Heliyon 10 (2024) e37606

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Physicochemical characterization and determination of trace metals in different edible fats and oils in Bangladesh: Nexus to human health

Md. Samrat Mohay Menul Islam [a], Hasina Akter [b], Md. Hasan Ali [a], A.J. M. Morshed [a,*], Md. Ashraful Islam [a], Mohammad Helal Uddin [b], M.A.A. Shofi Uddin Sarkar [a], Md. Nure Alam Siddik [a]

[a] Bangladesh Council of Scientific and Industrial Research (BCSIR) Chattogram Laboratories, Chattogram, 4220, Bangladesh
[b] Dept of Applied Chemistry and Chemical Engineering (ACCE), University of Chittagong, Chattogram, 4331, Bangladesh

ARTICLE INFO

Keywords:
Carcinogenic risk assessment
Characterization
Non-carcinogenic risk
Monte Carlo simulation
Toxic metals

ABSTRACT

The study assessed the quality of four different edible fats and oils using standard analytical techniques. The presence of potentially toxic elements was determined using atomic absorption spectrometry. This study reveals that edible oils function admirably in terms of physical traits such as moisture content, boiling point, melting point, density, and specific gravity. Some edible fats and oils exceeded the standard limit of moisture, acid value, and peroxide value and these values were found in the range of 0.120–0.760 %, 0.220–2.45 mg KOH/g, and 1.23–21.7 meq/kg respectively. The iodine value for fats showed satisfactory results but for oils observed lower than the standard value varied from 68.2 to 104 g/100 g. The results of saponification value for most of the oils and fats were found satisfactory but others were lower than recommended limits and detected results were in the range of 167–224 mg KOH/g. Trace metals viz. Fe, Mn, Ni, Pb, Cd, Cu, and Co were measured in all samples and the concentration ranged from 0.070 to 47.0, 0.120–2.44, 0.540–27.1, 0.030–1.87, 0.010–4.63 and 0.060–8.39 ppm for iron, manganese, nickel, lead, copper, and cobalt respectively. The study found high levels of Fe, Mn, Ni, Cu, and Co in edible fats and oils in Bangladesh. No Cd was found, and Pb was not present in over half of the samples, which included the majority of mustard oils. The levels of Fe and Ni were higher than advised, but there was no discernible toxicological danger from Cd or Pb. The results of the health risk assessment indicated that there was no risk to children's health and possible hazards to adults' health.

1. Introduction

Triglycerides, comprised of three fatty acids and glycerol, form fats when solid at 25 °C and oils when liquid. Their diverse physical states reflect variations in molecular structure and play crucial roles in nutrition, cooking, and industrial applications [1,2]. Edible fat and oil are the most important things in our daily life and are known as lipid sources [3]. The importance of vegetable oils is one of the major concerns and research in human nutrition due to their nutritional, organoleptic, heat transfer and rheological properties [4].

* Corresponding author.
E-mail address: ajmmorshed.bcsir@gmail.com (A.J.M. Morshed).

https://doi.org/10.1016/j.heliyon.2024.e37606
Received 21 June 2024; Received in revised form 5 September 2024; Accepted 6 September 2024
Available online 10 September 2024

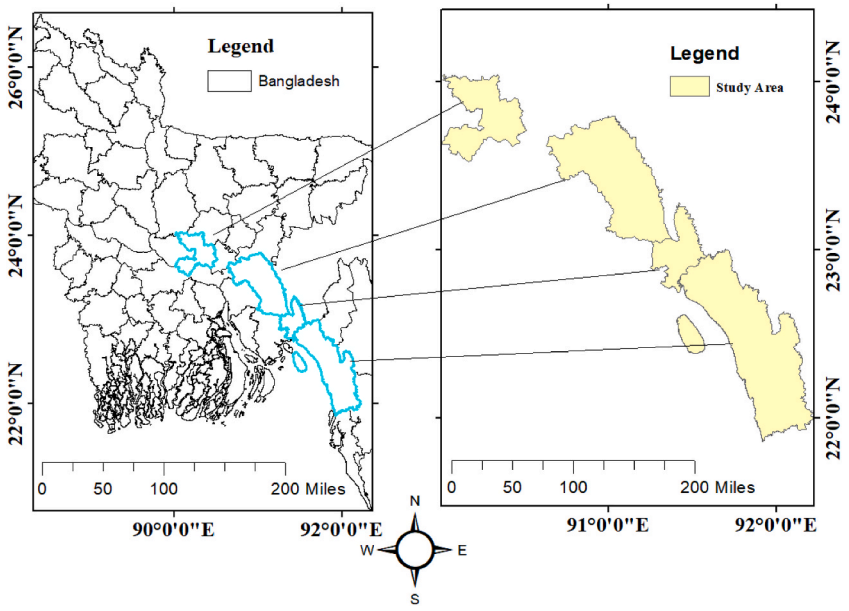

Fig. 1. Study area showing 4 districts of Bangladesh.

They provide vital high-energy fatty acids, including linoleic and linolenic acids, and serve as carriers for fat-soluble vitamins such as A, D, E, and K [5].

Oils and fats also have an important effect and cause metabolic reactions in the human body. 10 % or fewer of calories consumed daily should be from saturated fat and 20–35 % of total daily calories come from polyunsaturated and monounsaturated fats [6]. Small amounts of saturated fat are common in the diet [7]. Various physical and chemical parameters of edible oils have been used to control the blending quality of the oils [8]. A good type of edible fats and oil used for cooking must consider a proven range of physicochemical parameters. Once we understand the properties, we can evaluate the oil for human health, industrial use, etc. Low-density oils are very valuable to consumers [9]. Oils with higher moisture content can be used for food texturing, baking, and frying and industrially in manufacturing soaps, detergents, cosmetics, and oil paints [10]. The higher the saponification values, the shorter the average chain length of the fatty acids, and the lower the average molecular weight of the fatty acids and vice versa [11]. The examination of peroxide value reveals the quality and stability of fats and oils, reflecting rancidity reactions during storage. Elevated peroxide values signify increased rancidity, indicating higher oxidation levels in fats and oils [10]. A higher acid value indicates that triglycerides of fats and oils are converted into fatty acids and glycerol which cause rancidity of the oil [12]. Therefore, the cooking fats and oils must have lower acid values otherwise the fat or oil can damage human health. The iodine value measures the degree of unsaturation in a fat or vegetable oil. Higher unsaturation indicates a greater possibility of the fats and oils going rancid [13]. Some Scientists have examined the physicochemical parameters to determine the quality and functionality of the fats and oils [14–16]. Certain metals often produce deleterious effects when present in edible fats and oils [17]. The presence of metals in vegetable oils depends on so many factors: they could originate from the soil, fertilizers, and the presence of industry or highways near the plantations, and be incorporated into the oil [18]. Metals can enter oil during various production processes like refining, bleaching, and deodorization, or from contaminated equipment. To ensure safety, trace metal levels should be minimized using chelating agents at different stages [19]. Potentially toxic elements are persistent, do not decompose in the environment, and are magnified biologically through the ecological food chain [20–22]. These metals bioaccumulate at the primary producer level and are then finally transported to the consumer level by their consumption [23,24]. Elevated levels of trace metals such as Ni, Pb, Cd, Fe, and Cu accelerate oil oxidation and pose toxicity risks [25]. Few metals are integral to biological molecules, such as iron (Fe) in hemoglobin, which is essential for oxygen transport. In contrast, many toxicelements like mercury (Hg) and chromium (Cr(VI)) are non-essential and toxic, posing significant health risks by binding to substrates and creating imbalances in biological systems [26,27]. Lead, arsenic, and cadmium cause gastrointestinal issues, tremors, hemoglobinuria, ataxia, paralysis, vomiting, and pneumonia. Toxic metal effects include acute or chronic toxicity, carcinogenicity, mutagenicity, and neurotoxicity [28].

Research literature examining toxic elements in various vegetable oils was reviewed. Over 25 toxic elements were assessed in 35 different oils from 24 countries [29]. Recently adulterated edible oils are marketed as highly purified oils in Bangladesh. Therefore, determining the physicochemical properties of edible fats and oil is important to maintain the quality of various processed foods. In Bangladesh, despite extensive research on toxic metals & Polycyclic Aromatic Hydrocarbons (PAHs) in sediments [30,31], water [32–34], and fish [35], and there has been some research on potentially toxic elements in only soybean oil [36]. Different kind of food preservatives (benzoate, sorbate, paraben) recently reported in different food items in Bangladesh [37]. A comprehensive study encompassing all available edible fats and oils in the local market is still needed. A notable research gap exists concerning the long-term health implications of chronic exposure to trace amounts of toxic elements through regular consumption of edible fats and

oils. Limited research on toxic elements accumulation mechanisms during oil processing and packaging exists, with a need for a comprehensive investigation into the potential synergistic or antagonistic effects of multiple toxic elements in edible fats and oils. Understanding their bioavailability and pathways is crucial for consumer safety. Addressing these gaps, the current study can provide valuable insights into risk assessment and regulatory measures to minimize toxic elements contamination in all available edible fats and oils at the local market. The present study aims to qualitatively analyze the properties of soybean, mustard oil, ghee (clarified butter), and dalda (hydrogenated vegetable cooking oil) and assess toxic elements of different types of edible fats and oils with human health risk analysis.

2. Materials and methods

2.1. Sample collection

A total of 30 different types of edible fats and oils such as soybean oil, mustard oil, ghee, and dalda, were collected from different local markets such as Dhaka, Chattogram, Cumilla, and Feni (Fig. 1). Among them, 10 were soybean oil, 10 were mustard oil, 5 were ghee, and 5 were dalda.

2.2. Sample analysis

All the analyses were performed using the standard methods of oil analysis by AOAC, [38]. Iodine value was determined by following the Hanus method [39].

2.2.1. Moisture content (MC)

Water is present in most edible fats and oils. The decrease in mass of the sample on heating at 105 ± 10 °C under operating conditions (Moisture machine: MAC-50, RADWAG, Poland) specified for oils and fats is moisture content.

$$\text{Moisture Content } (\%) = \frac{W_1 \times W_2}{W_1} \times 100$$

where W_1 is the weight (g) of the sample before drying and W_2 is the weight (g) of the sample after drying.

2.2.2. Density

Density (ρ) is the main physical property of matter. For a homogeneous object, it is defined as the ratio of its mass (m) to its volume (V)

$$\text{Density } (\rho) = \frac{Mass(m)}{Volume(v)}$$

2.2.3. Specific gravity (SG)

The formula for specific gravity, given that the reference substance is water, is the density of the object divided by the density of the water. Here, a Greek symbol called Rho is used to indicate density.

$$\text{Specific gravity} = \frac{(\text{Density of the Object})}{(\text{Density of Water})}$$

2.2.4. Acid value (AV)

Acid value of the oil sample was determined by the titrimetric method. About 2–3 g of each oil sample was weighed into a 250 mL Erlenmeyer flask, 50 mL 95 % ethanol was added, and shaken well to dissolve the sample. The sample solution was boiled with a reflux condenser to dissolve the oil or fat completely. Then the conical flask containing the sample was cooled. Then 0.5 mL of 1 % phenolphthalein indicator was added to it. The sample was titrated against 0.1N KOH until a permanent light pink color appeared.

$$\text{Then, the Acid value } (\text{mg KOH / g}) = \frac{56.1 \times (S - B) \times N}{W}$$

where S= Volume of potassium hydroxide used for sample titration,

B = volume of potassium hydroxide required by blank titration,
N= Normality of the potassium hydroxide solution or Sodium hydroxide solution,
W= Weight in g of the sample.
Under the same conditions, a blank experiment was carried out.

2.2.5. Saponification value (SV)

About 1.0–2.0 g of sample was taken into a 250 mL conical flask. A 20 mL of 2 % alcoholic potassium hydroxide was added, and a reflux condenser was attached to the flask. The flask was gently heated, and occasionally shaking, while adjusting the heat so that the

refluxing alcohol/ethanol would not reach the top of the condenser. After heating for 30 min until it became homogeneous, the flask was then immediately cooled. The solution was then titrated with 0.5 N HCl using a phenolphthalein indicator. A blank test was also performed without a sample, following the same steps.

$$\text{Saponification value (mg KOH / g)} = \frac{56.1 \times (B - S) \times N}{W}$$

where B is mL of HCl required by blank,

S is mL of HCl required by the oil sample,
N means Normality of HCl, and
W means Weight (g) of oil.

2.2.6. Iodine value (IV)

The iodine value is a measure of the unsaturation of fats and oils. It is the mass of iodine absorbed in grams by 100 g of oil or fat, depending on the conditions of the test. The iodine value (IV) was determined following the Hanus method. In this method, approximately 0.3 g (5–8 drops) of the oil sample and 10 mL of chloroform (99.8 %, Honeywell, Germany) were added to a 12 mL of Hanus (Merck, Germany) solution in a well-stoppered conical iodine flask. The mixture was left to stand for 30 min to allow complete reaction between the iodine and the unsaturated bonds in the oils.

$$\text{Iodine value (g I2 / 100g oil)} = \frac{(V_2 - V_1) \times N \times 0.127 \times 100}{W}$$

where V_2 = ml of 0.1N Na2S2O3 required for blank titration, V_1 = ml of 0.1N Na2S2O3 required for sample, N= Strength of Na2S2O3 solution, and W= Weight (g) of oil sample.

2.2.7. Peroxide value (PO)

An important parameter specifies the content of oxygen as peroxides, especially hydroperoxides, in a substance. The peroxide value is defined as the amount of peroxide oxygen per 1 kg of fat or oil. To determine the peroxide value, approximately 5 g of the sample were mixed with a 3:2 solvent mixture of acetic acid (99 %, Merck, Germany) chloroform (30 mL), and 1 mL of saturated KI (Emsure, Germany) solution. The mixture was then titrated with 0.01 N sodium thiosulfate solution (99 %, Merck, Germany) using 1 mL of starch solution as an indicator. The peroxide value can be estimated using the following equation:

$$\text{Peroxide value} = \frac{(S - B) \times N \times 1000}{W}$$

where S is the quantity of sodium thiosulphate required for the sample,

B is the quantity of sodium thiosulphate required for blank,
N is the normality of sodium thiosulphate, and
W is the weight of the sample.

2.2.8. Determination of trace metals and quality control

Analytical-grade chemicals were used in sample digestion. 1 g of each sample was accurately weighed using an analytical balance and transferred into a 250 mL conical flask. Then, 10 mL of the acid digestion mixture (perchloric (70 %, Emsure, Germany), nitric (65 %, Emsure, Germany), and sulfuric acids (95–97 %, Emsure, Germany) in a 1:2:2 ratio) was added. The mixture was heated on a hot plate in a fume hood until it turned colorless, indicating complete digestion. The digested sample was then cooled, 20 mL of distilled water was added, and filtered using an ash-less Whatman filter paper into a 100 mL volumetric flask. Finally, distilled water was added to bring the volume to the mark. Analysis of all digested samples was performed using Atomic Absorption Spectrophotometer (AAS) (Thermo Scientific, iCE 3000, USA). The results of the calibration curve value indicated correlation coefficient (r^2) for all metals was greater than 0.99856. The soundness of the analytical procedure was further reinforced by performing spike samples and obtaining recoveries. The analytical results were compared using replicate analysis. Furthermore, a reagent blank was analyzed after every five samples, and a standard solution was measured after every ten samples.

2.3. Statistical analysis

OriginPro (version 9.0) and SigmaPlot (version 14.0) were used to construct graphs and ArcMap (version 10.8) was used to demonstrate the study area map. Microsoft Excel (version 2016) was used to calculate average, standard deviation, and human health risk. Limit of Detection (LOD) of iron, manganese, nickel, lead, cadmium, copper, and cobalt were 0.02 mg/L, 0.01 mg/L, 0.01 mg/L, 0.01 mg/L, 0.002 mg/L, 0.03 mg/L, and 0.01 mg/L, respectively. For example, in the case of iron (Fe), the standard deviation was 0.00666, so the value of LOD is SD × 3 = 0.02 where multiplying factor 3 is called the t-value. A significance level of 5 % was pre-determined before initiating the analyses. A probability-probability p-p plot statistical approach was used to evaluate the dataset's normality. Using this technique, one may see how data points are distributed and ascertain whether or not they follow a normal

distribution. Values below the LOD were adjusted to half of the LOD before statistical analyses were performed [40]. The differences in the amounts of the seven toxic metals among the four different types of fats and oils were investigated using Kruskal–Wallis one-way analysis of variance testing. When neither the homogeneity of variance nor the normality of distribution is satisfied, this non-parametric test can be used to compare many groups. Risk assessment uncertainty is an ingrained element that must be considered since risk assessment entails evaluating prospective dangers based on known facts, human attributes, environmental unpredictability, and lack of accuracy [41–43]. In this investigation, Monte Carlo Simulation has been performed on probabilistic carcinogenic risk associated with Pb, and Ni using RStudio. With three percentile (5th, 50th & 95th) cut points and 10,000 iterations, this approach ensures numerical stability.

2.4. Health risk assessment

2.4.1. Estimated daily intake (EDI)

To determine the average daily loading of metal into the body system of a consumer with a certain body weight, the EDI was evaluated. Estimated daily intakes (EDIs) for toxic metals were calculated using the following formula:

$$\mathrm{EDI} = \frac{FIR \times CM}{WAB}$$

where FIR is the rate of food ingestion, CM is the metal concentration in the sample (mg/kg ww), and WAB is the average body weight (70 kg for adults). Metal concentration in the sample was obtained on the basis of wet weight (ww). As there is study done on the daily intake of soyabean oil, mustard oil, dalda and ghee, we built a hypothesis that daily intake of those four groups were 40 mL, 35 mL, 5 g, and 10 g.

2.4.2. Target hazard quotient (THQ)

Using the basic assumption for integrated risk analysis, the Target Hazard Quotient (THQ) may be computed to estimate the risk level of non-carcinogenic exposure to pollutants. THQ is the ratio of a trace metal's anticipated exposure to the reference dose, below which no significant danger exists. Using the Region III Risk-Based Concentration Table [44], the target hazard quotient for Pb, Co, Cu, Cd, Mn, Fe, and Ni in collected sample was determined in this study. This equation was utilized to estimate THQ:

$$\mathrm{THQ} = \frac{EF \times ED \times FIR \times CM}{RfD \times WAB \times ATN} \times 10^{-3}$$

where EF is the exposure frequency (365 days per year), ED is the exposure duration (30 years for non-cancer risk as defined by USEPA [44] and THQ is the target hazard quotient. Food Ingestion Rate (FIR); toxic metal concentration (CM) is mg/kg; average body weight (WAB) is 70 kg; average exposure time (ATN) is 365 days/year for 30 years (ATN = 10,950 days) as used in EF × ED (EF × ED) calculations used to characterize non-cancer risk [44]; reference dose (RfD) is the amount of metal (an estimate of the daily exposure to which the human population may be continuously exposed over a lifetime without a significant risk of adverse effects).

2.4.3. Hazard index (HI)

The sum of each THQ is used to calculate the Hazard index, which is the cumulative effect of a person's exposure to several toxicants [35,45]. The following equation was utilized to determine the Hazard Index (HI) based on THQ values.

$$\mathrm{HI} = (\mathrm{THQ}_{\mathrm{contaminats1}} + \mathrm{THQ}_{\mathrm{contaminats2}} + \mathrm{THQ}_{\mathrm{contaminats3}} + \ldots + \mathrm{THQ}_{\mathrm{contaminatsn}})$$

where THQ stands for Target Hazard Quotient (of each metal) and HI stands for Hazard Index (unitless). The sum of all THQ is known as HI. An estimate of this parameter was created for each sample.

2.4.4. Cancer risk (TR)

The carcinogenic risk associated with toxic metal was expressed as TR in this study. For carcinogens having accessible cancer risk values, the cancer risk (TR) was computed. The USEPA Region III Risk-Based Concentration Table [46] was used to estimate the values. The following formula was utilized to estimate TR:

$$\mathrm{TR} = \frac{EF \times ED \times FIR \times CM \times Cfo}{WAB \times ATN} \times 10^{-3}$$

whereas CM is the metal concentration in sample (mg/kg), food ingestion rate (FIR) for adults (70 kg) is 40 mL, 35 mL, 5 g and 10 g for soyabean oil, mustard oil, dalda and ghee and for children (21 kg) is half amount of adult, TR is the target cancer risk, EF is the exposure frequency (365 days/year), and ED is the exposure duration for adult (30 years) and children (6 years) [47]. ATN is the average duration of exposure to carcinogens (365 days/year for 70 years, as used by USEPA [46] WAB is the average body weight, and Cfo is the carcinogenic potency slope, oral (mg/kg bw/day). The study employed Cfo values of 3.8, 8.5×10^{-3}, and 1.7 for Cd, Pb, and Ni, respectively [46].

Table 1
Physicochemical parameters of edible oils and fats.

Sample	MC (%)	Density (g/ml)	Specific gravity	AV mg KOH/g	SV mg KOH/g	IV g/100g	PV meq/kg
S_1	0.140	0.910	0.930	0.270	188	85.3	4.51
S_2	0.180	0.900	0.920	0.830	187	86.3	4.16
S_3	0.480	0.910	0.920	0.770	186	77.0	5.32
S_4	0.260	0.910	0.930	0.420	185	84.9	7.72
S_5	0.120	0.910	0.930	0.35	194	86.3	6.98
S_6	0.220	0.900	0.920	0.250	189	77.6	10.4
S_7	0.170	0.900	0.920	0.770	194	86.2	8.08
S_8	0.130	0.890	0.910	0.480	184	80.3	11.1
S_9	0.210	0.900	0.920	0.230	187	89.1	13.2
S_{10}	0.140	0.900	0.920	0.220	191	68.2	13.3
M_1	0.470	0.900	0.920	1.31	179	92.1	6.05
M_2	o.430	0.890	0.900	1.23	174	101	6.55
M_3	0.580	0.890	0.910	1.72	174	89.7	5.89
M_4	0.260	0.890	0.900	0.630	167	88.4	1.97
M_5	0.470	0.880	0.900	1.92	175	99.9	5.51
M_6	0.760	0.900	0.920	1.83	175	104	8.01
M_7	0.530	0.900	0.920	1.29	184	91.9	13.4
M_8	0.440	0.890	0.910	1.23	172	96.2	13.8
M_9	0.410	0.890	0.910	1.74	182	100	11.2
M_{10}	0.520	0.890	0.910	2.45	178	91.0	5.70
G_1	0.530	0.910	0.920	1.31	215	40.4	1.27
G_2	0.430	0.910	0.930	1.09	213	40.8	1.23
G_3	0.350	0.900	0.910	0.630	213	53.6	1.38
G_4	0.360	0.891	0.910	0.690	204	49.9	2.63
G_5	0.460	0.900	0.920	1.14	224	36.9	1.32
D_1	0.170	0.920	0.940	0.830	198	37.1	12.2
D_2	0.180	0.940	0.960	0.830	193	40.5	18.6
D_3	0.190	0.930	0.950	0.530	195	39.4	18.7
D_4	0.240	0.950	0.960	0.900	195	42.3	20.6
D_5	0.350	0.930	0.950	0.280	196	42.0	21.7

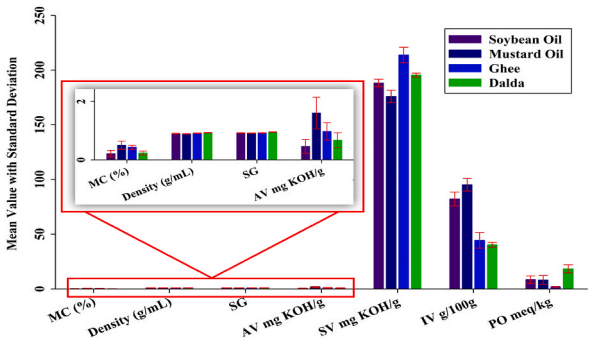

Fig. 2. Physicochemical properties (average ± SD) of different edible fats and oils (MC= Moisture Content, SG= Specific Gravity, AV=Acid Value, SV= Saponification Value, IV= Iodine Value, PO= Peroxide Value).

3. Result and discussion

3.1. Physicochemical parameters of edible fats and oils

Physicochemical parameters are summarized in Table 1. The moisture in fats and oils can cause rancidity and foul smells, affecting flavor. Ranges of moisture content were noted for soybean oil (0.120–0.480 %), mustard oil (0.260–0.760 %), ghee (0.350–0.530 %), and dalda (0.170–0.350 %). Precise extraction and good preservation are essential to keep soybean oil at the recommended moisture levels of 0.200–0.300 % [48–50]. Increased moisture levels can intensify off-flavors and free fatty acids [51]. At 0.490 %, mustard oil had the greatest moisture content. Higher moisture content oils are preferred for industrial uses, baking, frying, and texturizing food [52]. The composition of fats and oils, especially the types and quantity of fatty acids they contain, affects their density. From the data for soybean oil, the range was 0.890–0.910 g/mL; for mustard oil, it was 0.880–0.900 g/mL; for ghee, it was 0.890–0.910 g/mL; and for dalda, it was 0.920–0.950 g/mL of oil at 30 °C. Dalda had a mean density of 0.930 g/mL, which was the highest. These densities are within the 0.860–0.920 g/mL [53]. Understanding the density of fats and oils helps in ensuring the quality, safety, and efficiency of

Table 2
Trace metal concentration of different edible fats and oils.

	No. of samples	Fe	Mn	Ni	Pb	Cd	Cu	Co
Soybean oils	S_1	2.70	0.270	1.53	0.380	<BDL	1.15	0.940
	S_2	35.9	0.300	3.50	0.040	<BDL	2.88	2.24
	S_3	2.00	1.92	13.0	0.160	<BDL	1.82	8.16
	S_4	13.1	0.680	10.1	1.87	<BDL	3.98	6.65
	S_5	0.080	0.940	5.42	1.44	<BDL	4.63	3.36
	S_6	4.38	0.660	0.760	0.240	<BDL	0.680	0.430
	S_7	12.5	0.220	6.26	1.78	<BDL	1.74	3.39
	S_8	5.99	0.180	6.19	0.050	<BDL	1.61	3.58
	S_9	5.75	0.440	7.70	0.330	<BDL	1.86	4.63
	S_{10}	1.73	1.16	4.33	<BDL	<BDL	1.65	2.76
Mustard oils	M_1	2.49	0.160	5.71	<BDL	<BDL	3.00	3.87
	M_2	9.37	1.69	10.9	<BDL	<BDL	4.18	7.26
	M_3	10.7	1.62	0.550	<BDL	<BDL	1.22	0.100
	M_4	0.270	0.440	1.22	<BDL	<BDL	0.770	0.770
	M_5	5.26	0.880	1.19	<BDL	<BDL	1.13	0.730
	M_6	26.9	1.48	11.3	0.490	<BDL	0.730	5.27
	M_7	5.00	0.590	5.95	<BDL	<BDL	2.63	2.66
	M_8	10.4	0.120	1.83	<BDL	<BDL	2.10	0.880
	M_9	3.26	1.24	2.67	<BDL	<BDL	1.78	0.910
	M_{10}	24.6	0.630	8.02	0.73	<BDL	0.020	2.47
Ghee	G_1	12.7	1.55	4.69	<BDL	<BDL	0.310	2.95
	G_2	8.52	1.93	7.04	0.490	<BDL	1.37	4.36
	G_3	6.84	0.870	0.740	<BDL	<BDL	1.85	0.190
	G_4	0.810	2.41	7.59	0.640	<BDL	1.44	4.78
	G_5	5.72	2.45	7.64	0.050	<BDL	1.23	4.84
Dalda	D_1	36.9	1.66	10.4	0.290	<BDL	0.230	3.56
	D_2	39.0	2.34	16.3	0.680	<BDL	0.190	8.40
	D_3	22.5	0.150	10.3	<BDL	<BDL	0.360	3.22
	D_4	47.0	0.150	27.1	<BDL	<BDL	2.12	1.26
	D_5	6.45	0.730	1.07	<BDL	<BDL	0.090	1.10

various industrial processes and consumer products.

The most important parameter of specific gravity was conducted at 30 °C of temperature. The specific gravities of the oils varied from 0.910 to 0.930 for soybean oil, 0.900–0.920 for mustard oil, 0.908–0.928 for ghee, and 0.940–0.960 for dalda at 30 °C. From the results shown in Fig. 2, dalda (D4) had the highest specific gravity of 0.960 g/mL, while mustard oil (M5) had the lowest specific gravity of 0.900 g/mL. The majority of samples fall below the 0.910–0.920 g/cm^3 acceptable range [54]. Mustard oil had the lowest average specific gravity (0.910) and dalda the highest (0.950). contributes π-bonds in dalada may contribute to its increased density by making it stiffer and preventing C-C bond rotation [55]. High Specific Gravity can be associated with higher unsaturation, longer fatty acid chains, increased free fatty acids, and oxidation products. Low Specific Gravity is linked to higher saturation, shorter fatty acid chains, and lower molecular weight triglycerides.

The acid value of oil, which represents free fatty acids, indicates its quality; larger levels indicate lesser quality and possible rancidity [56]. For soybean oil, 0.220–0.830 mg KOH/g, mustard oil, 0.630–2.450 mg KOH/g, ghee, 0.630–1.31 mg KOH/g, and dalda, 0.280–0.900 mg KOH/g were the acid values. 0.600 mg KOH/g is the maximum that is advised [57,58]. In terms of average acid value, soybean oil had the lowest (0.410 mg KOH/g), within the recommended range, while mustard oil had the highest (1.54 mg KOH/g), surpassing the limit. By turning triglycerides into fatty acids and glycerol, higher acid values signify rancidity and low quality. It was observed from this experiment that the average SV value (214 mg KOH/g) was in ghee and (176 mg KOH/g) was in mustard oil. The SV of almost all the mustard oils was observed within the range of 170–178 mgKOH/g [59]. The mean SV value for ghee was found within the range of 210–250 mg KOH/g [51]. The results of SV in soybean oil range from 184 to 194 mg KOH/g and the ranges from 194-198 mg KOH/g was observed for dalda. Low SV value (higher fatty acid average length) indicating not suitable for soap making. High saponification values suggest the presence of shorter-chain fatty acids, while lower values indicate longer-chain fatty acids [60].

The iodine value (IV) is a vital parameter in assessing the degree of unsaturation in fats and oils. It measures the amount of iodine, in grams, that is absorbed by 100 g of fat or oil, reflecting the presence of double bonds in the fatty acid chains. The iodine value was observed in the ranges of 68.2–89.1 g/100 g for soybean oil, 88.4–104 g/100 g for mustard oils, 37–53.6 g/100 g for ghee, and 37.1–42.3 g/100 g for dalda. According to BSTI specification and Bangladesh standards, the Iodine value requirement for soybean oil is 120–143 [57]. Iodine value ranges from 68.2 to 89.1 g/100 g for soybean oil, and 88.5–104 g/100 g for mustard oils below the recommended limit. Low IV value in oils implies that the sample may be blended with other less unsaturated and cheap vegetable oil. The peroxide value (PO), which represents fats and oils' propensity to get rancid, is a crucial measure of their acidity and oxidation. The result tabulated in Table 1 showed the range of peroxide value was between 4.16 and 13.3 meq/kg for soybean oils, 1.97–13.7 meq/kg for mustard oil, 1.23–2.63 meq/kg for ghee and 12.2–21.7 meq/kg for dalda. Superior quality and stability are indicated by lower PO values. The required limitations are met by the mean PO values of ghee, soybean oil, and mustard oil; however, the mean PO values of dalda are exceeded, indicating a greater vulnerability to rancidity. PO rises with oxygen and light exposure during storage, which lowers quality [51,61]. Hierarchical Cluster Analysis (HCA) of physicochemical properties of edible fats and oils was performed

Table 3
Showing EDI & THQ.

Descripti on	Sample ID	Estimated Daily Intake (EDI)						Target Hazard Quotient (THQ)					
		Fe	Mn	Ni	Pb	Cu	Co	Fe	Mn	Ni	Pb	Cu	Co
Soyabea n Oil	S1	1.54	0.160	0.870	0.220	0.660	0.530	0.000	0.000	0.040	0.060	0.020	**1.78**[a]
	S2	20.5	0.170	2.00	0.020	1.65	1.28	0.030	0.000	0.100	0.010	0.040	**4.26**[a]
	S3	1.14	1.10	7.45	0.090	1.04	4.66	0.000	0.010	0.370	0.030	0.030	**15.6**[a]
	S4	7.47	0.390	5.75	1.07	2.27	3.80	0.010	0.000	0.290	0.310	0.060	**12.7**[a]
	S5	0.050	0.540	3.10	0.820	2.65	1.92	0.000	0.000	0.150	0.240	0.070	**6.41**[a]
	S6	2.50	0.380	0.430	0.130	0.390	0.240	0.000	0.000	0.020	0.040	0.010	0.810
	S7	7.15	0.120	3.57	1.02	0.990	1.94	0.010	0.000	0.180	0.290	0.020	**6.45**[a]
	S8	3.42	0.100	3.54	0.030	0.920	2.05	0.000	0.000	0.180	0.010	0.020	**6.82**[a]
	S9	3.28	0.250	4.40	0.190	1.06	2.65	0.000	0.000	0.220	0.050	0.030	**8.82**[a]
	S10	0.990	0.660	2.48	0.000	0.940	1.57	0.000	0.000	0.120	0.000	0.020	**5.25**[a]
Mustard Oil	M1	1.24	0.080	0.300	0.000	1.50	1.94	0.000	0.000	0.140	0.000	0.040	**6.45**[a]
	M2	4.69	0.840	0.570	0.000	2.09	3.63	0.010	0.010	0.270	0.000	0.050	**12.1**[a]
	M3	5.35	0.810	0.030	0.000	0.610	0.050	0.010	0.010	0.010	0.000	0.020	0.170
	M4	0.130	0.220	0.060	0.000	0.380	0.390	0.000	0.000	0.030	0.000	0.010	**1.29**[a]
	M5	2.63	0.440	0.060	0.000	0.560	0.360	0.000	0.000	0.030	0.000	0.010	**1.21**[a]
	M6	13.4	0.740	0.590	0.240	0.360	2.63	0.020	0.010	0.280	0.070	0.010	**8.78**[a]
	M7	2.50	0.300	0.310	0.000	1.32	1.33	0.000	0.000	0.150	0.000	0.030	**4.44**[a]
	M8	5.21	0.060	0.100	0.000	1.05	0.440	0.010	0.000	0.050	0.000	0.030	**1.47**[a]
	M9	1.63	0.620	0.140	0.000	0.890	0.460	0.000	0.000	0.070	0.000	0.020	**1.52**[a]
	M10	12.3	0.320	0.420	0.370	0.010	1.24	0.020	0.000	0.200	0.100	0.000	**4.12**[a]
Dalda	G1	0.900	0.110	0.330	0.000	0.020	0.210	0.000	0.000	0.020	0.000	0.000	0.700
	G2	0.610	0.140	0.500	0.030	0.100	0.310	0.000	0.000	0.030	0.010	0.000	**1.04**[a]
	G3	0.490	0.060	0.050	0.000	0.130	0.010	0.000	0.000	0.000	0.000	0.000	0.050
	G4	0.060	0.170	0.540	0.050	0.100	0.340	0.000	0.000	0.030	0.010	0.000	**1.14**[a]
	G5	0.410	0.170	0.550	0.000	0.090	0.350	0.000	0.000	0.030	0.000	0.000	**1.15**[a]
Ghee	D1	5.27	0.240	1.49	0.040	0.030	0.510	0.010	0.000	0.070	0.010	0.000	**1.69**[a]
	D2	5.58	0.330	2.33	0.100	0.030	1.20	0.010	0.000	0.120	0.030	0.000	**4.00**[a]
	D3	3.22	0.020	1.47	0.000	0.050	0.460	0.000	0.000	0.070	0.000	0.000	**1.53**[a]
	D4	6.72	0.020	3.87	0.000	0.300	0.180	0.010	0.000	0.190	0.000	0.010	0.600
	D5	0.920	0.100	0.150	0.000	0.010	0.160	0.000	0.000	0.010	0.000	0.000	0.520

[a]Bold values = THQ>1.

Table 4
Showing different standard for edible oils.

Trace Metals	Codex	GB/T23347-2021 (China)	RD 308/1983 (Spain)	BDS Standard, 1979
Pb	0.100	NC	0.100	0.100
Cu	NC	≤0.100	0.400	0.100
Fe	NC	≤3.00	10.0	1.500
Ni	NC	NC	NC	0.100
Mn	NC	NC	NC	0.100

*NC=Not Considered.

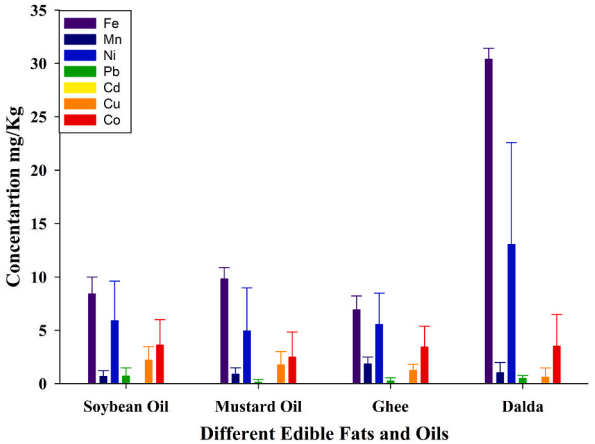

Fig. 3. Average concentration of trace metals with standard deviation.

to investigate (Euclidean Distance and Single Linkage Method) if there was any similarity pattern in the values of different physico-chemical variables. Fig. 6a shows associations between the different metal variables analyzed. It demonstrated major clusters MC/AV/IV and Density/SG/PV/SV. These two clusters are very similar in their pattern. In the case of physicochemical parameters, all parameters were significantly ($p < 0.05$) different from each other.

3.2. Trace metals in different edible fats and oils

Metal concentrations in edible oils were found between 0.080 and 35.9, 0.12.0–1.91, 0.540–13.0, 0.040–1.87, 0.020–4.63, and 0.090–7.26 ppm for Iron, Manganese, Nickel, Lead, Copper, and Cobalt respectively. The concentration of toxic elements in edible fats was observed to range from 0.810 to 47.0 ppm, 0.140–2.44 ppm, 0.730–27.1 ppm, 0.040–0.680 ppm, 0.080–2.12 ppm, 0.190–8.39 ppm for Fe, Mn, Ni, Pb, Cu, and Co respectively (Table 2). The approved contents of these metals in oils are 0.100 mg/kg for Cu & Pb, 1.00–1.50 mg/kg for Fe, 0.200 mg/kg for Ni, and 0.050 mg/kg for Cd [62]. Different standards of Maximum Permissible Limit (MPL) of trace metals are summarized in Table 4.

The results in Fig. 3 show the concentration of trace metals in different types of edible fats and oils. The lowest iron content (0.070 ppm) was observed in S_5 soybean oil while the highest iron concentration (35.9 ppm) was observed in S_2 soybean oil. According to the national and international standards for Fats and Oils, the approved iron content in vegetable oils and fats is 1.00–1.50 ppm [29]. Iron concentration in our investigated edible oil samples was higher than the range of the approved limits. An adequate amount of iron is necessary for our diet to decrease the occurrence of anemia [63]. If we intake excess amount of Iron then liver, heart and pancreas can be affected [64]. The presence of iron content in commercially available edible oils and ghee samples may be due to the reaction between the relatively high-unsaturated portion of the oil with the surface of iron containers to be used during transportation, storage, and processing of oils and fats or due to natural sources.

The lowest concentration of manganese (0.120 ppm) was found in mustard oil (M_8) and the highest concentration (2.45 ppm) in ghee (G_5). Manganese concentrations were reported in the literature as 0.100 mg/kg [65]. In this investigation, the ranges of manganese were found between those demonstrated in the literature. Manganese is an essential element since they plays an important role in biological systems. Manganese deficiency can produce severe skeletal and reproductive abnormalities in mammals. High doses of manganese produce adverse effects totally on the lungs and on the brain [66]. The amount of Manganese in our research can come in oils and fats through several pathways, including Plants absorb manganese from the soil and it can accumulate in their tissues, including the seeds and fruits from which oils are extracted, During the processing of oils and fats, manganese can be introduced through equipment, water, or other materials used in the extraction and refining processes, Manganese-containing fertilizers or pesticides can lead to the accumulation of manganese in plants e.t oils and fats. This research can help in monitoring and controlling the manganese content in oils and fats to ensure they meet safety and quality standards.

The amount of nickel content may be beneficial as an activator of some enzymes but its toxicity is more prominent at a higher level. In this investigation, Nickel contents were found in soybean oils in the range of 0.760–13.0 ppm which was lower than found in the literature 0.320–18.5 mg/kg [36]. In the case of mustard oil, nickel content ranges from 0.540 to 11.3 ppm which was higher than found in the literature (0.030-0-060 ppm) for mustard oil [67]. Overall, the minimum nickel concentration was found in mustard oil (average 4.93 ppm) and the maximum nickel concentration (average 13.0 ppm) was found in the hydrogenated oil D_4 sample because nickel was used as a hardening or hydrogenating agent for the conversion of glycerides of unsaturated fatty acid to saturated fatty acid of another series.

Lead has no important role in human metabolism. It was well known for its chronic and acute poisoning which may lead to failure of the heart, liver, kidney, and immune system. Long-term exposure to such toxic elements also causes cancer [68]. In almost half of the samples, Pb was below the detection limit. In fourteen samples out of thirty, lead was not detected in ppm level. Only two (M_6& M_{10}) out of ten mustard oil lead concentrations were detected. The lowest lead concentration (0.040 ppm) was observed in S_2 soybean oil while the highest lead concentration (1.87 ppm) was observed in S_4 soybean oil shown in Table 2. The reported lead values for oil samples were 0.310–2.35 mg/kg [36] and 0.100 mg/kg [69]. The lead concentration in this studied oils and fat samples was below the limits.

Cadmium may be a highly toxic metal with a natural occurrence in soil, but it's also spread within the environment caused by human activities. Excessive cadmium exposure may produce renal, pulmonary, hepatic, skeletal, and reproductive effects and cancer [70]. In this study, Cd was below the detection limit. That means, there is no toxicological health risk from Cd.

Copper is an essential trace metal known to be both vital and toxic for many biological systems and may enter the food materials from the soil through mineralization by crops, food processing, or environmental contamination, as in the application of agricultural inputs, such as copper-based pesticides which are in common use in farms in some countries [71]. In this study, Copper ranges from 0.680 to 4.63 for soybean oil, 0.020–4.18 for mustard oil, 0.310–1.85 for ghee, and 0.090–2.12 for hydrogenated vegetable cooking oil. We can see, on average the lowest copper levels were in hydrogenated vegetable cooking oil (0.600 ppm) and the highest copper level (2.200 ppm) in soybean oil. National and International Limits of Copper in oil and fat are reported as 0.100–0.400 mg/kg [29]. Copper concentration in our investigated edible oil and fat samples was higher than the range of the approved limits. Cobalt is vital to human life due to the importance of vitamin B-12.

Here Cobalt concentration ranges from 0.430 to 6.65 ppm for soybean oil, 0.100–7.26 ppm for mustard oil, 0.190–4.84 ppm for ghee, and 1.01–8.40 ppm for hydrogenated vegetable cooking oil. This observed data for most of the samples are lower than the literature values which were reported as 0.920–5.45 mg/kg [72].

According to BDS limits, 90 % of samples exceeded the permissible levels for iron (Fe), 93.33 % for copper (Cu), and 43.33 % for lead (Pb). In the cases of manganese (Mn) and nickel (Ni), all samples (100 %) surpassed the BDS limits. 43.33 % of all samples exceed

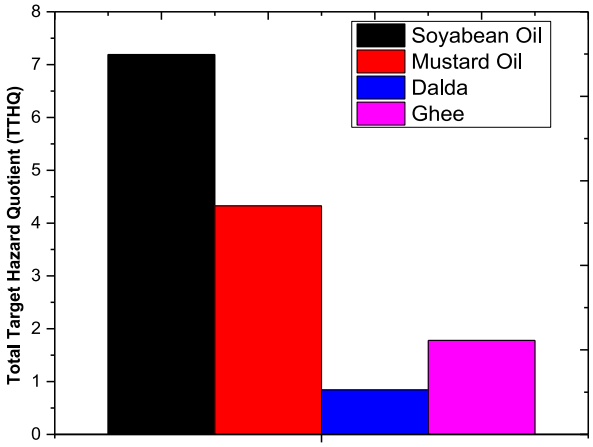

Fig. 4. Total target hazard quotient (TTHQ).

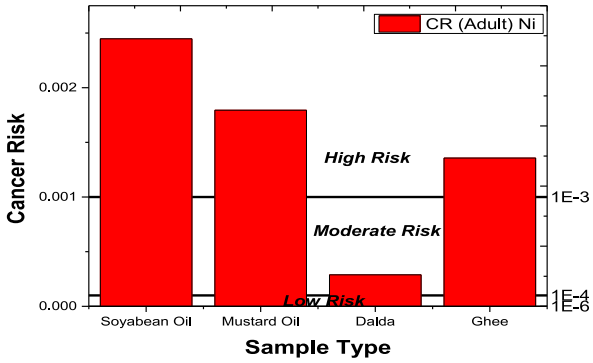

Fig. 5a. Cancer risk of Ni for adults.

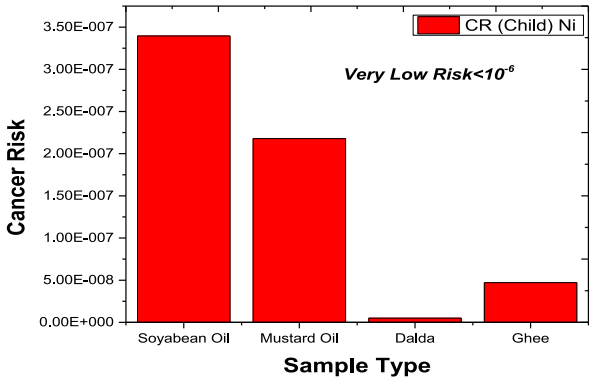

Fig. 5b. Cancer risk of Ni for children.

the codex limit for Pb whereas 10 % of all samples are below the limit. Among all trace metals, the GB (China) standards only consider Fe and Cu. Based on this data, 96 % of all samples exceed the limit for Fe, while 13.33 % exceed the limit for Cu. However, RD 308/1983 (Spain) considers Fe, Pb, and Cu. The findings can be summarized as follows: 40 % of all samples exceed the limit for Fe, 80 % exceed the limit for Cu, and 43.33 % exceed the limit for Pb. Additionally, a few samples (10 %) are below the limit for Pb.

The impact of potentially toxic metals on plant tissues and cells is highly dependent on their concentration levels. At low concentrations, certain potenrially toxic elements like copper (Cu), zinc (Zn), and manganese (Mn) are essential micronutrients, playing crucial roles in various physiological and biochemical processes [73]. However, these metals at elevated concentrations become toxic, leading to oxidative stress, disruption of cellular functions, and damage to cellular structures. High levels of toxic elements such as cadmium (Cd), lead (Pb), and mercury (Hg) can inhibit photosynthesis, respiration, and nutrient absorption, ultimately stunting plant

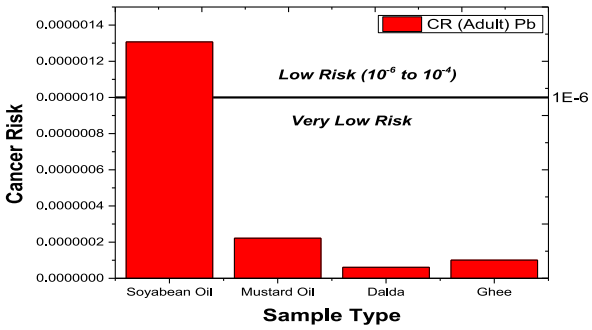

Fig. 5c. Cancer risk of Pb for adults.

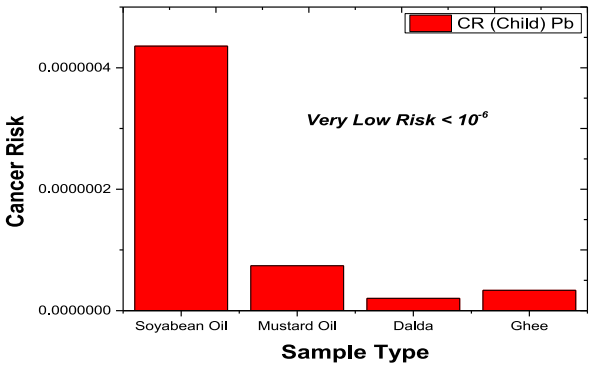

Fig. 5d. Cancer risk of Pb for children.

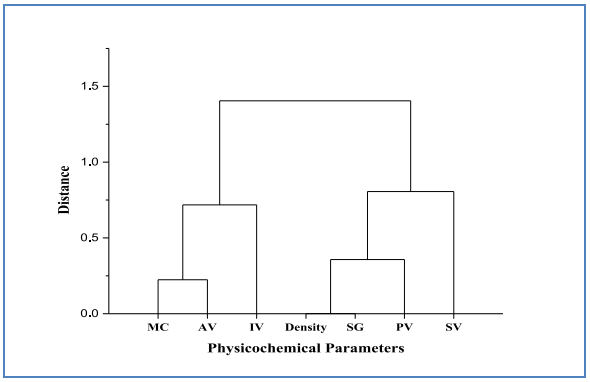

Fig. 6a. Hierarchical cluster analysis (HCA) of physicochemical properties of edible fats and oils; MC= Moisture Content, AV= Acid Value, IV= Iodine Value, SG= Specific Gravity, PV= Peroxide Value, SV= Saponification Value.

growth and reducing biomass [74]. Toxic concentrations induce the generation of reactive oxygen species (ROS), which can cause lipid peroxidation, protein denaturation, and DNA damage [75]. Plants have developed mechanisms such as metal chelation, compartmentalization, and the activation of antioxidant defenses to mitigate these toxic effects. Nonetheless, excessive accumulation of toxic elements can overwhelm these protective systems, leading to cellular damage and impaired physiological functions [76,77]. Only for Pb, Kruskal–Wallis one-way analysis of variance tests showed significant ($p < 0.05$) results. Fig. 6b shows associations between the different metal variables analyzed. It demonstrated three major clusters Pb/Cu, Co/Mn, and Ni/Fe.

3.3. Noncarcinogenic & carcinogenic risk

Estimated Daily Intake (EDI) and Target Hazard Quotient (THQ) are summarized in Table 3. Generally, values of THQ greater than 1 are unacceptable. THQ was less than 1 for Fe, Ni, Cu, Mn, and Pb. Only for Co, THQ was higher than 1. In 90 % of samples of Soyabean oil and mustard oil, THQ crossed 1. In case of dalda and ghee, in 60 % sample THQ happened to be higher than 1. The highest

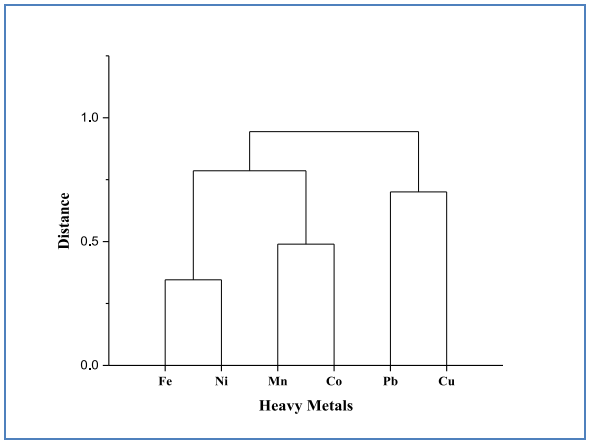

Fig. 6b. Hierarchical cluster analysis (HCA) of metals of edible fats and oils; Fe= Iron, Ni= Nickel, Mn = Manganese, Co= Cobalt, Pb = Lead, Cu= Cupper.

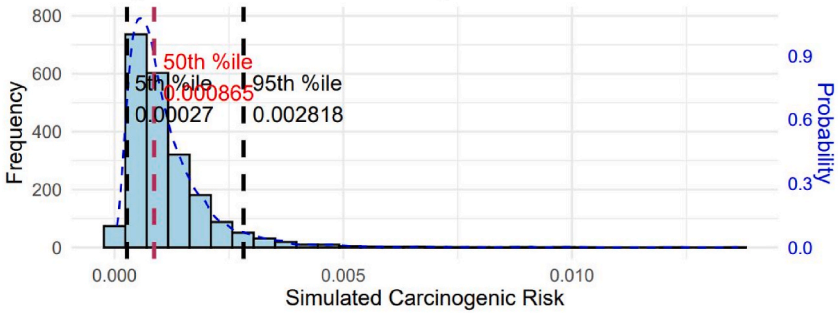

Fig. 7a. Monte Carlo simulation for carcinogenic risk of Ni (adult).

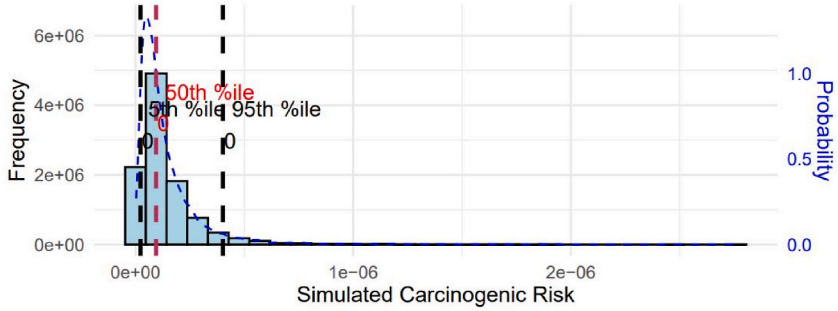

Fig. 7b. Monte Carlo simulation for carcinogenic risk of Ni (child).

average THQ was for soyabean oil and the lowest was for dalda. Cobalt showed maximum THQ and Manganese showed lowest. The total Target Hazard Quotient (TTHQ) is presented in Fig. 4.Target cancer risk is presented in Fig. 5. According to USEPA, the acceptable value range of TR is 10^{-4} to 10^{-6} (low risk). TR values were found in the following order for both adults and children: Soyabean Oil > Mustard Oil > Ghee > Dalda. The average target cancer risk associated with Ni for adults was high for soyabean oil, mustard oil, and ghee whereas cancer risk was moderate for dalda. Cancer risks associated with Pb were negligible for adults. The cancer risk associated with both Ni and Pb for children was found to be very low ($<10^{-6}$) because of less amount of daily intake. The findings of the cancer risk of Pb were similar to a study conducted on imported rice bran oil in Iran [78]. According to the health risk assessment, the examined vegetable oil (Canola & Soyabean) samples did not appear to pose any health risks to adults or children [79]. The Monte Carlo Simulation (MCS) results are presented in Fig. 7. The simulation also indicates a higher risk for adults associated with Nickel and no risk from Lead.

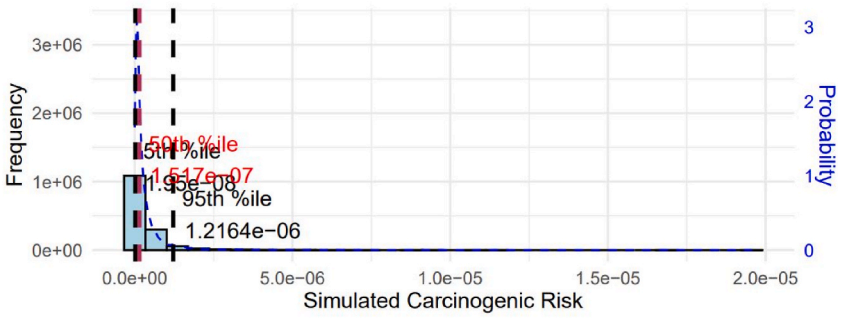

Fig. 7c. Monte Carlo simulation for carcinogenic risk of Pb (adult).

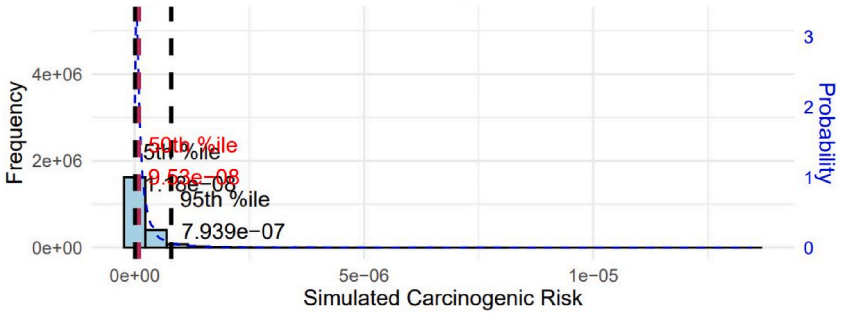

Fig. 7d. Monte Carlo simulation for carcinogenic risk of Pb (child).

4. Conclusion

Analytical characterization and study of potentially toxic elements in different types of soybean oil, mustard oil, ghee, and dalda were investigated in this present study. When consumed in moderation, essential trace metals can be beneficial to humans; when ingested in excess, they can be harmful to the body. The concentration of each element in food and the quantity eaten determine how much of that element is ingested. Although the results of this study suggested that there was no cause for worry regarding the amount of toxic metals in oils and fats for children, Nickel is one of these elements that can hurt human health, particularly in adults, since its TR value is higher the permissible threshold (10–6). This makes regular monitoring and assessment of these oils, fats as well as other edible oils essential. To shield individuals from the non-carcinogenic and carcinogenic consequences of potentially toxic metals, techniques to remove these metals from the body and avoid their excessive buildup in the body should also be taken into consideration. Therefore, understanding this topic is crucial to healthily sustaining our citizen's health.

Data availability

The datasets generated and analyzed during the current study will be available from the corresponding author upon reasonable request.

Ethics approval and consent to participate

Not applicable.

CRediT authorship contribution statement

Md. Samrat Mohay Menul Islam: Writing – review & editing, Writing – original draft, Visualization, Supervision, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Hasina Akter:** Writing – original draft, Investigation, Formal analysis, Data curation. **Md. Hasan Ali:** Writing – review & editing, Visualization. **A.J.M. Morshed:** Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Md. Ashraful Islam:** Writing – review & editing. **Mohammad Helal Uddin:** Investigation, Formal analysis, Data curation. **M.A.A. Shofi Uddin Sarkar:** Investigation, Formal analysis, Data curation. **Md. Nure Alam Siddik:** Validation, Methodology, Investigation, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that there are no financial or non-financial conflicts of interest associated with this research.

Acknowledgment

The authors would like to convey their deepest and heartfelt gratitude to the authority of the Bangladesh Council of Scientific and Industrial Research (BCSIR) for giving permission and providing all the facilities during research work.

References

[1] Q. Xia, Z. Du, D. Lin, L. Huo, L. Qin, W. Wang, L. Qiang, Y. Yao, Y. An, Review on contaminants in edible oil and analytical technologies, Oil Crop Science 6 (2021) 23–27.
[2] A.C. Skulas-Ray, P.W.F. Wilson, W.S. Harris, E.A. Brinton, P.M. Kris-Etherton, C.K. Richter, T.A. Jacobson, M.B. Engler, M. Miller, J.G. Robinson, C.B. Blum, D. Rodriguez-Leyva, S.D. De Ferranti, F.K. Welty, On behalf of the American heart association Council on arteriosclerosis, thrombosis and vascular biology; Council on lifestyle and cardiometabolic health; Council on cardiovascular disease in the young; Council on cardiovascular and stroke nursing; and Council on clinical cardiology, omega-3 fatty acids for the management of hypertriglyceridemia: a science advisory from the American heart association, Circulation 140 (2019), https://doi.org/10.1161/CIR.0000000000000709.
[3] E.-T. Phuah, J.W.-L. Yap, C.-W. Lau, Y.-Y. Lee, T.-K. Tang, Vegetable oils and animal fats: sources, properties and recovery, in: Y.- Ying Lee, T.-K. Tang, E.-T. Phuah, O.-M. Lai (Eds.), Recent Advances in Edible Fats and Oils Technology, Springer Singapore, Singapore, 2022, pp. 1–26, https://doi.org/10.1007/978-981-16-5113-7_1.
[4] A. Kumar, A. Sharma, K. C Upadhyaya, Vegetable oil: nutritional and industrial perspective, Curr. Genom. 17 (2016) 230–240.
[5] M. Ebrahimi, M.A. Rajion, Y.M. Goh, Effects of oils rich in linoleic and α-linolenic acids on fatty acid profile and gene expression in goat meat, Nutrients 6 (2014) 3913–3928.
[6] L.M. Thomas, B.J. Holub, Nutritional aspects of fats and oils, in: B.S. Kamel, Y. Kakuda (Eds.), Technological Advances in Improved and Alternative Sources of Lipids, Springer US, Boston, MA, 1994, pp. 16–49, https://doi.org/10.1007/978-1-4615-2109-9_2.
[7] V.M. Gershuni, Saturated fat: Part of a healthy diet, Curr Nutr Rep 7 (2018) 85–96, https://doi.org/10.1007/s13668-018-0238-x.
[8] F. Hashempour-Baltork, M. Torbati, S. Azadmard-Damirchi, G.P. Savage, Vegetable oil blending: a review of physicochemical, nutritional and health effects, Trends Food Sci. Technol. 57 (2016) 52–58, https://doi.org/10.1016/j.tifs.2016.09.007.
[9] J. Pan, H. Shen, J. You, Y. Luo, Changes in physiochemical properties of myofibrillar protein from silver carp (Hypophthalmichthys mollitrix) during heat treatment: heat treatment study on silver carp myofibrillar protein, J. Food Biochem. 35 (2011) 939–952, https://doi.org/10.1111/j.1745-4514.2010.00431.x.
[10] S. Krist, Introduction, in: S. Krist (Ed.), Vegetable Fats and Oils, Springer International Publishing, Cham, 2020, pp. 1–26, https://doi.org/10.1007/978-3-030-30314-3_1.
[11] U.A. Birnin-Yauri, S. Garba, Comparative Studies on some physicochemical properties of baobab, vegetable, peanut and palm oils, Nigerian Journal of Basic and Applied Sciences 19 (2011). https://www.ajol.info/index.php/njbas/article/view/69345. (Accessed 15 August 2024).
[12] G. Talbot, 16 - the stability and shelf life of fats and oils, in: P. Subramaniam (Ed.), The Stability and Shelf Life of Food, second ed., Woodhead Publishing, 2016, pp. 461–503, https://doi.org/10.1016/B978-0-08-100435-7.00016-2.
[13] F.C. Ekwu, A. Nwagu, Effect of processing on the quality of cashew nut oils, J. Sci. Agric. Food Tech. Environ 4 (2004) 105–110.
[14] M. Hagos, E.E. Yaya, B.S. Chandravanshi, M. Redi-Abshiro, Determination of fatty acids composition by GC-MS and physicochemical parameters of pumpkin (Cucurbita maxima) seed oil cultivated in Ethiopia, Bull. Chem. Soc. Ethiop. 37 (2023) 565–577.
[15] M. Ramezani, M. Hashemi, M. Varidi, M. Rezaie, Health risk assessment and determination of heavy metals in sesame oils, Journal of Nutrition, Fasting and Health 9 (2021) 342–352.
[16] A. Yetesha, B.S. Chandravanshi, W. Yohannes, Major and heavy metals contents and health risk assessment of pumpkin peel, flesh and seed by microwave plasma-atomic emission spectroscopy, Bull. Chem. Soc. Ethiop. 37 (2023) 533–551.
[17] D. Mendil, Ö.D. Uluözlü, M. Tüzen, M. Soylak, Investigation of the levels of some element in edible oil samples produced in Turkey by atomic absorption spectrometry, J. Hazard Mater. 165 (2009) 724–728.
[18] G. Dugo, L. La Pera, G.L. La Torre, D. Giuffrida, Determination of Cd (II), Cu (II), Pb (II), and Zn (II) content in commercial vegetable oils using derivative potentiometric stripping analysis, Food Chem. 87 (2004) 639–645.
[19] H.A. Panahi, M. Karimi, E. Moniri, H. Soudi, Development of a sensitive spectrophotometeric method for determination of copper, Afr. J. Pure Appl. Chem. 2 (2008) 96–99.
[20] S. Kumar, S. Prasad, K.K. Yadav, M. Shrivastava, N. Gupta, S. Nagar, Q.-V. Bach, H. Kamyab, S.A. Khan, S. Yadav, Hazardous heavy metals contamination of vegetables and food chain: role of sustainable remediation approaches-A review, Environ. Res. 179 (2019) 108792.
[21] J. Baby, J.S. Raj, E.T. Biby, P. Sankarganesh, M.V. Jeevitha, S.U. Ajisha, S.S. Rajan, Toxic effect of heavy metals on aquatic environment, Int. J. Brain Cognit. Sci. 4 (2010). https://www.ajol.info/index.php/ijbcs/article/view/62976. (Accessed 15 August 2024).
[22] S.S. Sonone, S. Jadhav, M.S. Sankhla, R. Kumar, Water contamination by heavy metals and their toxic effect on aquaculture and human health through food Chain, Lett. Appl. NanoBioScience 10 (2020) 2148–2166.
[23] J. Liu, L. Cao, S. Dou, Trophic transfer, biomagnification and risk assessments of four common heavy metals in the food web of Laizhou Bay, the Bohai Sea, Sci. Total Environ. 670 (2019) 508–522.
[24] R. Peirovi-Minaee, A. Alami, F. Esmaeili, A. Zarei, Analysis of trace elements in processed products of grapes and potential health risk assessment, Environ. Sci. Pollut. Res. 31 (2024) 24051–24063, https://doi.org/10.1007/s11356-024-32654-x.
[25] S. Charlesworth, E. De Miguel, A. Ordóñez, A review of the distribution of particulate trace elements in urban terrestrial environments and its application to considerations of risk, Environ. Geochem. Health 33 (2011) 103–123, https://doi.org/10.1007/s10653-010-9325-7.
[26] N.S. Hosseini, S. Sobhanardakani, M. Cheraghi, B. Lorestani, H. Merrikhpour, Heavy metal concentrations in roadside plants (Achillea wilhelmsii and Cardaria draba) and soils along some highways in Hamedan, west of Iran, Environ. Sci. Pollut. Res. 27 (2020) 13301–13314, https://doi.org/10.1007/s11356-020-07874-6.
[27] S. Sobhanardakani, Potential health risk assessment of heavy metals via consumption of caviar of Persian sturgeon, Mar. Pollut. Bull. 123 (2017) 34–38, https://doi.org/10.1016/j.marpolbul.2017.09.033.
[28] J.O. Duruibe, M.O.C. Ogwuegbu, J.N. Egwurugwu, Heavy metal pollution and human biotoxic effects, Int. J. Phys. Sci. 2 (2007) 112–118.
[29] P. González-Torres, J.G. Puentes, A.J. Moya, M.D. La Rubia, Comparative study of the presence of heavy metals in edible vegetable oils, Appl. Sci. 13 (2023) 3020.
[30] S. Sakib, G.K. Kundu, Md.S.M.M. Islam, R. Akhter, M. Moniruzzaman, B. Saha, Md.A. Rahman, Md.A.A. Shaikh, Md.M. Islam, Heavy metal accumulation in fish, sediment and water from three riverine ecosystems in the south-western Bangladesh and nexus to human health, Biol. Trace Elem. Res. (2024), https://doi.org/10.1007/s12011-024-04321-2.
[31] S. Barua, R. Mutsuddi, S. Sultana, Md.S.M.M. Islam, S. Das, M. Mostafa, D. Chakraborty, I.M.M. Rahman, Polycyclic aromatic hydrocarbons in ship breaking area and associated ecological risk assessment: evidence from the Sitakund ship-breaking area in Bangladesh, Environ. Sci. Pollut. Res. (2024), https://doi.org/10.1007/s11356-024-34569-z.

[32] Md.A. Hossen, M.G. Mostafa, Assessment of heavy metal pollution in surface water of Bangladesh, Environmental Challenges 13 (2023) 100783, https://doi.org/10.1016/j.envc.2023.100783.
[33] J.N. Jannat, M.Y. Mia, M.M.M.F. Jion, Md.S. Islam, M.M. Ali, M.A.B. Siddique, M.R.J. Rakib, S.M. Ibrahim, S.C. Pal, R. Costache, G. Malafaia, A.R.M.T. Islam, Pollution trends and ecological risks of heavy metal(loid)s in coastal zones of Bangladesh: a chemometric review, Mar. Pollut. Bull. 191 (2023) 114960, https://doi.org/10.1016/j.marpolbul.2023.114960.
[34] D. Pandit, M.M. Haque, Md.S. Bhuyan, A. Harun-Al-Rashid, P.P. Barman, R. Roy, B. Sarker, Md.K. Saifullah, M. Kunda, A comprehensive scenario of heavy metals pollution in the rivers of Bangladesh during the last two decades, Environ. Sci. Pollut. Res. (2024), https://doi.org/10.1007/s11356-024-34225-6.
[35] A.A. Ullah, M.A. Maksud, S.R. Khan, L.N. Lutfa, S.B. Quraishi, Dietary intake of heavy metals from eight highly consumed species of cultured fish and possible human health risk implications in Bangladesh, Toxicol Rep 4 (2017) 574–579.
[36] J. Das, D. Chakraborty, S. Das, S.C. Bhattacharjee, P.K. Das, Physicochemical parameters and heavy metal content in soybean oil from Bangladesh, Pakistan J. Nutr. 15 (2016) 565.
[37] S. Das, M.N. Uddin, A.S.M. Khaled, M.R.O.K. Noyon, D. Chakraborty, M. Mostafa, Md.S.M.M. Islam, S.C. Bhattacharjee, S.K. Das, M. Uddin, Health risk assessment of three preservatives in beverage, cake, ketchup, and therapeutic products available in Bangladesh using the new validated HPLC-PDA method, J. Food Compos. Anal. 126 (2024) 105907, https://doi.org/10.1016/j.jfca.2023.105907.
[38] W. Horwitz, G. Latimer, AOAC International: Gaithersburg, MD, USA 18 (2005).
[39] J. Hanus, Z. Untersuch, Nahr. u, Genus 4 (1901) 913–920.
[40] P.A. Succop, S. Clark, M. Chen, W. Galke, Imputation of data values that are less than a detection limit, J. Occup. Environ. Hyg. 1 (2004) 436–441, https://doi.org/10.1080/15459620490462797.
[41] M.Granger. Morgan, Max. Henrion, S.C. Morris, D.A.L. Amaral, Uncertainty in risk assessment, Environ. Sci. Technol. 19 (1985) 662–667, https://doi.org/10.1021/es00138a002.
[42] C.D. Carrington, P.M. Bolger, Uncertainty and risk assessment, Hum. Ecol. Risk Assess. 4 (1998) 253–257, https://doi.org/10.1080/10807039891284325.
[43] M. Mesa-Frias, Z. Chalabi, T. Vanni, A.M. Foss, Uncertainty in environmental health impact assessment: quantitative methods and perspectives, Int. J. Environ. Health Res. 23 (2013) 16–30, https://doi.org/10.1080/09603123.2012.678002.
[44] U. EPA, Guidance Manual for Assessing Human Health Risks from Chemically Contaminated Fish and Shellfish, Guidance Manual for Assessing Human Healt H Risks from Chemically Contaminated Fish and Shellfish, OoWRa, Standard, 1989. Washington.
[45] Md.S. Islam, Md.K. Ahmed, Md. Habibullah-Al-Mamun, Md.F. Hoque, Preliminary assessment of heavy metal contamination in surface sediments from a river in Bangladesh, Environ. Earth Sci. 73 (2015) 1837–1848, https://doi.org/10.1007/s12665-014-3538-5.
[46] U. Epa, Regional Screening Levels (RSLs)-Generic Tables, 2018. Last Updated September.
[47] E. Nyarko, C.M. Boateng, O. Asamoah, M.O. Edusei, E. Mahu, Potential human health risks associated with ingestion of heavy metals through fish consumption in the Gulf of Guinea, Toxicol Rep 10 (2023) 117–123.
[48] Y.H. Hui, A.H. Yee, M.R. Nordin, Banley Industrial Oil and Fat Products, vol. 4, John Willey and Sons Inc, USA, 1996, pp. 192–196.
[49] M. Gupta, Practical Guide to Vegetable Oil Processing, Elsevier, 2017.
[50] J.K. Daun, M.N. Eskin, D. Hickling, Canola: Chemistry, Production, Processing, and Utilization, Elsevier, 2015, in: https://books.google.com/books?hl=en&lr=&id=gcxcCgAAQBAJ&oi=fnd&pg=PP1&dq=Daun,+J.+K.,+Eskin,+M.+N.,+%26+Hickling,+D.+(Eds.).+(2015).+Canola:+chemistry,+production,+%09processing,+and+utilization.+Elsevier.&ots=noZpHtZW7z&sig=_yGkQW765fO606UNBM_07gZy0N8. (Accessed 15 August 2024).
[51] R.D. O'brien, Fats and Oils: Formulating and Processing for Applications, CRC press, 2008. https://www.taylorfrancis.com/books/mono/10.1201/9781420061673/fats-oils-richard-brien. (Accessed 15 August 2024).
[52] E. Zahir, R. Saeed, M.A. Hameed, A. Yousuf, Study of physicochemical properties of edible oil and evaluation of frying oil quality by Fourier Transform-Infrared (FT-IR) Spectroscopy, Arab. J. Chem. 10 (2017) S3870–S3876.
[53] H. Noureddini, B.C. Teoh, L. Davis Clements, Viscosities of vegetable oils and fatty acids, J Americ Oil Chem Soc 69 (1992) 1189–1191, https://doi.org/10.1007/BF02637678.
[54] A. Devi, B.S. Khatkar, Thermo-physical properties of fats and oils, Int. J. Eng. Technocal Res 7 (2017) 45.
[55] A. Philippaerts, S. Goossens, P.A. Jacobs, B.F. Sels, Catalytic production of conjugated fatty acids and oils, ChemSusChem 4 (2011) 684–702, https://doi.org/10.1002/cssc.201100086.
[56] S.A. Mahesar, S.T.H. Sherazi, A.R. Khaskheli, A.A. Kandhro, Analytical approaches for the assessment of free fatty acids in oils and fats, Anal. Methods 6 (2014) 4956–4963.
[57] B. Standard, Specification for Soyabean Oil, BDS 909: 1979, Bangladesh Standards and Testing Institution (BSTI), 1979. Dhaka.
[58] C. Alimentarius, Fats, Oils and Related Products, Food Agricult, Organization, Rome, 2001.
[59] M. Mittelbach, C. Remschmidt, Biodiesel. The Compherensive Handbook, 2004. https://www.sidalc.net/search/Record/cat-fedepalma-19932/Description. (Accessed 15 August 2024).
[60] A.I. Alajtal, F.E. Sherami, M.A. Elbagermi, Acid, peroxide, ester and saponification values for some vegetable oils before and after frying, AASCIT Journal of Materials 4 (2018) 43–47.
[61] J.G. Nangbes, J.B. Nvau, W.M. Buba, A.N. Zukdimma, Extraction and characterization of Castor (Ricinus communis) seed oil. https://www.academia.edu/download/44971381/Extraction_and_Characterization_of_Castor_Ricinus_Communis_Seed_Oil.pdf, 2013. (Accessed 15 August 2024).
[62] E.T. Ghane, A. Poormohammadi, S. Khazaei, F. Mehri, Concentration of potentially toxic elements in vegetable oils and health risk assessment: a systematic review and meta-analysis, Biol. Trace Elem. Res. 200 (2022) 437–446, https://doi.org/10.1007/s12011-021-02645-x.
[63] S. Bathla, S. Arora, Prevalence and approaches to manage iron deficiency anemia (IDA), Crit. Rev. Food Sci. Nutr. 62 (2022) 8815–8828, https://doi.org/10.1080/10408398.2021.1935442.
[64] W. Kimita, M.S. Petrov, Iron metabolism and the exocrine pancreas, Clin. Chim. Acta 511 (2020) 167–176, https://doi.org/10.1016/j.cca.2020.10.013.
[65] D. Bakircioglu, Y.B. Kurtulus, S. Yurtsever, Comparison of extraction induced by emulsion breaking, ultrasonic extraction and wet digestion procedures for determination of metals in edible oil samples in Turkey using ICP-OES, Food Chem. 138 (2013) 770–775.
[66] P. Chen, J. Bornhorst, M.A. Aschner, Manganese metabolism in humans. https://publishup.uni-potsdam.de/files/42743/pmnr711.pdf, 2018. (Accessed 15 August 2024).
[67] S. Sehwag Swati, M. Das, A brief overview: present status on utilization of mustard oil and cake, IJTK 14 (2) (2015). http://nopr.niscpr.res.in/handle/123456789/32079. (Accessed 20 August 2024).
[68] B. Debnath, W.S. Singh, K. Manna, Sources and toxicological effects of lead on human health, Indian J. Med. Specialities 10 (2019) 66–71.
[69] H.S. Green, S.C. Wang, Evaluation of proposed CODEX purity standards for avocado oil, Food Control 143 (2023) 109277.
[70] R. Nazar, N. Iqbal, A. Masood, M.I.R. Khan, S. Syeed, N.A. Khan, Cadmium toxicity in plants and role of mineral nutrients in its alleviation, AJPS (Asian J. Plant Sci.) 3 (2012) 1476–1489, https://doi.org/10.4236/ajps.2012.310178.
[71] M. Adrees, S. Ali, M. Rizwan, M. Ibrahim, F. Abbas, M. Farid, M. Zia-ur-Rehman, M.K. Irshad, S.A. Bharwana, The effect of excess copper on growth and physiology of important food crops: a review, Environ. Sci. Pollut. Res. 22 (2015) 8148–8162, https://doi.org/10.1007/s11356-015-4496-5.
[72] B. Dimitrios, Olive oil - constituents, quality, health properties and bioconversions. https://doi.org/10.5772/1378, 2012.
[73] M. Butnariu, P. Negrea, L. Lupa, M. Ciopec, A. Negrea, M. Pentea, I. Sarac, I. Samfira, Remediation of rare earth element pollutants by sorption process using organic natural sorbents, Int. J. Environ. Res. Publ. Health 12 (2015) 11278–11287.

[74] M. Butu, M. Butnariu, S. Rodino, A. Butu, Study of zingiberene from lycopersicon esculentum fruit by mass spectometry, Dig. J. Nanomater. Biostruct. 9 (2014). https://search.ebscohost.com/login.aspx?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=18423582&AN=97179267&h=mTI85VHZGKlUz4V4Jl060ZzEFi2C5hiJzgdsCE6gg7ByOMeDOBpS8FjVDYMQ6du05Fpx%2FlSujr%2FzE%2FvRgaWU6w%3D%3D&crl=c. (Accessed 15 August 2024).
[75] I. Ianculov, R. Palicica, M. Butnariu, D. Dumbravă, I. Gergen, Obţinerea în stare cristalină a clorofilei din cetină de brad (Abies alba) şi de pin (Pinus sylvestris), Rev. Chem. 56 (2005) 441–443.
[76] M. Butnariu, A. Caunii, Design management of functional foods for quality of life improvement, Ann. Agric. Environ. Med. 20 (2013). https://bibliotekanauki.pl/articles/51773.pdf. (Accessed 15 August 2024).
[77] Á. Ferencz, R. Juhász, M. Butnariu, A. Deér, I. Varga, J. Nemcsók, Expression analysis of heat shock genes in the skin, spleen and blood of common carp (Cyprinus carpio) after cadmium exposure and hypothermia, Acta Biol. Hung. 63 (2012) 15–25.
[78] A. Mohajer, A.N. Baghani, P. Sadighara, K. Ghanati, S. Nazmara, Determination and health risk assessment of heavy metals in imported rice bran oil in Iran, J. Food Compos. Anal. 86 (2020) 103384.
[79] S. Sobhanardakani, Health Risk Assessment of As and Zn in Canola and Soybean Oils Consumed in Kermanshah, Iran, (n.d.).