocopherol positively influences vitamin E activity and may prevent cancer and cardiovascular diseases (8).

Sesame is gaining importance as a source of healthy edible oils and a high-quality source of protein for human nutrition. Sesame seeds are mostly used for oil extraction, with the remnants applied for other consumption purposes (9). The

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quality and quantity of the oil content of sesame seeds depend on factors such as the climate, soil, plant maturity, and seed cultivars (10).

The physicochemical properties of oil are directly correlated with their lipid and glyceride composition. In the chemical composition of sesame, the seed is the main source of oil (50-60%), protein (18-25%), carbohydrates (13.5%), and ash (5%) (11). Sesame oil contains high levels of unsaturated fatty acids, which are used in the preparation of margarine and cooking oils. Sesame also contains significant amounts of lignans sesamin and sesamolin, which exert beneficial effects on the serum lipid rate and liver activity, rendering sesame seed oil a potent antioxidant (12). The main fatty acids in sesame oil include palmitic acid (16:0; 7.0-12.0%), stearic acid (18:0; 6.0-3.5%), oleic acid (18:1; 35-50%), and linoleic acid (18:2; 35-50%) (13, 14).

Measuring the elements found in edible oils is momentous due to the metabolic function of metals and feasibilities for adulteration tracing and oil characterization. Metal content is one of the main criteria for the quality assessment of vegetable oils. The presence of metals in vegetable oils is attributed to endogenous agents, which is associated with herbage metabolism and exogenous factors such as contamination during agronomic production, seed accumulation, and oil extraction and treatment processes, as well as equipment, packaging materials, and storage (15, 16).

Toxic metals could be highly hazardous even in trace amounts when consumed over a long period (17). Essential metals could also cause toxic effects if they are used exceedingly elevated (18). In terms of freshness, storability, and toxicity, the quality of edible oils could be assessed by determining various trace elements. Trace metals such as copper (Cu), zinc (Zn), iron (Fe), manganese (Mn), and nickel (Ni) are reported to enhance the rate of oil oxidation, while other elements such as arsenic (As), cadmium (Cd), and lead (Pb) are considered more significant in terms of toxicity and metabolic task. Lead, arsenic, mercury, and cadmium are toxic heavy metals found in different oils (19). Exposure to even low levels of lead and cadmium has been shown to be cumulative due to the lack of a mechanism to regulate the levels of these toxic materials. Lead poisoning may be correlated with neurological complications, renal dysfunction, and anemia (20). Cadmium is also a highly toxic metal, which is easily transmitted from soil to plants and has a cumulative effect on living tissues (21).

Arsenic is a ubiquitous metalloid and one of the most toxic elements for human and animal health; this element causes toxic and detrimental biological complications, including different cancers. Mercury is another important toxic element, which could be found in aquatic animal tissues grown in polluted water. It could exert numerous toxic effects on humans, such as impaired vision and hearing, dizziness, vomiting, muscular weakness, allergies, weakened immune system, brain damage, and even death (22).

Several studies have investigated the fatty acid (FA) profile, toxic metal concentration, and health risk assessment in vegetable oils (Mohammed F. et al., 2018; Zhu F. et al., 2011; Ashraf M.W. et al., 2014; Kheirati Rounizi S. et al., 2021; Eghbaljoo H. et al., 2020; Sobhanardakani et al., 2015) (10, 19, 23-26). However, few of these articles have examined the presence of heavy metals and health risk assessments in industrial and non-industrial sesame oil. Given the development of industries and increasing environmental pollution in recent decades, food contamination by heavy metals has become a pressing health concern. Although the owners of this industry claim that their product is of high quality, the veracity of this claim is yet to be verified. Extraction of natural oils with high purity in the presence of the customer is a new innovative business in our country during which different types of oil kernels and grains are extracted in stores using small press samples. Currently, information is scarce regarding the heavy metal contents of Iranian sesame oil products and their health risks.

The present study aimed to evaluate the concentration and health risk assessment, including target hazard quotients (THQs) and incremental lifetime cancer risk (ILCR), of lead, arsenic, cadmium, mercury, and iron in imported sesame oil via inductively-coupled plasma atomic emission spectroscopy (ICP-OES).

Materials and Methods

Sampling and Chemicals

Traditional sesame oil samples (n=20) were purchased from local extraction stores in 13 regions of Mashhad city, Iran (region division of the Municipality of Mashhad), and industrial sesame oil samples (n=10) were purchased from all the commercial brands of sesame oil available in the hypermarkets of Mashhad. The traditional sesame oil samples were extracted on the day of purchase, and the minimum expiration date of the industrial sesame oil samples was considered to be one year. The collected sesame oil samples were packed in polyethylene bags and stored at the temperature of 4°C until analysis.

The reagents and standard stock solutions used in the study included ammonium thiocyanate, 95% ethanol, hexane, chloroform, 96% methanol, barium chloride, hydrogen chloride, acetonitrile, methanol, sodium chloride, and HPLC grade water, which were obtained from Merck Chemicals. These chemicals were of analytical grade purity, and distilled water was also used for the preparation of the reagents. Laboratory ware (pipette tips and glass tubes) were washed with a detergent solution and rinsed with water before drying in the oven.

Table 1. Percentage of fatty acid components of non-industrial (n-Ins) and Industrial (Ins) sesame oils

Sample codes	C16:0	C18:0	C18:1	C18:2	C18:3	C20:0	C20:2
n-Ins1	8.2258	5.212	43.7125	40.141	0	0.4215	0.421
n-Ins2	9.0435	5.5838	43.4675	40.6704	0	0.5642	0.4011
n-Ins3	9.9338	5.3731	41.4396	42.1939	0	0.5473	0
n-Ins4	8.5335	5.2757	42.8934	39.8453	0	0.6745	1.2301
n-Ins5	9.4317	5.6393	40.467	41.5602	0	0.4845	0.3849
n-Ins6	9.0913	5.0372	39.7872	43.1625	0	0.5341	0.1807
n-Ins7	10.1134	5.2106	40.7154	42.9615	0	0.5781	0
n-Ins8	8.7429	5.4475	44.5761	40.3208	0	0.5127	0.1132
n-Ins9	8.8268	5.8687	43.9293	40.358	0.3135	0.5815	0.1224
n-Ins10	9.8721	5.563	40.6234	42.5684	0	0.5444	0.4162
n-Ins11	9.5369	5.7956	42.3096	40.733	0	0.5581	0.3566
n-Ins12	8.8905	5.5833	42.87	39.1361	0	0.5691	0
n-Ins13	9.8778	5.7066	40.4629	42.6215	0.2708	0.5306	0.1321
n-Ins14	9.8004	5.9969	41.0163	42.3637	0	0.4975	0
n-Ins15	8.7908	5.2079	40.7009	43.7234	0	0.4907	0.3773
n-Ins16	9.6662	5.3478	40.9114	42.8755	0.2932	0.5685	0.0997
n-Ins17	9.0435	5.5838	43.4675	40.6704	0	0.5642	0.4011
Mean ±SD[A]	9.26±0.56	5.49±0.26	41.96±1.51	41.52±1.37	0.05±0.11	0.5±0.5	0.27±0.22
Range	8.23-10.11	5.05-6	39.79-44.58	39.14-43.72	0.00-0.31	0.00-0.67	0.00-0.42
Saturated fatty acid	15.3						
Unsaturated fatty acid	83.49						
Ins1	9.3647	5.6356	41.1828	42.6972	0.2125	0.5311	0
Ins2	8.9546	5.5142	43.6353	40.7778	0.2585	0.5341	0.1327
Ins3	8.186	5.2817	41.4112	44.1327	0	0.3011	0.3153
Ins4	8.9951	5.3816	42.5396	43.2136	0	0.3075	0.1357
Ins5	9.4135	5.3974	43.2707	41.1989	0.2489	0.4706	0
Ins6	9.6104	5.1678	39.8805	42.5825	0	0.468	0.604
Ins7	9.5814	5.1314	39.5914	45.3837	0	0.3121	0
Mean ±SD[A]	9.15±0.5	5.35±0.18	41.64±1.58	42.85±1.59	0.08±0.13	0.4±0.41	0.16±0.22
Range	8.19-9.61	5.13-5.64	39.59-43.64	40.74-45.38	0.00-0.29	0.31-0.53	0.00-0.6
Saturated fatty acid	14.53						
Unsaturated fatty acid	**84.5**						

a: No significant different between fatty acid profiles of Industrial and non-industrial sesame oils (P>0.05)

Analytical Methods

FA Composition of Sesame Oil

In the present study, FA composition was determined using the method proposed by William W. Christie (1993). Initially, FAs were converted into fatty acid methyl esters by shaking a solution containing 0.1 milligram of oil, 1,100 microliters of hexane, and 100 microliters of methanolic KOH (2 N), followed by analysis via gas chromatography using a Varian 450 (Varian Inc.). The chromatograph was equipped with a flame ionization detector. The utilized column was a CP-Wax 52CB column (30 m×0.25 mm i.d.; Varian Inc., Middelburg, the Netherlands). The carrier gas was hydrogen, and the total gas flow rate was 1 ml/min. The initial and final column temperature was 240°C and 260°C, respectively, which was increased by steps of 4°C/min. In addition, the temperature of the injector and detector was set at 230°C. The obtained results were expressed as the relative percentage of each FA found in the samples (27).

Heavy Metal Measurement

To determine the heavy metal content of the samples, ICP-OES was performed (SPECTRO ARCOS System-76004555, Paris, France). In this study, the limit of detection (LOD) for an aliquot of each oil sample (2.0-3.0 g) was weighed directly into the test tube, and one milliliter of 10% dilute nitric acid was added. The oil-acid mixture was shaken at 50 Hz for 60 seconds using a test tube mixer until the layers were completely mixed. Following that, the capped test tube was placed in a shaking water bath at the temperature of 50°C for two hours. After centrifugation at 2,800 rpm for 10 minutes, the lower acid aqueous layer was withdrawn with a pipette, filled to 25 milliliters by adding deionized water, and loaded directly into the autosampler of the ICP-OES apparatus (28). Table 1 shows the performance of the analytical method.

Health Risk Assessment

The human health risk assessment models developed by the States Environment Protection Agency (U.S.EPA) were employed to assess the human health risk (non-carcinogenic and carcinogenic risk) of heavy metals in sesame oil. The health risks associated with the consumption of sesame oil were estimated based on THQs as non-carcinogenic risk. The hazard quotient (HQ) was also calculated using Equation 1, as follows (29, 30):

$$THQ = CDI/RfD \qquad \text{Eq. 1}$$

If THQ≥1, it is considered as the non-carcinogenic effects of concern, while THQ<1 shows an acceptable level of non-carcinogenic risk for consumption. In the equation above, *CDI* (chronic daily intake) is the daily dose of heavy metals (mg/kg/day) to which consumers might be exposed, and *RfD* represents the oral reference dose of heavy metals (mg/kg/day), which is an estimate of the daily exposure level for the human population (including sensitive sub-populations) that is likely without an appreciable risk of adverse effects during a lifetime. *RfD* for lead, cadmium, arsenic, and mercury is set at 0.0035, 0.04, 0.001, and 0.0003 mg/kg/day, respectively. The CDI was calculated using Equation 2, as follows (31, 32):

$$CDI = (C \times IR \times EF \times ED) / (BW \times AT) \qquad \text{Eq. 2}$$

Where *C* is the concentration of lead, cadmium, arsenic, and mercury in the sesame oil samples (mg/kg), and *IR* shows the average daily ingestion rate of sesame oil (kg/person/day). Intake of elements through food consumption is dependent on the element concentrations in food and the amount of consumed food. In the present study, *IR* was used based on the possible health threats associated with the consumption of edible vegetable oils in Iran. The maximum dietary intake of 25 g/n/day of a single type of fat/oil is recommended by the World Health Organization (WHO) (19, 33). In Equation 2, *ED* is the exposure duration (standard exposure for adults and children: 70 and 6 years, respectively as suggested by the literature). *BW* is the body weight (70 kg for adults and 20 kg for children), and *AT* indicates the average exposure time (EF×ED) which is 25,550 and 2,190 days for adults and children, respectively (29). Finally, *EF* shows the exposure frequency, which is set at 365 and 365 days/year for adults and children, respectively (29).

Interactive effects were considered in the current research since more than one toxicant was identified in the samples. The hazard index (HI) was also determined to estimate the total potential health effects of non-carcinogenic risks caused by exposure to a mixture of metals in the sesame oil samples. The HI showing the sum of the HQ values for all the heavy metals was calculated using Equation 3, as follows:

$$HI = \Sigma THQ \qquad \text{Eq. 3}$$

If the HI value is <1, the exposed local population (consumers) is considered safe; if the HI value is ≥1, consumption is considered unsafe for human health (34).

After calculating the HQ and HI, cancer risk should also be calculated. To assess carcinogenic risk, the ILCR was estimated using Equation 4, as follows (32, 35):

$$ILCR = CDI \times CSF \times ADAF \qquad \text{Eq. 4}$$

where *CSF* is the cancer slope factor (kg/day/mg) used to assess the lifetime probability of a person exposed to chemical agents in terms of carcinogenic risks, *ADAF* shows the potency adjustment factor for adults and children, and *CSF* for cadmium and lead are estimated at 1.5 and 0.0085 kg/day/mg, respectively (36).

The permissible level of ILCR is 1×10-6 (1 in 1,000,000) to 1×10-4 (1 in 10,000) based on the recommendations of the United States Environmental Protection Agency (USEPA). As mentioned earlier, ADAF is the potency adjustment factor for adults and children, which is set at 1 and 3 (dimensionless), respectively (37).

Monte Carlo Simulation (MCS)

Monte Carlo simulation (MCS) is an algorithm used to estimate the health risk assessment of any type of probability distribution. The MCS method is often focused on the variables affecting uncertainties (25, 38). If uncertainty factors (parameter uncertainty, model uncertainty, and scenario uncertainty) are not considered, the obtained data will not be accurate (39). To overcome this defect, the USEPA recommends using the MCS method (40). To specify the uncertainty of each influential parameter, probabilistic statistics are used. Therefore, this simulation method represents the better stochastic behavior of human risks (41). In this technique, each value of parameter distribution is inserted into the exposure equation randomly, and the process is completed several times until the distributions of the predicted results, indicating that the overall uncertainty of the input parameters has been obtained (41, 42). All the MCS calculations were performed in the MS Excel software.

Statistical Analysis

Data analysis was performed in SPSS version 16.0 (Statistical Package of Social Science), and all the chemical analyses were carried out in triplicate. Data were expressed as mean and standard deviation. Mean comparison was also performed, followed by independent samples t-test. The industrial and non-industrial sesame oil samples were compared at the significance level of P<0.05.

Results and Discussion

FA Composition of Sesame Oil

FA composition is an essential indicator of the nutritional value of oils. Evidence suggests that the consumption of vegetable oils has beneficial effects on the human health mainly owing to their FA composition, in which unsaturated FAs are prominent (43, 44). The FA composition of oils may largely differ depending on the region of origin and plant variety. Therefore, determining the FA profile could provide a reliable index of product authenticity. Table 1 shows the detailed FA composition of the examined sesame oils in the present study. Accordingly, the examined oils had extremely low amounts of saturated fatty acids (SFAs; 14.52% of industrial samples, 15.3% of non-industrial samples). According to our findings, the level of unsaturated FAs was significantly higher (83.49%) in the non-industrial sesame oil samples and 84.5% in the industrial sesame oil samples. Unsaturated FAs in the non-industrial sesame oils consisted of 41.977% monounsaturated FAs and 41.52% polyunsaturated FAs. The industrial sesame oils contents also consisted of 41.65% monounsaturated FAs and 42.85% polyunsaturated FAs.

In the present study, palmitic acid was the main SFA in the industrial and non-industrial sesame oil samples. On the other hand, the industrial sesame oil samples had a lower content of oleic acid (41.64%) compared to the non-industrial samples (41.96%), which had a higher linoleic acid content (42.85%) compared to the industrial oil samples (41.52%). The main components of the FA composition of the sesame oil samples in the current research were palmitoleic acid (C16:1), stearic acid (C18:0), oleic acid (C18:1), and linolenic acid (C18:3), which had no significant differences between the industrial and non-industrial sesame oil samples. Figure 1 depicts a sample chromatogram of the FA composition of the sesame oil samples.

In the present study, a slight difference was observed in the FA composition of the sesame oil samples, which could be due to the different cultivars of the sesame seeds. Previous studies have also demonstrated that some agricultural parameters could change the FA composition of sesame seed oil (11, 45, 46), the most important of which are cultivar and origin, fruit ripening, harvest period, and climatic conditions. In the present study, the minor FA components of the sesame oil samples, including linolenic acid (C18:3), eicosanoic acid (C20:2), and arachidic acid (C20:0), had no significant differences in the two sample groups.

Our findings indicated that the FA composition of the sesame oil samples was within the range of the values reported by Faez Mohammed et al. (2018), Olasunkanmi et al. (2017), Borchani et al. (2010), and Rahman M.A. et al. (2007) (10, 47-

49). Since the examined oil samples contained more oleic and linoleic acids (83.49-84.5% of total FAs), the sesame oil samples could be classified into oleic and linoleic acid groups. This is consistent with the findings of Olasunkanmi et al. (2017) and Kheirati Rounizi et al. (2021) (24, 50). Compared to the national and international Codex standards of sesame oil, our findings regarding the FA composition of sesame oil were in compliance with the recommended ranges of the Codex standards and the Iranian national standards for sesame oil (No. 13392). Therefore, the originality of the oils was confirmed, and the likelihood of adulteration with other oils was very low.

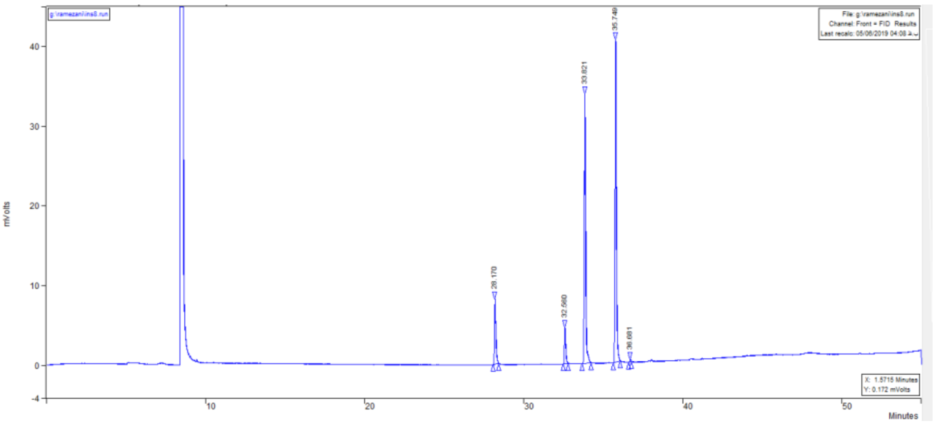

Figure 1. chromatogram of the fatty acids profile in sesame oil

Heavy Metal Determination

In the present study, the concentrations of the elements (cadmium, arsenic, lead, mercury, and iron) in the industrial and non-industrial sesame oil samples were analyzed via ICP-OES. The elements were extracted by treating the industrial and non-industrial sesame oil samples with diluted nitric acid. Table 2 shows the results of the analyses. Soil metal content is naturally place-dependent, while it may also result from human activities such as mining, spilled industrial wastes, vehicle emissions, fertilizers, paints, treated woods, poor effluents, inadequate sanitary conditions, strong corrosion, and possibly metal accumulation in natural puddles favored by low rainfall. The two considerable industrial processes that lead to the arsenic contamination of the environment (especially atmospheric contamination) are the smelting of non-ferrous metals and energy production from fossil fuels. Metal elements could move into plants through the roots, leaf and stem pores, and hulls of seeds and fruits. Due to the diversity of the geographic origin of the sesame plant, it may grow in soils containing various metal contents.

According to the results of the present study, iron was the dominant elemental ion in the samples, followed by lead and cadmium. In general, the presence of excessive amounts of heavy metals is unacceptable since they could be toxic and oxidative to consumers, thereby facilitating the degradation of oil and decreasing its shelf life. In the current research, arsenic and mercury were not detected in the examined sesame oil samples. In addition, no significant difference was observed in the toxic heavy metal content of the industrial and non-industrial sesame oil samples. Notably, the iron content of the industrial and non-industrial sesame oil samples had a significant difference ($P<0.05$). The minimum and maximum detected iron levels were 0.83 and 4.363 mg/kg in the industrial sesame oil and 0.114 and 6.632 mg/kg in the non-industrial sesame oil, respectively.

According to national and international provisions, the permissible contents of these metals in oils are 1-1.5 mg/kg (Fe), 0.1 mg/kg (Pb and As), and 0.05 mg/kg (Cd) (1). In the current research, the iron levels in the sesame oil samples were higher than the permissible limits. Sufficient dietary iron is essential to decreasing the incidence of anemia. Iron is a potent oxidant, and its high content in sesame oil is possibly due to the high amount of available iron in the agricultural soils where the sesame plant grows.

The analysis of elements such as lead and cadmium in foods is a general concern since these elements are toxic to humans, especially children are more sensitive to these metals compared to adults. In the current research, the minimum and maximum amounts of cadmium were 0.01 and 0.042 mg/kg in the industrial sesame oil and 0.001 and 0.045 mg/kg in the non-industrial sesame oil, respectively. As for lead, the minimum and maximum levels were 0.000.2 mg/kg in the industrial sesame oil and 0.008 and 1.318 mg/kg in the non-industrial sesame oil, respectively.

Table 2. Heavy metal concentrations in sesame oil samples (mg/kg)

Sample codes	Pb	Cd	Hg	As	Fe
n-Ins1	0.1635	0.0135	n.d	n.d	1.774
n-Ins2	0.2615	0.0375	n.d	n.d	5.4345
n-Ins3	0.3705	0.0175	n.d	n.d	1.9125
n-Ins4	0.3125	0.0225	n.d	n.d	5.883
n-Ins5	0.324	0.0365	n.d	n.d	5.1395
n-Ins6	0.179	0.0285	n.d	n.d	3.4935
n-Ins7	0.227	0.0435	n.d	n.d	6.078
n-Ins8	0.175	0.0175	n.d	n.d	3.284
n-Ins9	0.1565	0.025	n.d	n.d	3.018
n-Ins10	0.2035	0.027	n.d	n.d	5.0725
n-Ins11	0.0085	0.0015	n.d	n.d	0.1135
n-Ins12	0.4395	0.0455	n.d	n.d	4.037
n-Ins13	0.185	0.0375	n.d	n.d	3.102
n-Ins14	0.184	0.0275	n.d	n.d	2.826
n-Ins15	0.1245	0.0215	n.d	n.d	2.5875
n-Ins16	0.2785	0.016	n.d	n.d	1.671
n-Ins17	0.2705	0.0325	n.d	n.d	3.0295
n-Ins18	1.318	0.032	n.d	n.d	6.6325
n-Ins19	0.157	0.0365	n.d	n.d	5.0385
n-Ins20	0.2025	0.0285	-	-	3.3805
Mean ±SD	0.277±0.26 a	0.027±0.01 a	-	-	3.675±1.706b
Range	0.008-1.33	0.001-0.048	-	-	0.113-6.74
Ins1	0.116	0.038	n.d	n.d	2.91
Ins2	0.1835	0.042	n.d	n.d	4.363
Ins3	0.158	0.038	n.d	n.d	2.438
Ins4	0	0.0165	n.d	n.d	0.83
Ins5	0.122	0.0365	n.d	n.d	3.3465
Ins6	0.1445	0.0335	n.d	n.d	1.9395
Ins7	0.2	0.042	n.d	n.d	2.6065
Ins8	0.163	0.0345	n.d	n.d	2.1385
Ins9	0.181	0.0235	n.d	n.d	0.8945
Ins10	0.1635	0.038	n.d	n.d	2.5655
Mean ±SD	0.143±0.056 a	0.034±0.008 a	-	-	2.403±1.058 b
Range	0.113-0.207	0.016-0.043	-	-	0.809-4.426

a: no significant difference between toxic heavy metals content of industrial and non-industrial sesame oil

b: significant different between Industrial and Non-industrial sesame oil samples (P<0.05)

n.d = not detected

Cadmium is an extremely poisonous element with a natural occurrence in soil, and the soil concentration of this element is increasing due to human activities. Extreme cadmium exposure may cause renal, pulmonary, hepatic, skeletal, and fertility complications, as well as various cancers. Children aged less than six years are particularly vulnerable to the noxious effects of lead as the blood-brain barrier is not yet quite developed until adolescence. The adverse hematological and neurological effects of lead manifest even at lower levels than the threshold in adults. Lead also affects erythropoiesis and heme biosynthesis. Chronic lead poisoning in adults leads to anemia, some cancers, and generative damage in males. The danger of chronic intoxications is the more pressing issue in this regard. In the current research, the level of cadmium in the evaluated sesame oil samples was lower than the permissible limit, while the level of lead in the analyzed sesame oil samples was higher than the recommended level by the European Community (0.1 mg/kg). The presence of lead at such high concentrations may be due to environmental contamination. Specifically, the content of lead would be justified by the existence of streets, highways, and metallurgic industries nearby farmlands. One of the reasons for the contamination of oil with lead could be the contamination of the soil in which the sesame plant grows, causing the absorption of lead by the sesame plant.

In a study in this regard, Bakircioglu et al. (2013) reported the concentration of lead, cadmium, and iron in edible oil samples to be 0.99-0.134, 0.022-0.058, and 8-12.5 mg/kg, respectively. Other studies have shown the concentration of cadmium, lead, arsenic, and iron in edible oil samples to be 5.44 ng/g, 0.018, 0.019, and 38.5 mg/kg (51), 5.78 ng/g, 0.017, and 0.018 mg/kg, respectively (52). In the study by Zhu et al., the concentration of lead and arsenic in the sesame oil samples was 0.014-0.018 mg/kg (lower than our findings) and 0.015-0.019 mg/kg (higher than our findings) (19). According to the study by Ashraf, the concentration of arsenic and cadmium in sesame oil was 0.013 and 2.36 mg/kg, respectively, and the levels of heavy metals were higher than the current research (23). Based on these assessments, it could be inferred that the quantity of trace metals is directly correlated with their origination and production.

Health Risk Assessment

Non-carcinogenic Risk

Table 3 shows the HQ of the assessed heavy metals. The HQ of lead for adults and children is set at 0.023 and 0.083, respectively. In the present study, the HQ of lead for both adults and children was less than one. The HQ of cadmium for adults and children is 1.6 and 3.71, respectively. The HQ level of heavy metals in the sesame oil samples of the current research indicated the order Cd>Pb. In addition, the HQ of cadmium in the sesame oil samples was higher than one, which increased their vulnerability. The HQ values of lead were particularly lower for adults and children; therefore, they were not considered as non-acceptable health risks for children and adults despite their presence in sesame oil.

The HI of lead and cadmium for adults and children was estimated at 1.08 and 3.79, respectively. Although the HI for child consumers of sesame oil is ~3 times higher than adults, it was above the threshold value of one for both groups, which is consistent with the results obtained by Anyanwu et al. (2020) and Onyinyechi et al. (2018) (29, 53). Based on the HI, the non-carcinogenic adverse effects cannot be overlooked. Our HQ values for cadmium was also in line with the findings of Anyanwu et al. (2020) and Ghaderpoori et al. (2019) (29, 34). Moreover, our findings regarding the HQ value of lead are consistent with the studies by Zhu et al. (2011) and Rounizi et al. (2021) (19, 34).

Carcinogenic Risk

According to the information in Table 3, the mean ILCRs for toxic metals in adults were 7.05 and 1.59 for lead and cadmium, respectively. The ILCRs for children were also estimated at 7.4 for lead and 0.00016 for cadmium, which exceeded the recommended value by the USEPA. Different results have been obtained by Mohajer et al. (2019) in imported rice bran oil (54) in Iran and Hu et al. (2010) in ambient air in Nanjing, China (55).

Table 3. The incremental lifetime cancer risks (ILCRs), Target hazard quotients (THQs) calculated for heavy metals.

Toxic metal	*n*	*Mean±SD* (mg/kg)	Adults ILCR	Adults THQ	Adults HI	Children ILCR	Children THQ	Children HI
Pb	30	0.2324±0.224	7.05	0.023	1.08	7.40	0.083	3.79
Cd	30	0.0297±0.01	1.59	1.06		0.00016	3.71	
Hg	30	0	-	-	-	-	-	-
As	30	0	-	-	-	-		-

Conclusion

According to the results, linoleic acid, oleic acid, palmitic acid, and stearic acid were the predominant FAs with the mean concentrations estimated at 0.05±0.11-0.08±0.13, 41.96±1.51-41.64±1.58, 9.26±0.56-9.15±0.5, and 5.49±0.26-5.35±0.18 in the non-industrial and industrial sesame oil samples, respectively. The minimum and maximum levels of cadmium were 0.01 and 0.042 mg/kg in the industrial sesame oil and 0.001 and 0.045 mg/kg in the non-industrial sesame oil, respectively. The minimum and maximum levels of lead were estimated at 0.000.2 mg/kg in the industrial sesame oil and 0.008 and 1.318 mg/kg in the non-industrial sesame oil, respectively.

Toxic metals arsenic and mercury were not detected in the sesame oil samples. Since heavy metals and several other chemical pollutants may accumulate over the lifetime of humans, the assessment of health risks attributed to these pollutants is essential. Carcinogenic (ILCRs) and non-carcinogenic health risks (HQ and HI/THQ) were calculated via MCS, and the index values for lead and cadmium were observed to be higher than the permissible limits. Therefore, the consumption of sesame oil may pose a risk to human health, which is a major concern for both adults and children consuming sesame oil. Although legislation and supervision remain essential in order to ensure the health of consumers in terms of toxic metals, effective methods are still required to guarantee the safety of consumers against the toxic effects of heavy metals and maintain public health. For instance, proper agricultural practices should be carried out with the aim of reducing the growth of fungi throughout the processing stages on farms and during storage, as well as improving the quality of the whole process. It is also essential to monitor the presence of heavy metal contaminants and the quality of imported sesame seeds prior to oil production.

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