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Probabilistic risk assessment of exposure to multiple metals and pesticides through consumption of fruit juice samples collected from Iranian market

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ABSTRACT

The current study assessed the risk posed to Iranian consumers by oral exposure to a mixture of 20 pesticides and six metals in 96 fruit juice (FJ) samples (3 batches × 4 brands × 8 types of FJs) collected from Iran market. Concentrations of metals and pesticides in FJs were quantified by inductively coupled plasma-optical emission spectrometry (ICP-OES) and chromatography-mass spectrometry (GC-MS), respectively. The mean concentration of all pesticides was below the maximum residue limits (MRLs) set by the European Union (EU). The calculated target hazard quotients (THQs) and total hazard index (HI) were <1.0 for all pesticides residue, indicating no risk. For the carcinogenic metals (As, Ni, and Pb), estimated incremental lifetime cancer risks (ILCRs) at the 50th and 95th centiles were respectively 4.25×10^{-5} and 5.30×10^{-5} (for As), 2.85×10^{-5} and 3.71×10^{-5} (for Ni), and 2.84×10^{-8}, and 3.97×10^{-8} (for Pb), indicating no risk. At the 50th and 95th centiles, HI for non-carcinogenic metals (Cd, Hg, and Cr) was <1.0, indicating no risk. Based on sensitivity analyses of the input variables, the concentration of metals and pesticides, and the FJs ingestion rate had significant influential impacts on the calculated THQ and HI.

1. Introduction

Fruit juices (FJs) are regarded as beverages that are extensively consumed by people from various age groups all over the world. Because of the increasing awareness of their nutritional values (such as high levels of vitamins and low levels of calories) and positive health effects, their consumption is on the rise particularly by children (Pallares et al., 2021; Szymczycha-Madeja et al., 2014). Beneficial health effects of FJs are due to the presence of carbohydrates, proteins, flavonoids, and several antioxidants, vitamins and oligoelements (Bartoszek and Polak, 2016). Cardioprotective effect of FJs (e.g. apple and pomegranate juice) has been shown (Ahmad et al., 2021; Kazemirad and Kazerani, 2018). Pomegranate juice anti-inflammatory and antihypertensive effects were also indicated (Wang et al., 2018). According to the Dietary Guidelines for America (2020–2025), FJs can cover up to half of the recommended daily amount of fruit (Ruxton and Myers, 2021). Trace/ultra-trace essential metals are of immense importance to our health providing that they exist at levels below recommended daily intake, or else they may cause deleterious effects (Hariri et al., 2015). FJs are categorized as 100% FJs and fruit nectars, the former being defined as beverages

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containing pure filtered juice. Juice is made from different fruits e.g. orange, apple, grape, and pomegranate. Nectars are prepared from diluted FJs and pulp (based on the regulations) and they have additives such as natural and artificial sweeteners and preservatives (Demir et al., 2015). The entrance of metals into food matrices from various sources such as contaminated irrigation water, soil, metal-based pesticides and chemical fertilizers, and harvesting and post-harvest operations, can produce serious health problems (Wang et al., 2015). Even if insufficient concentrations of pesticides are used to control pests, significant concentrations can accumulate on crops and enter the environment and food chain (Liu et al., 2013; Sapbamrer and Hongsibsong, 2019). In co-exposure to multiple metals, their interactions not only affect the way they are absorbed or metabolized but also influence their distribution, and excretion (Bárány et al., 2002).

In terms of carcinogenicity, as per the International Agency for Research on Cancer (IARC), Arsenic (As), Cadmium (Cd), and nickel (Ni) are classified as Group 1, lead (Pb) and Mercury (Hg) as group 2B, and Cr (VI) as a Group 1 human carcinogen (IARC, 2017). Chronic exposure to As affects the vascular system, causing hypertension and cardiovascular disease (Balarastaghi et al., 2022; Yang et al., 2020). Cadmium amasses in plants and creatures with a long half-life. The liver and kidneys are sensitive to Cd toxicity and the toxicity has been mainly attributed to an oxidative state and apoptosis (Chakraborty et al., 2022; Genchi et al., 2020). Ni toxicity induces oxidative stress and DNA damage and can cause respiratory allergies and cancers (Rehman et al., 2018). Prolonged consumption of unsafe levels of Pb can lead to its accumulation in the kidney (Taghizadeh et al., 2017). Mercury toxicity leads to a range of neurological deteriorations, comprising cognitive diseases and auto-immune dysfunctions (Bjørklund et al., 2017).

To safeguard consumers' health, metal composition of FJs should be monitored regularly. Beside the essential metals that our body receives through FJ consumption, it is possible that toxic metals that could potentially disturb consumer's health, are taken (Todorovska and Popovski, 2012). Different factors were shown to contribute to introduction of contaminants in FJs, for instance, fertilizers/pesticides over-use, the origin of raw fruit, storage situation, processing approaches, and polluted water used for irrigation. Exposure to toxic metals -even at very low levels-may lead to adverse effects; importantly, the difference between non-toxic and toxic concentrations of essential metals is usually small (Pramod and Devendra, 2014).

Pesticides can be categorized into three primary groups: insecticides, herbicides, and fungicides (Bresson et al., 2022). Concerning the level of pesticides residue in processed foods, several studies underline the significance of the different phases of food processing including cutting, washing and heating in reduction of pesticides content (González-Rodríguez et al., 2011). Such reductions are achieved due to hydrolysis and enzymatic mechanisms or differences in temperature. Besides washing is the leading strategy in minimizing pesticides content, cutting, sealing, and pasteurizing may affect the level of these chemicals residue (Chung, 2018; Đorđević and Đurović-Pejčev, 2016). Of note, most of pesticides that are dissolvable in water are trapped within the fruit pulp. Generally, the physical/chemical traits of a pesticide, especially its solubility in water, define its accumulation in fruit pulp and juice. The probability of harmful impacts of pesticides residue on human health is associated with the sum ingested. Human health risk for exposure to a chemical is assessed by calculating the estimated daily intake (EDI) based on the ingestion per capita and is compared with its acceptable daily intake (ADI) (Cámara et al., 2020).

Iran (during 2012–2014) used an average of about 14,000 tonnes of agriculture pesticides each year (Morteza et al., 2017). Herbicides (43%), insecticides and acaricides (37%), and fungicides (19%) constituted the main categories. The formulated products met the criteria of WHO Class Ib (highly hazardous) and Class II (moderately hazardous) products. Chlorpyrifos, diazinon, and paraquat were identified as products of secondary concern because of their acute human health hazard (Morteza et al., 2017). In the present work, we conducted the probabilistic assessment using the Monte Carlo simulation (MCS). Dietary assessment of exposure to pesticide residues is traditionally performed for individual compounds. However, people are exposed to more than one pesticide every day through their diet because foods may contain residue of more than a single pesticide or people ingest combinations of foods with different pesticides. When these compounds share the same toxicological endpoint and mechanism of action, the traditional way of separately assessing the dietary risk of pesticide exposure can lead to an underestimation of the health risk (Quijano et al., 2016).

Orange, pineapple, mango, apple, peach, sour cherry, grape, and pomegranate have health-promoting properties (Montefusco et al., 2021). In the present study, almost all –as far as the authors know-types of tetra pack FJ products that are commercially available in Iran were analyzed for pesticides and HMs residue.

The current study presents: (I) concentrations of 6 metals and 20 pesticides in a total of 96 samples (3 batches × 4 brands × 8 types of FJs) of the major FJs consumed in Iran and (II) results of carcinogenic and non-carcinogenic health risk assessment, and (III) sensitivity analysis to determine which variable affects the risk calculation results. To the best of our knowledge, this is the first health risk assessment of oral exposure to a mixture of metals and pesticides residue through consumption of FJs.

2. Materials and methods

2.1. Chemicals

All standards (of 99% purity) were purchased from Sigma-Aldrich (Steinheim, Germany). Solvents high performance liquid chromatography (HPLC) grade including methanol and nitric acid (HNO_3) (of 98% purity) were purchased from Merck (Darmstadt, Germany) and Sigma-Aldrich (Steinheim, Germany).

2.2. Sample ccollection

A total of 96 samples of the major FJs consumed in Iran were randomly collected from the markets in March 2022, including three batches from eight types of FJs (i.e. orange, pineapple, mango, apple, peach, sour cherry, grape, and pomegranate), from four brands [3 batches × 4 brands × 8 types of FJs = 96 samples] (Fig. 1). The FJs were stored at 4 °C until analyses. All samples were in tetra packages and they were totally liquid and contained no-pulp.

2.3. Instrumentation

2.3.1. Microwave digestion system and ICP-OES

For determination of the level of metals (As, Cd, Ni, Pb, Hg, and Cr) in the collected FJs, samples were digested using a microwave digestion system (the operation program is presented in Table 1) (Taghizadeh et al., 2020b). Comparison of the dry ashing and wet digestion methods used for elemental analysis in food samples showed relatively higher levels of metals in the dry-ashed samples however, the difference was non-significant (Akinyele and Shokunbi, 2015). For metals such as arsenic and mercury, which are volatile, due to the influence of furnace temperature (550 °C), usually the wet digestion method is used (Taghizadeh et al., 2017).

2.3.2. Inductively coupled plasma-optical emission spectrometry (ICP-OES)

For simultaneous determination of metals level, ICP-OES (SPECTRO ARCOS, Germany) with Torch type of Flared end EOP Torch 2.5 mm was used. The power of plasma was 1.2 kW. Argon was the carrier gas with flow rate 15.0 L/min, the auxiliary flow rate was 1.50 L/min, and the pressure of nebulizer was 250 kPa. The standard mode of sample uptake, stabilization, sample analysis, rinse out, and total sample were 0.4 (1.2 mL/min × 20 s), 0.2 (0.4 mL/min × 30 s), 1.2 (0.4 mL/min × 180 s), 0.3 (1.2 mL/min × 15 s), and 2.1 mL, respectively (Taghizadeh et al.,

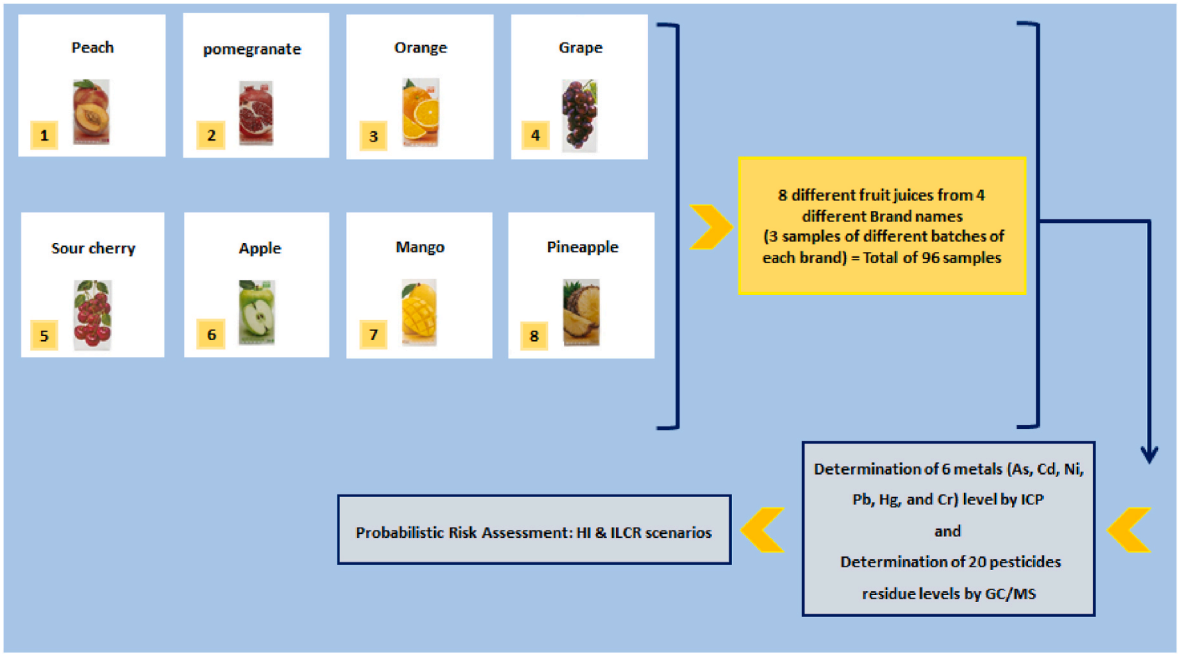

Fig. 1. Schematic presentation of the current study methodology.

Table 1
Operating program used for microwave digestion.

Phase	Initial Temperature (°C)	Final Temperature (°C)	Time (min)	Power (W)
1	25	90	5	700
2	90	90	3	600
3	90	170	10	600
4	170	170	7	600

2022a).

2.3.3. Gas chromatography-mass spectrometry (GC-MS) for pesticide residues

An Agilent 7890A GC-MS system (Agilent, Santa Clara, USA) equipped with a programmable temperature vaporizer inlet and 7683B auto injector was used. Helium was used as the carrier gas at a flow rate of 1.0 mL/min. HP-5 MS column was 30 m × 0.25 mm × 0.25 μm. The initial temperature was 60 °C (held for 1 min), then it was raised at 10 °C/min ramp to 120 °C and held for 5 min, then, increased to 250 °C at 5 °C/min (held for 10 min) (Fattahi et al., 2021). The temperature of the injection port and volume of the injection was 250 °C and 1 μL volume, respectively. The electro voltage for electron ionization was 70 eV. The quadrupole analyzer measured the abundance of ions of m/z from 50 to 490. Pesticides were identified by comparing the observed indices (under temperature-programmed conditions) with those of standard solutions of pesticides and by considering characteristic ions (Farhadi et al., 2020; Taghizadeh et al., 2021c).

2.4. Extraction procedures

2.4.1. Metals

For metals extraction, 20 mL of each FJ sample were digested by 120 mL 2% HNO_3 and 40 mL of concentrated H_2O_2 (30%) using microwave digestion system and then, diluted to 200 mL using 2% HNO_3. The digested FJ samples were analyzed by ICP-OES. Blank preparation was performed in the same way (Taghizadeh et al., 2022c).

2.4.2. Pesticides

- Initial preparation

Firstly, 20 mL of FJ samples were diluted with distilled water to a volume of 100 mL. Then, 1.0 mL of Carrez solution I including potassium hexacyanoferrate (II) trihydrate 15% w/v in water was added. After mixing the solution, 1.0 mL of Carrez solution II including $ZnSO_4$–$7H_2O$, 30% w/v in water, was mixed. Then, the solution was transferred to a 100-mL volumetric flask and distilled water was added. The solution was filtered through a Fluted filter paper to separate the insoluble compounds before solid-phase extraction-dispersive liquid-liquid microextraction SPE–DLLME procedure (Taghizadeh et al., 2022b).

- SPE procedure

The extraction of pesticides was conducted using a solid-phase extraction (SPE) cartridge (500 mg C18 sorbent) (6-mLsyringe barrel, USA). The sorbent was treated with 3 and 2 mL of methanol and ultra-pure water, respectively. Then, 20 mL FJ was placed in a 100 mL flask, spiked with a mixture of pesticides (20 μg/L) and the flask was filled with ultra-pure water. Authentic FJ samples and spiked samples were loaded at a flow rate of 10 mL/min with a vacuum pump (Heidolph, Germany). In order to eliminate the matrix interferences, C_{18} cartridges were washed with 2 mL of water. The filter was flushed with air, and then, the pesticide content was eluted with 2.0 mL methanol and collected in a glass tube. The glass tube was completely sealed (Shamsipur et al., 2016).

- DLLME procedure

Briefly, 5 mL NaCl solution (1 mol/l) was transferred to each glass tube. A mixture of 1.5 mL solution eluted from the SPE stage and 20 μl of extraction solvent (chlorobenzene) were added to the solution in the glass tube and then, shaken well for 1 min. When a cloudy solution was obtained, the pesticides were extracted into fine chlorobenzene micro droplets. Consequently, the mixture was centrifuged at 2500 g for 5 min for phase separation. At this step, the dispersed droplets of the extraction phase were deposited at the bottom of glass tube (10.0 μL). The

deposited phase was transferred into a vial using a 10 μL Hamilton syringe (Reno, NV, USA) and 1 μL of this deposited phase was used for GC/MS analysis (Shamsipur et al., 2016).

2.5. Analytical performance

2.5.1. Analytical performance of metals level determinations

To plot the calibration curves, standard solutions of metals (As, Cd, Ni, Pb, Hg, and Cr) were prepared at 1000 mg/l. Stock solution was diluted with HNO_3 solution (0.2%). Based on the recovery determination, spiked samples were treated as described in sample preparation (n = 3). Spiked calibration curves were used for calculation of recoveries (Taghizadeh et al., 2021a).

2.5.2. Analytical performance of pesticides level determinations

Analytical performance, including linear range, limit of detection (LOD), and reproducibility were identified. The LOD values were calculated as the concentration equivalent to three times of standard deviation of the blank divided by the slope of calibration curve for different pesticides. The intra-day and inter-day precision were assessed by calculation of RSD% (relative standard deviation) for five replicates of each extract (Shamsipur et al., 2016).

2.6. Relative potency factor (RPF)

As recommended by the European Food Safety Authority (EFSA) and the United States Environmental Protection Agency (USEPA), the relative potency factor (RPF) was used in the risk assessment method. By considering the following pesticides as leaders of each group, methamidophos for organophosphorus (OPs), oxamyl for carbamates (CBs), and deltamethrin for pyrethroid (PYs) (Table 2), using Index Compound (IC) from the USEPA, other pesticides are normalized (Jardim et al., 2018).

2.7. Health risk assessment

2.7.1. Non-carcinogenic scenario

Exposure daily intake (EDI) (mg/kg body weight (BW)) and target hazard quotient (THQ) were calculated by Equations 1 and 2 (Fakhri et al., 2018).

$$EDI = \frac{C \times IR \times EF \times ED}{BW \times AT} \quad (1)$$

$$THQ = \frac{EDI}{ADI} \quad (2)$$

In Equation (1): C: Contaminant concentration in FJs (mg/kg); IR: Ingestion rate, the daily date consumption (kg), which was considered 0.03 kg/person/day for Iranian general population; EF: Exposure frequency (365 meals/year); ED: Exposure duration for elders (70 years); BW: Average body weight for Iranian adult population is considered 70 kg; and AT: Average time (25550 days or 70 years) (Fathabad et al., 2018).

In Equation (2): Acceptable daily intakes (ADIs) values of 6 metals and 20 pesticides considered in the current study, are presented in Table 2 (Taghizadeh et al., 2021b).

In order to estimate the total risk from non-carcinogenic contaminants, the hazard index (HI) was calculated from the sum of THQs (Equation (3)) (Fakhri et al., 2018).

$$HI = \sum_{n=0}^{i} THQn \quad (3)$$

An HI value below one indicates no appreciable risk, a value of 1.1–10 shows moderate risk and an HI > 10 reflects a high risk for non-cancer effects (Taghizadeh et al., 2019).

2.7.2. Carcinogenic scenario

Based on the IARC classification, As (Group 1), Pb (Group 2B), and Ni (Group 1) are considered carcinogenic metals. The incremental lifetime cancer risk (ILCR) was calculated by Equation (4).

$$ILCR = EDI \times CSF \quad (4)$$

In Equation (4): CSF: cancer slope factor (Table 2). It is noteworthy that among metals, Cd is also classified as group 1 carcinogens, but since no CSF for its oral exposure was found, it was included in the non-carcinogenic scenario (Taghizadeh et al., 2022a). The calculated ILCRs are interpreted as follows: an ILCR of 10^{-4} - 10^{-6} represents no carcinogenic risk for consumers while an ILCR $>10^{-4}$ specifies relatively great risk (USEPA, 2015).

2.8. Probabilistic and sensitivity calculations

MCS was used to identify dependent and independent variables, evaluate their distributions, and simulate the independent variables. MCS was conducted with 10,000 iterations of non-carcinogenic and carcinogenic risks associated with oral exposure to FJs. We considered a distribution by SAS software JMP 8 (Campus Drive, Cary, NC 27513). Sensitivity analysis was also conducted to reveal the input parameters with the greatest impact on the carcinogenic and non-carcinogenic health risk (Taghizadeh et al., 2020a).

2.9. Statistical analysis

SAS software JMP 8 (Campus Drive, Cary, NC 27513) was used to assess differences among mean values and statistical difference was considered significant at $p < 0.05$. JMP 8 implemented all uncertainty and sensitivity analyses.

3. Results

3.1. Analytical performance

3.1.1. Analytical performance of metals determination

Recoveries (at three concentrations of 50, 100 and 150 μg/kg) were in the range of 90.1–99.5%, with associated Relative Standard Deviations (RSDs %) of ≤4.1%. Based on the results, the recoveries reflected the appropriateness of extraction. In all calibration curves, coefficients of determination (R^2) presented significant linear relationships (97.0–99.9%) (Table 3).

3.1.2. Analytical performance of pesticides determination

As shown in Table 4, the samples were spiked at 10, 20, and 50 μg/kg with three groups of standard pesticides including CBs, PYs, and OPs. Recoveries (at three concentrations of 10, 20 and 50 μg/kg) were in the range of 90.1–99.5%. The RSDs % were ≤4.5%. Analytical performance results were in accordance with SANTE, 2019 (SANTE, 2019). The calibration plot revealed indices of R^2 of each pesticide being in the range of 99.5–99.9% (Table 4).

3.2. Concentrations of contaminants

3.2.1. Metals

As shown in Table 5, the mean metal levels varied signifcantly among FJ type. The mean levels of Pb in mango, orange, peach, pineapple, pomogranate, and sour cherry were below LOD. The mean levels of As did not show significant variations among peach, pineapple, and pomogranate juice samples (i.e. in these samples As levels were <LOD). The mean levels of Cd in grape, orange, peach, pineapple, and pomogranate juice samples were below LOD (Table 5). As summarized in Table 6, the mean concentrations of Hg were below LOD in all examined brands (1–4) and types of fruits (Table 6).

In each raw, lowercase superscripts (a, b, c, etc.) express statistical variations among different types of fruit juices. In each element, values

Table 2
European Food Safety Authority (EFSA) maximum accepted values for metals and pesticides residues in fruit juices included in the present risk assessment.

Pesticide	European union (EU)											
	MRL (mg/kg)								ADI (mg/kg Body weight/day)	RPF	CSF (mg/kg Body weight/day)	REF
	Apple	Grape	Mango	Orange	Peach	Pineapple	Pomegranate	Sour cherry				
Carbamate										IC= Oxamyl	–	
Carbaryl	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.008	0.15	–	Reg. (EU) No 1096/2014
Carbofuran	0.001	0.002	0.01	0.01	0.002	0.01	0.01	0.002	0.00015	2.4	–	Regulation (EU) 2015/399
Methomyl	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.0025	0.67	–	Reg. (EU) 2016/1822
Oxamyl	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.001	1.00	–	Reg. (EU) 2019/552
Pirimicarb	0.50	0.01	0.01	3.00	1.50	0.01	0.01	5.00	0.02	0.02	–	Reg. (EU) 2016/71
Propamocarb	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.40	0.00	–	Reg. (EU) 2020/856
Pyrethroid										IC = Deltamethrin	–	
Deltamethrin	0.20	0.20	0.01	0.04	0.15	0.01	0.01	0.10	0.01	1.00	–	Reg. (EU) 2018/832
Permethrin	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.09	–	Reg. (EU) 2017/623
Organophosphorus										IC = Methamidophos	–	
Acephate	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.08	–	Reg. (EU) No 899/2012
Azinphos-methyl	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.005	0.10	–	Reg. (EU) 2020/1633
Chlorpyrifos	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.001	0.06	–	Reg. (EU) 2020/1085
Chlorpyrifos-methyl	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.005	–	Reg. (EU) 2020/1085
Diazinon	0.01	0.01	0.01	0.01	0.01	0.3	0.01	0.01	0.0002	0.01	–	Reg. (EU) No 834/2013
Dimethoate	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.002	0.32	–	Reg. (EU) 2021/155
Ethion	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.002	1.00	–	Reg. (EU) No 310/2011
Fenitrothion	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.005	0.083	–	Reg. (EU) No 899/2012
Fenthion	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.007	0.33	–	Reg. (EU) No 310/2011
Malathion	0.02	0.02	0.02	2.00	0.02	0.02	0.02	0.02	0.03	0.00	–	Regulation (EU) 2015/399
Methamidophos	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.001	1.00	–	Reg. (EU) No 899/2012
Methidathion	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.001	0.32	–	Reg. (EU) No 310/2011
Trace metals												
Cd	–	–	–	–	–	–	–	–	0.001	–		–
Hg	–	–	–	–	–	–	–	–	0.0005	–		–
Cr	–	–	–	–	–	–	–	–	0.005	–		–
As	–	–	–	–	–	–	–	–	0.0001	–	1.50	–
Ni	–	–	–	–	–	–	–	–	0.005	–	0.91	–
Pb	–	–	–	–	–	–	–	–	0.003	–	0.0085	–

MRL: Maximum residue limit.
ADI: Acceptable daily intake.
RPF: Relative potency factor.
IC: Index compound.
CSF: Cancer slope factor.

Table 3
A summary of analytical performance attributes for metals determination.

Trace metal	Spike concentrations						R^2	LOD (mg/kg)	LOQ (mg/kg)
	0.05 mg/kg		0.1 mg/kg		0.15 mg/kg				
	Recovery (%)	RSD%	Recovery (%)	RSD%	Recovery (%)	RSD%			
As	92.40	2.10	99.50	3.50	98.10	4.10	0.970	0.001	0.003
Cd	91.50	2.00	99.50	3.00	96.20	3.30	0.999	0.001	0.003
Ni	90.10	2.20	99.30	2.50	98.40	3.00	0.999	0.007	0.021
Pb	95.10	2.00	99.00	3.00	98.00	3.50	0.992	0.001	0.003
Hg	90.50	1.50	99.50	2.40	97.10	3.50	0.989	0.001	0.003
Cr	95.30	2.10	99.50	3.10	97.50	3.20	0.990	0.001	0.003

RSD: Relative standard deviation.
R^2: Coefficients of determination.
LOD: Limit of detection.
LOQ: Limit of quantitation.

Table 4
A summary of analytical performance attributes for pesticides determination.

Pesticide	Spike concentrations						R^2	LOD (mg/kg)	LOQ (mg/kg)
	0.01 mg/kg		0.02 mg/kg		0.05 mg/kg				
	Recovery (%)	RSD%	Recovery (%)	RSD%	Recovery (%)	RSD%			
Carbamate									
Carbaryl	97.10	2.40	99.50	3.50	98.50	2.50	0.999	0.0032	0.0096
Carbofuran	98.50	1.30	99.30	3.50	98.50	2.10	0.999	0.0001	0.0003
Methomyl	96.50	2.50	99.00	4.10	97.30	3.20	0.999	0.0050	0.0140
Oxamyl	96.30	2.50	99.00	4.50	98.20	3.10	0.998	0.0021	0.0060
Pirimicarb	95.10	2.00	99.00	3.20	98.50	2.50	0.997	0.0031	0.0092
Propamocarb	97.00	3.00	99.20	4.00	98.00	2.10	0.998	0.0030	0.0090
Pyrethroid									
Deltamethrin	96.50	4.10	98.50	4.50	97.50	3.30	0.999	0.0025	0.0075
Permethrin	94.50	3.50	99.00	4.10	96.30	3.30	0.999	0.0025	0.0075
Organophosphorus									
Acephate	92.50	3.30	99.50	3.20	95.40	3.20	0.995	0.0020	0.0060
Azinphos-methyl	91.50	3.50	99.00	4.10	92.50	3.10	0.999	0.0032	0.0095
Chlorpyrifos	92.30	4.40	99.10	4.30	96.30	3.10	0.998	0.0001	0.0003
Chlorpyrifos-methyl	93.00	4.50	99.50	4.20	96.00	3.50	0.999	0.0001	0.0003
Diazinon	95.50	3.00	99.50	3.50	97.50	3.30	0.995	0.0005	0.0015
Dimethoate	96.30	3.50	98.10	4.00	97.00	3.30	0.999	0.0020	0.0060
Ethion	91.00	4.10	99.50	3.40	94.00	4.10	0.999	0.0020	0.0060
Fenitrothion	92.40	4.20	99.20	4.40	93.20	3.50	0.999	0.0001	0.0003
Fenthion	93.00	4.10	99.30	3.10	95.40	3.50	0.995	0.0001	0.0003
Malathion	93.40	4.00	98.30	4.50	96.30	4.10	0.998	0.0022	0.0065
Methamidophos	94.50	3.10	99.30	3.30	97.20	4.30	0.996	0.0025	0.0075
Methidathion	90.10	3.00	98.50	3.50	96.50	3.30	0.998	0.0021	0.0063

RSD: Relative standard deviation.
R^2: Coefficients of determination.
LOD: Limit of detection.
LOQ: Limit of quantitation.

Table 5
Mean concentrations (mg/kg) ± SD of metals analyzed in 96 fruit juice samples.

Trace metal	Apple juice	Grape juice	Mango juice	Orange juice	Peach juice	Pineapple juice	Pomegranate juice	Sour cherry juice
As	<LOD	0.004 ± 0.001^{c}	0.026 ± 0.001^{b}	0.168 ± 0.030^{ab}	<LOD	<LOD	<LOD	0.223 ± 0.01^{a}
Cd	0.010 ± 0.003^{a}	<LOD	0.008 ± 0.001^{b}	<LOD	<LOD	<LOD	<LOD	0.004 ± 0.001^{b}
Ni	0.083 ± 0.003^{bc}	0.090 ± 0.012^{b}	<LOD	0.044 ± 0.002^{b}	0.112 ± 0.022^{a}	0.093 ± 0.010^{b}	<LOD	0.035 ± 0.005^{b}
Pb	<LOD	0.044 ± 0.005^{a}	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Hg	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Cr	0.230 ± 0.013^{ab}	0.113 ± 0.011^{b}	0.620 ± 0.021^{a}	<LOQ	0.011 ± 0.003^{c}	0.063 ± 0.004^{c}	<LOD	0.027 ± 0.005^{c}

LOD: Limit of detection.
LOQ: Limit of quantitation.

with similar superscripts are not significantly different from each other but those with different superscripts are significantly different.

3.2.2. Pesticides

Mean concentrations of 20 pesticides in 96 FJs samples of 4 brands are shown in Tables 7 and 8. The mean levels of CBs, PYs, and OPs showed statistically significant differences ($p<0.05$) among different fruit types (i.e. apple, grape, mango, orange, peach, pineapple, pomegranate, and sour cherry). The mean amounts of each different CBs in pineapple were below LOD. However, propamocarb was only detected

Table 6
Mean concentrations (mg/kg) ± SD of metals analyzed in 96 samples of 4 fruit juice-producing brands.

Trace metal	Brand 1	Brand 2	Brand 3	Brand 4
As	0.070 ± 0.005^{b}	0.126 ± 0.013^{a}	0.015 ± 0.005^{ab}	<LOD
Cd	<LOD	0.0043 ± 0.00^{a}	<LOQ	<LOQ
Ni	0.050 ± 0.004^{ab}	0.072 ± 0.003^{ab}	0.091 ± 0.011^{a}	0.021 ± 0.0050^{b}
Pb	<LOD	<LOD	0.013 ± 0.003^{a}	0.008 ± 0.0002^{b}
Hg	<LOD	<LOD	<LOD	<LOD
Cr	0.310 ± 0.022^{a}	0.143 ± 0.030^{b}	0.041 ± 0.005^{b}	0.040 ± 0.0010^{b}

LOD: Limit of detection.
LOQ: Limit of quantitation.
In each raw, lowercase superscripts (a, b, c, etc.) express statistical variations among different types of brands. In each element, values with similar superscripts are not significantly different from each other but those with different superscripts are significantly different.

in sour cherry samples (Table 7). Of note, the four brands were significantly different in terms of pesticides levels. The mean concentrations of acephate were below LOD in all FJs of brand 1 (Table 8). Based on international regulatory authorities the levels of pesticides in each sample were lower than that of standard levels acceptable daily intake (ADI) and maximum residue limit (MRL) established by the European Union (EU) (Table 2).

3.3. Health risk assessments

3.3.1. Trace metals

Based on the MCS model results, the ILCRs at the 50th and 95th centiles for As were respectively 4.25×10^{-5} and 5.30×10^{-5}, whereas for Ni, these values were 2.85×10^{-5} and 3.71×10^{-5}, respectively. Considering Pb concentration in FJs, 50th and 95th centiles of ILCR were 2.84×10^{-8}, and 3.97×10^{-8}, respectively. For the non-carcinogenic metals, HI values were <1 at both centiles for all samples (Table 9).

3.3.2. Pesticides

HI values for CBs content in FJs at 50th and 95th centiles were 0.071, and 0.101, respectively. HI value for PYs content in FJs was 0.001 at the 50th centile and 0.002 at the 95th centile. HI values for OPs content were 0.464 at the 50th centile and 0.6 at the 95th centile. Overall, HI values were <1 at 50th and 95th centile (Table 10). These results indicate *de minimis* risks due to exposure to these chemicals via FJs consumption.

3.4. Sensitivity analysis

Based on the MCS sensitivity analysis, in case of THQ for both metals and pesticides, IR and concentration had the greatest impact on the risk of exposure. In addition, in case of ILCR for both groups of contaminants, IR and concentration were the most influential parameters in non-carcinogenic and carcinogenic scenarios. Body weight had the lowest effect on the calculated THQ and ILCR for both groups of contaminants (Fig. 2).

Table 7
Mean residue levels (mg/kg) ± SD of pesticides analyzed in 96 fruit juice samples.

Pesticide	Apple juice	Grape juice	Mango juice	Orange juice	Peach juice	Pineapple juice	Pomegranate juice	Sour cherry juice
Carbamate								
Carbaryl	tr	<LOD	0.010 ± 0.001^{b}	0.030 ± 0.004^{a}	<LOD	<LOD	<LOD	<LOD
Carbofuran	0.002 ± 0.001^{d}	0.022 ± 0.003^{a}	<LOD	0.001 ± 0.0003^{e}	0.010 ± 0.003^{ab}	<LOD	0.005 ± 0.0003^{c}	0.010 ± 0.002^{ab}
Methomyl	tr	0.017 ± 0.004^{b}	<LOD	0.015 ± 0.005^{b}	0.190 ± 0.021^{a}	<LOD	<LOD	tr
Oxamyl	<LOD	<LOD	<LOQ	0.024 ± 0.003^{a}	0.016 ± 0.005^{b}	<LOD	<LOD	<LOD
Pirimicarb	<LOD	<LOD	<LOD	<LOD	0.231 ± 0.033^{a}	<LOD	<LOD	0.124 ± 0.021^{b}
Propamocarb	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Pyrethroid								
Deltamethrin	0.036 ± 0.003^{b}	0.143 ± 0.005^{a}	<LOD	<LOD	0.022 ± 0.003^{b}	<LOD	<LOD	0.017 ± 0.003^{b}
Permethrin	0.052 ± 0.005^{b}	0.641 ± 0.043^{a}	<LOD	<LOD	0.021 ± 0.044^{b}	<LOD	0.634 ± 0.013^{a}	0.030 ± 0.003^{b}
Organophosphorus								
Acephate	0.052 ± 0.004^{a}	<LOD	<LOD	<LOD	0.007 ± 0.001^{b}	<LOD	<LOD	<LOD
Azinphos-methyl	0.034 ± 0.003^{b}	0.168 ± 0.022^{a}	0.016 ± 0.005^{b}	<LOD	0.033 ± 0.002^{b}	<LOD	<LOD	0.010 ± 0.001^{b}
Chlorpyrifos	0.041 ± 0.005^{c}	2.046 ± 0.131^{a}	0.074 ± 0.005^{c}	0.043 ± 0.005^{c}	0.685 ± 0.012^{b}	0.230 ± 0.011^{b}	0.267 ± 0.014^{b}	0.320 ± 0.011^{b}
Chlorpyrifos-methyl	0.086 ± 0.003^{c}	0.043 ± 0.005^{c}	0.246 ± 0.034^{b}	0.062 ± 0.005^{c}	1.947 ± 0.081^{a}	0.271 ± 0.030^{b}	0.100 ± 0.021^{b}	0.123 ± 0.011^{b}
Diazinon	0.518 ± 0.013^{b}	0.108 ± 0.032^{bc}	0.150 ± 0.022^{bc}	0.403 ± 0.012^{b}	0.663 ± 0.014^{b}	0.902 ± 0.011^{b}	1.114 ± 0.053^{a}	0.831 ± 0.021^{b}
Dimethoate	1.050 ± 0.144^{a}	0.086 ± 0.005^{c}	<LOD	0.346 ± 0.034^{b}	0.785 ± 0.021^{b}	<LOD	1.328 ± 0.015^{a}	0.180 ± 0.011^{b}
Ethion	1.311 ± 0.251^{a}	1.250 ± 0.033^{a}	1.201 ± 0.025^{a}	1.238 ± 0.114^{a}	1.057 ± 0.012^{a}	1.303 ± 0.014^{a}	1.170 ± 0.024^{a}	1.882 ± 0.034^{a}
Fenitrothion	0.121 ± 0.012^{bc}	0.825 ± 0.012^{b}	1.170 ± 0.042^{a}	0.774 ± 0.072^{b}	0.958 ± 0.032^{b}	1.350 ± 0.015^{a}	1.412 ± 0.032^{a}	0.141 ± 0.012^{bc}
Fenthion	0.420 ± 0.011^{b}	0.350 ± 0.023^{b}	0.082 ± 0.005^{c}	0.051 ± 0.005^{c}	0.743 ± 0.045^{b}	1.100 ± 0.011^{a}	1.696 ± 0.023^{a}	0.326 ± 0.024^{b}
Malathion	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Methamidophos	0.034 ± 0.002^{c}	0.106 ± 0.055^{ab}	0.197 ± 0.015^{ab}	0.116 ± 0.035^{ab}	0.996 ± 0.013^{a}	0.430 ± 0.052^{a}	0.081 ± 0.004^{c}	<LOD
Methidathion	0.680 ± 0.045^{a}	0.078 ± 0.005^{b}	<LOD	0.213 ± 0.011^{a}	0.075 ± 0.005^{b}	<LOD	0.254 ± 0.001^{a}	0.206 ± 0.001^{a}

LOD: Limit of detection.
LOQ: Limit of quantitation.
tr: trace (between LOD and LOQ).
In each raw, lowercase superscripts (a, b, c, etc.) express statistical variations among different types of fruit juices. In each pesticide, values with similar superscripts are not significantly different from each other but those with different superscripts are significantly different.

Table 8
Mean residue levels (mg/kg) ± SD of pesticides analyzed in 96 fruit juices samples from 4 fruit juice-producing brands.

Pesticide	Brand 1	Brand 2	Brand 3	Brand 4
Carbamate				
Carbaryl	tr	tr	tr	tr
Carbofuran	0.006 ± 0.001[a]	0.005 ± 0.003[a]	<LOQ	0.008 ± 0.001[a]
Methomyl	0.053 ± 0.001[a]	0.046 ± 0.004[a]	0.012 ± 0.003[a]	tr
Oxamyl	tr	0.007 ± 0.001[a]	tr	0.007 ± 0.001[a]
Pirimicarb	0.043 ± 0.003[a]	0.037 ± 0.001[a]	0.065 ± 0.003[a]	0.031 ± 0.004[a]
Propamocarb	tr	tr	tr	tr
Pyrethroid				
Deltamethrin	0.033 ± 0.003[a]	0.031 ± 0.005[a]	0.030 ± 0.001[a]	<LOD
Permethrin	0.160 ± 0.012[a]	0.167 ± 0.011[a]	0.174 ± 0.01[a]	0.171 ± 0.01[a]
Organophosphorus				
Acephate	<LOD	0.010 ± 0.005[a]	0.008 ± 0.005[b]	0.010 ± 0.005[a]
Azinphos-methyl	0.017 ± 0.003[a]	0.024 ± 0.002[a]	0.012 ± 0.005[a]	0.077 ± 0.002[a]
Chlorpyrifos	0.160 ± 0.011[a]	0.520 ± 0.001[a]	0.678 ± 0.005[a]	0.530 ± 0.005[a]
Chlorpyrifos-methyl	0.475 ± 0.013[a]	0.428 ± 0.005[a]	0.271 ± 0.021[a]	0.265 ± 0.011[a]
Diazinon	0.452 ± 0.013[a]	0.428 ± 0.002[a]	0.271 ± 0.022[a]	0.265 ± 0.023[a]
Dimethoate	0.340 ± 0.012[a]	0.785 ± 0.005[a]	0.557 ± 0.003[a]	0.205 ± 0.014[a]
Ethion	1.171 ± 0.145[a]	1.497 ± 0.033[a]	1.478 ± 0.042[a]	1.060 ± 0.012[a]
Fenitrothion	0.905 ± 0.005[a]	0.971 ± 0.012[a]	0.724 ± 0.002[a]	0.775 ± 0.012[a]
Fenthion	0.738 ± 0.011[a]	0.540 ± 0.012[a]	0.693 ± 0.005[a]	0.414 ± 0.015[a]
Malathion	<LOD	<LOD	<LOD	<LOD
Methamidophos	0.102 ± 0.003[a]	0.138 ± 0.015[a]	0.283 ± 0.005[a]	0.271 ± 0.035[a]
Methidathion	0.102 ± 0.015[a]	0.138 ± 0.012[a]	0.283 ± 0.005[a]	0.228 ± 0.011[a]

LOD: Limit of detection.
LOQ: Limit of quantitation.
tr: trace (between LOD and LOQ).
In each raw, lowercase superscripts (a, b, c, etc.) express statistical variations among different types of brands. In each pesticide, values with similar superscripts are not significantly different from each other but those with different superscripts are significantly different.

4. Discussion

In this study, we analyzed the levels of six metals and 20 pesticide residues in tetra-packed FJs samples (i.e. all samples were in similar packaging) (n = 96) collected from Iran market and assessed probabilistic potential health risks of oral exposure to these chemicals through FJs consumption for Iranians, under carcinogenic and non-carcinogenic scenarios. Mean concentrations of metals and pesticides in FJs samples analyzed in the present work, showed statistically significant variations among different fruit samples and different brands. MRLs were not exceeded in every single sample. Also, we found that the THQs, HIs and ILCRs for metals and pesticides are not indicative of toxic or carcinogenic risks. Based on sensitivity analyses on the input variables, the concentration of metals and pesticides, and the ingestion rate (IR) of FJs had the most influential impact on risk calculation results in terms of THQ and HI levels.

Due to the different occurrence of pests and applied pesticide products, different fruit varieties were expected to have different pesticide application patterns, and different processing conditions of FJs products caused various contamination factors, with great impact on pesticide persistence in plants as well as trace metals. However, in the current study, no significant differences were found in the total pesticide content with comparison to MRLs. Foods are subjected to many processes from very simple washing to complicated processes at home and in industry to extend shelf life, increase variety, improve taste and nutritional value. Washing or cleaning, peeling, blanching, baking, pasteurization, firing, and various techniques and methods generally reduce pesticide residues (Kaushik et al., 2009; Xiao et al., 2021). However, in some cases, more toxic products or metabolites may be formed during processing (Uygun et al., 2007). In addition, some processes can lead to an increase in pesticide residues. For this reason, the effect of different food processes on pesticide residues has some importance for the legal and public health aspect. When assessing the residue behavior of pesticides, not only residue studies on plants or plant products but also residue studies on processed products must be taken into account (Xiao et al., 2021).

Meng et al. (2010) subjected 8 different juice samples (apple, orange, grape, strawberry, carrot, cucumber, tomato, and celery juices) to GC-Orbitrap/MS to get a pesticide residue screen using m-PFC method and at the effective exclusion of matrix interference. The results showed the presence of 350 pesticides with a linear variation of 5–500 μg/kg (LOD 0.3–3.0 μg/kg and LOQ 1.0–10.0 μg/kg) (Meng et al., 2021).

Shamsipur et al. (2016) determined chemicals residue in orange juice samples and some other products using SPE–DLLME–GC–MS and over the ranges of 1–10,000 ng/kg with LOD range of 0.5–1 ng/kg, primicarb (0.17 ± 0.1 ng/g), metalaxyl (1.29 ± 0.1 μg/kg), and ethion (0.43 ± 0.04 ng/g) were detected in orange juice samples (Shamsipur et al., 2016).

A well-rounder risk assessment practice was also done by Jeong et al. (2011) as they analyzed the pesticidal contamination of omija (five flavor berries) fruits and omija juice, and contrasted the residue ranges with the respective EDI and ADI of the residing pesticides in the samples. 33 pesticides were chosen for the screening, being categorized based on their LOD level for fruits and juice sequentially, into three groups: (0.0250 mg/L and 0.00250 mg/L), (0.0125 mg/L and 0.0013 mg/L), and (0.005 mg/L and 0.0005 mg/L). Of the 33 analyzed pesticides, 4 were detected in 320 fresh fruits samples. Ethoprophos was the predominant compound with a detection ratio of 39.06% and a 1.23% ratio of being over MRL, followed by pendimethalin and endosulfan (Jeong et al., 2012). Similarly, among the pesticides analyzed in 100 FJs samples, ethoprophos was the predominant compound followed by hexaconazole and pendimethalin, but none of these 3 pesticides exceeded MRL. Since the EDI to ADI ratio of these 3 compounds were respectively 28.0, 13.6 and 4.5%, it was concluded that the concentrations of these contaminants were relatively low and they would not pose a threat to the consumers' health (Jeong et al., 2012).

Farajzadeh and Dabbagh (2020) determined pesticides residue level in FJ samples of various kinds (peach, grape, sour cherry, orange, apricot, apple, and mango) without the adsorbent synthesis step. The results indicated the presence of ametryn, chlorpyrifos, enconazole, oxadiazon, diniconazole, clodinafop–propargyl, and ebuconazole in the analyzed samples (Farajzadeh and Dabbagh, 2020).

Several factors lead to introduction of pesticides to food. Many farmers do not follow the recommended mixing concentrations on the label directions for pesticides, nor the recommended pre-harvest intervals between applying pesticides and harvesting fruit and vegetables. In addition, farmers and market vendors use pesticides to extend the shelf life of fruit and vegetables. The presence of high levels of pesticide residues in fruit may be partly due to farmers' poor knowledge of good agricultural practices and sustainable farming practices such as crop rotation and minimal tillage (Ssemugabo et al., 2022). Consumption of pesticide residues in fruit and vegetables can decrease along the farm-to-table chain. Depending on the physical and chemical properties of a particular pesticide, residues can degrade over time through hydrolysis, oxidation, microbial degradation, photodegradation, and heat degradation. Storage and post-harvest practices in industrial or

Table 9
Probabilistic THQ, HI, and ILCR calculated for carcinogenic and non-carcinogenic metals.

Fruit juice sample	Percentile	Cd	Hg	Cr	As	Ni	Pb
		THQ	THQ	THQ	ILCR	ILCR	ILCR
Apple	50th	6.00×10^{-3}	5.93×10^{-4}	2.74×10^{-2}	4.17×10^{-7}	4.21×10^{-5}	2.36×10^{-9}
	95th	1.52×10^{-2}	1.51×10^{-3}	6.98×10^{-2}	5.83×10^{-7}	5.90×10^{-5}	3.31×10^{-9}
Grape	50th	2.96×10^{-4}	5.93×10^{-4}	1.34×10^{-3}	3.64×10^{-6}	4.60×10^{-5}	2.11×10^{-7}
	95th	7.56×10^{-4}	1.51×10^{-3}	3.44×10^{-2}	5.10×10^{-6}	6.43×10^{-5}	2.96×10^{-7}
Mango	50th	4.86×10^{-3}	6.00×10^{-4}	7.43×10^{-2}	2.24×10^{-5}	1.77×10^{-6}	2.36×10^{-9}
	95th	1.24×10^{-2}	1.52×10^{-3}	1.90×10^{-1}	3.31×10^{-5}	2.48×10^{-6}	3.31×10^{-9}
Orange	50th	3.11×10^{-4}	6.22×10^{-4}	3.78×10^{-4}	1.40×10^{-4}	2.23×10^{-5}	2.36×10^{-9}
	95th	7.92×10^{-4}	1.58×10^{-3}	9.64×10^{-4}	1.96×10^{-4}	3.13×10^{-5}	3.15×10^{-9}
Peach	50th	3.11×10^{-4}	6.22×10^{-4}	1.47×10^{-3}	3.85×10^{-7}	5.25×10^{-5}	2.18×10^{-9}
	95th	7.92×10^{-4}	1.58×10^{-3}	3.76×10^{-3}	4.24×10^{-7}	6.30×10^{-5}	2.84×10^{-9}
Pineapple	50th	2.82×10^{-4}	5.65×10^{-4}	7.14×10^{-3}	3.85×10^{-7}	4.38×10^{-5}	2.18×10^{-9}
	95th	7.20×10^{-4}	1.44×10^{-3}	1.82×10^{-2}	4.24×10^{-7}	5.26×10^{-6}	2.84×10^{-9}
Pomegranate	50th	3.67×10^{-4}	7.35×10^{-4}	2.63×10^{-4}	3.85×10^{-7}	3.25×10^{-6}	2.18×10^{-9}
	95th	9.36×10^{-4}	1.87×10^{-3}	6.71×10^{-4}	4.24×10^{-7}	3.90×10^{-5}	2.84×10^{-9}
Sour cherry	50th	3.10×10^{-3}	2.66×10^{-2}	4.07×10^{-3}	1.72×10^{-5}	1.67×10^{-5}	2.18×10^{-9}
	95th	7.90×10^{-3}	6.80×10^{-2}	1.03×10^{-2}	1.90×10^{-4}	2.00×10^{-5}	2.84×10^{-9}
HI (50th) = 0.021 **HI (95th) = 0.055**							
ILCR	50th	–	–	–	4.25×10^{-5}	2.85×10^{-5}	2.84×10^{-8}
ILCR	95th	–	–	–	5.30×10^{-5}	3.71×10^{-5}	3.97×10^{-8}

THQ: Target hazard quotient.
HI: Hazard index.
ILCR: Incremental lifetime cancer risks.

residential areas can also affect residues level (Amvrazi, 2011). Post-harvest processing can decrease or increase the concentration of pesticide residues in fruit. The use of post-harvest chemicals to extend product shelf life has been reported to increase levels of pesticide residues. In summary, at every stage of the food chain, post-harvest handling and processing methods can affect levels of pesticide residues (James and Zikankuba, 2017).

Several factors influence the resistance of pesticides in food matrices. Some pesticides degrade rapidly under the influence factors including environmental conditions, characteristics of plants and pesticides, while others remain stable. As a side note, the physicochemical properties of pesticides such as solubility in water, pesticide volatilization, soil absorption coefficient, bio-concentration factor, half-life cycle, formulation, concentration, environmental conditions (e.g. air movement, precipitation, radiation, temperature, light relative humidity) affect the permanence of their products. Moreover, plant morphology and metabolic activity are the other main factors in the persistence of pesticides on plants. The processes applied to food are categorized as pre-treatment (e.g. washing, peeling, chopping), heat treatment (e.g. blanching, boiling, pasteurization, sterilization, and frying), production (e.g. cooking, canning, drying, and post-harvest storage. Several studies have shown that various pesticides remain stable or decrease only very slowly during food storage in the refrigerator or freezer. The storage temperature and the structure of the pesticide are important since compounds with low stability/high volatility are affected by temperature (Velioglu et al., 2018). For example, carbamate thiodicarb residues are stable and decrease at 10 and 4.5 °C, respectively (Yigit and Velioglu, 2020).

Monitoring the concentration of metals in commercial FJs is very important for safeguarding the consumers' health. In a study by Abdel-Rahman et al. (2019), samples of carbonated drinks, juices and flavored yoghurts were free (<LOD) of Pb, Cd, and Cr (Abdel-Rahman et al., 2019). According to the study by Bingl et al. (2010), As, Cu, Zn, Cd, and Pb (0.037, 0.070, 0.143, 0.005, and 0.029 mg/kg, respectively) were found in soft drink samples (Bingöl et al., 2010). In a study by Ogunlana et al. (2015), metal concentrations in 30% of the soft drink samples, while in the remaining 70% of the soft drink samples, the concentration of at least a metal exceeded WHO maximum limits (Ogunlana et al., 2015). Shariatifar et al. (2020) reported that the concentrations of Pb, Ni, Cr, Cu, Ba, Hg, Cd, and As in 150 commercial soft drinks marketed in Iran were lower than the EU limits. However, the concentrations of Fe, Al, Mn, and Zn were higher than those limits. They also indicated that the calculated HI reflected no non-carcinogenic risk by oral exposure to multiple metals through consumption of the examined soft drinks (Shariatifar et al., 2020).

A study from Turkey showed that the concentrations of Ag, As, Be, Bi, Cd, Co, Pb, Se, and V in the examined FJs were lower than the maximum limits international and Turkish codex value (Kılıç et al., 2015). Godwill et al. (2015) showed that the concentration of Pb in 22 samples of soft drink samples ranged from 0.17 to 3.39 mg/L, Hg ranged from 0.29 to 11.32 mg/L, and Cd only in one sample showed 0.149 mg/L (Godwill et al., 2015). Shariatifar et al. (2020) showed that the MCS of multivariate sensitivity analysis revealed that metal concentration (0.41%), exposure duration (0.34%), and soft drink intake rates (0.35%) were the important factors in the risk assessment of soft drink samples (Shariatifar et al., 2020).

In future works, comparisons should be made between the current methodology and risk characterizing methods that consider the aggregated exposure (Goumenou and Tsatsakis, 2019; Năstăsescu et al., 2020; Renieri et al., 2019; Stavroulaki et al., 2022).

5. Conclusion

In this work, human health risk of exposure of the general Iranian population to 6 trace metals and 20 pesticides through consumption of FJs, was assessed. Out of 96 FJs samples collected during 2021–2022, none exceeded MRLs set by the EU for any of the chemicals. Human health risk reflected as total HI value of three groups of pesticides (CBs, PYs, and OPs) was <1.0. Trace metals, based on the carcinogenic calculation, were not found to pose risk. Moreover, HI values for non-carcinogenic trace metals were below 1.0. The MCS of multivariate sensitivity analysis of input factors showed that the concentrations of trace metals and pesticides as well as the IR were the important sensitive

Table 10
Probabilistic THQ and HI calculated for pesticides residue.

Pesticide	Percentile	THQ for Apple juice	THQ for Grape juice	THQ for Mango juice	THQ for Orange juice	THQ for Peach juice	THQ for Pineapple juice	THQ for Pomegranate juice	THQ for Sour cherry juice
Carbamate									
Carbaryl	50th	6.00×10^{-5}	NA	1.06×10^{-4}	2.87×10^{-4}	NA	NA	NA	NA
	95th	8.52×10^{-5}	NA	1.51×10^{-4}	4.09×10^{-4}	NA	NA	NA	NA
Carbofuran	50th	2.75×10^{-2}	2.45×10^{-1}	NA	9.67×10^{-3}	1.14×10^{-1}	NA	1.14×10^{-2}	1.02×10^{-1}
	95th	3.90×10^{-2}	3.48×10^{-1}	NA	1.37×10^{-2}	1.62×10^{-1}	NA	2.08×10^{-2}	1.46×10^{-1}
Methomyl	50th	9.96×10^{-4}	2.63×10^{-3}	NA	2.40×10^{-3}	2.89×10^{-2}	NA	NA	1.77×10^{-3}
	95th	1.37×10^{-3}	3.62×10^{-3}	NA	3.31×10^{-3}	3.98×10^{-2}	NA	NA	2.44×10^{-3}
Oxamyl	50th	NA	NA	3.06×10^{-3}	1.10×10^{-2}	7.55×10^{-3}	NA	NA	NA
	95th	NA	NA	4.43×10^{-3}	1.60×10^{-2}	1.09×10^{-2}	NA	NA	NA
Pirimicarb	50th	NA	NA	NA	NA	6.00×10^{-5}	NA	NA	3.35×10^{-5}
	95th	NA	NA	NA	NA	8.60×10^{-5}	NA	NA	4.58×10^{-5}
Propamocarb	50th	NA	NA	NA	NA	NA	NA	NA	NA
	95th	NA	NA	NA	NA	NA	NA	NA	NA
HI (50th) = 0.071									
HI (95th) = 0.101									
Pyrethroid									
Deltamethrin	50th	4.18×10^{-4}	6.52×10^{-3}	NA	NA	1.03×10^{-3}	NA	NA	8.25×10^{-4}
	95th	5.99×10^{-4}	9.34×10^{-3}	NA	NA	1.48×10^{-3}	NA	NA	1.12×10^{-3}
Permethrin	50th	1.64×10^{-5}	5.24×10^{-4}	NA	NA	1.72×10^{-5}	NA	5.38×10^{-4}	2.55×10^{-5}
	95th	1.80×10^{-5}	5.78×10^{-4}	NA	NA	1.89×10^{-5}	NA	5.94×10^{-4}	2.68×10^{-5}
HI (50th) = 0.001									
HI (95th) = 0.002									
Organophosphorus									
Acephate	50th	6.77×10^{-5}	NA	NA	NA	9.15×10^{-6}	NA	NA	NA
	95th	7.11×10^{-5}	NA	NA	NA	9.60×10^{-6}	NA	NA	NA
Azinphos-methyl	50th	3.31×10^{-4}	1.61×10^{-3}	1.59×10^{-4}	NA	2.99×10^{-4}	NA	NA	9.01×10^{-5}
	95th	3.48×10^{-4}	1.69×10^{-3}	1.67×10^{-4}	NA	3.14×10^{-4}	NA	NA	9.46×10^{-5}
Chlorpyrifos	50th	1.19×10^{-3}	5.89×10^{-2}	2.13×10^{-3}	1.24×10^{-3}	1.81×10^{-2}	7.89×10^{-3}	7.08×10^{-3}	8.5×10^{-3}
	95th	1.25×10^{-3}	6.19×10^{-2}	2.24×10^{-3}	1.30×10^{-3}	1.90×10^{-2}	8.29×10^{-3}	7.44×10^{-3}	8.92×10^{-3}
Chlorpyrifos-methyl	50th	2.08×10^{-5}	1.04×10^{-5}	5.91×10^{-5}	1.51×10^{-5}	4.30×10^{-4}	6.00×10^{-5}	2.20×10^{-5}	2.73×10^{-5}
	95th	2.61×10^{-5}	1.31×10^{-5}	7.45×10^{-5}	1.90×10^{-5}	5.42×10^{-4}	7.56×10^{-5}	2.77×10^{-5}	3.44×10^{-5}
Diazinon	50th	1.24×10^{-2}	2.60×10^{-3}	3.58×10^{-3}	9.67×10^{-3}	1.46×10^{-2}	1.99×10^{-2}	2.45×10^{-2}	1.83×10^{-2}
	95th	1.56×10^{-2}	3.27×10^{-3}	4.51×10^{-3}	1.21×10^{-2}	1.84×10^{-2}	2.50×10^{-2}	3.09×10^{-2}	2.31×10^{-2}
Dimethoate	50th	8.06×10^{-2}	6.61×10^{-3}	NA	2.66×10^{-2}	5.55×10^{-2}	NA	9.38×10^{-2}	1.27×10^{-2}
	95th	1.07×10^{-1}	8.83×10^{-3}	NA	3.55×10^{-2}	7.41×10^{-2}	NA	1.25×10^{-1}	1.70×10^{-2}
Ethion	50th	3.14×10^{-1}	2.99×10^{-1}	2.88×10^{-1}	2.97×10^{-1}	2.33×10^{-1}	2.87×10^{-1}	2.58×10^{-1}	4.15×10^{-1}
	95th	4.28×10^{-1}	4.08×10^{-1}	3.92×10^{-1}	4.04×10^{-1}	3.17×10^{-1}	3.91×10^{-1}	3.51×10^{-1}	5.66×10^{-1}
Fenitrothion	50th	9.71×10^{-4}	6.58×10^{-3}	9.31×10^{-3}	6.16×10^{-3}	7.02×10^{-3}	9.89×10^{-3}	1.03×10^{-2}	1.03×10^{-3}
	95th	1.32×10^{-3}	8.96×10^{-3}	1.26×10^{-2}	8.40×10^{-3}	9.57×10^{-3}	1.34×10^{-2}	1.41×10^{-2}	1.41×10^{-3}
Fenthion	50th	9.50×10^{-3}	7.92×10^{-3}	1.86×10^{-3}	1.16×10^{-3}	1.80×10^{-2}	2.66×10^{-2}	4.11×10^{-2}	7.91×10^{-3}
	95th	1.22×10^{-2}	1.01×10^{-2}	2.39×10^{-3}	1.49×10^{-3}	2.31×10^{-2}	3.42×10^{-2}	5.28×10^{-2}	1.01×10^{-2}
Malathion	50th	NA	NA	NA	NA	NA	NA	NA	NA
	95th	NA	NA	NA	NA	NA	NA	NA	NA
Methamidophos	50th	1.52×10^{-2}	4.73×10^{-2}	8.78×10^{-2}	5.20×10^{-2}	1.04×10^{-1}	4.73×10^{-2}	9.62×10^{-2}	NA
	95th	1.60×10^{-2}	4.97×10^{-2}	9.22×10^{-2}	5.47×10^{-2}	1.09×10^{-1}	4.97×10^{-2}	1.01×10^{-1}	NA
Methidathion	50th	9.68×10^{-2}	1.12×10^{-2}	NA	3.04×10^{-2}	1.07×10^{-2}	NA	3.63×10^{-2}	2.94×10^{-2}
	95th	1.01×10^{-1}	1.17×10^{-2}	NA	3.19×10^{-2}	1.13×10^{-2}	NA	3.81×10^{-2}	3.09×10^{-2}
HI (50th) = 0.464									
HI (95th) = 0.600									
HI (Total 50th) = 0.537									
HI (Total 50th) = 0.702									

THQ: Target hazard quotient.
HI: Hazard index.
NA: Not available due to lack of access to concentration data (concentration <LOD).

factors in the risk assessment of FJs samples. Generally, it seems that trace metals and pesticides intake through FJs consumption pose no carcinogenic and non-carcinogenic risk to Iranian consumers. Agricultural and industrial policies can be applied to manage risk by using crops and their related products less likely to accumulate contaminants to reach a more appropriate balance between improve food safety and health risks. Additional studies are needed to assess trace metals and pesticides intakes from consumption of other fruit products and their resultant human health risk.

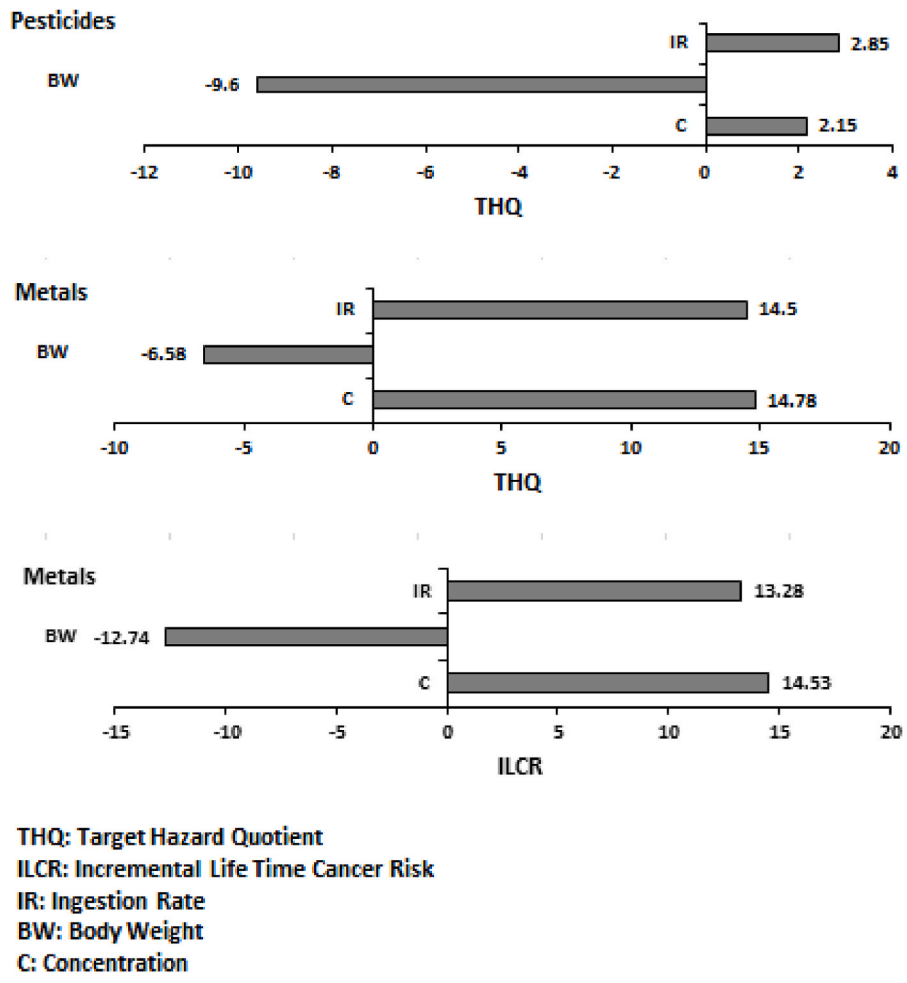

Fig. 2. The influence of different parameters (%) on the calculated THQ and ILCR.

CRediT authorship contribution statement

Seyedeh Faezeh Taghizadeh: Data curation, Formal analysis, Writing – original draft. **Gholamreza Karimi:** Investigation, Methodology, Project administration. **Manolis Tzatzarakis:** Methodology, Validation, Writing – review & editing. **Ioannis Tsakiris:** Methodology, Validation, Writing – review & editing. **Hamid Ahmadpourmir:** Data curation, Formal analysis. **Majid Azizi:** Investigation, Formal analysis. **Asma Afshari:** Data curation, Formal analysis. **Vahideh Ghorani:** Data curation, Formal analysis. **Fatemeh Yarmohammadi:** Data curation, Formal analysis, Writing – original draft. **Aristidis Tsatsakis:** Conceptualization, Project administration, Supervision, Writing – review & editing. **Ramin Rezaee:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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