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RESEARCH

Estimation of selected elemental impurities by inductively coupled plasma-mass spectroscopy (ICP-MS) in commercial and fresh fruit juices

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Abstract The main objective of the study is the estimation of elemental impurities in selected packaged commercial fruit juices and fresh fruit juices available in Ahmedabad, Gujarat. Estimation of seventeen samples (9 commercial fruit juices and 8 fresh fruit juices) was carried out for elemental impurities which include lead, cadmium, arsenic, mercury, methyl mercury, nickel, chromium, tin, copper, and zinc. Inductively coupled plasma-mass spectroscopy (ICP-MS) with microwave-assisted sample digestion was used to determine the element content of samples. The ICP-MS method was confirmed for accuracy by performing validation with validation parameters such as linearity, precision, and accuracy. The method's trueness was confirmed with single-element standards. The results were compared with Food Safety and Standards Authority of India (FSSAI) standards. Arsenic, mercury, methyl mercury, tin, and copper were within permissible limits in all samples of fruit juices. The concentration of lead was found to exceed limits in 5 samples of commercial fruit juices which were 0.07, 0.13, 0.18, 0.21, and 0.38 mg/kg, respectively. The concentration of nickel was found to be above permissible limits in 5 samples (1.26, 1.72, 1.95, 3.24, and 4.07 mg/kg) of commercial fruit juices and 6 samples of fresh fruit juices (0.19. 0.21, 0.21, 0.42, 0.66, and 2.42 mg/kg). The concentration of chromium was found to be above permissible limits in 5 samples (3.13, 3.51, 4.29, 5.91, and 6.02 mg/kg) of commercial fruit juices and 6 samples of fresh fruit juices (0.80. 0.88, 0.98, 0.99, 1.16, and 8.95 mg/kg). Health risk assessment was performed for elemental impurities. Target hazard quotient and health risk index for elemental impurities were found to be less than 1 which is considered safe for consumers. Hazard index for elemental impurities was found to be more than 1 in two samples which can cause serious non-carcinogenic risk to consumers. Target carcinogenic risk was found within acceptable levels for all elemental impurities in all samples of fruit juices. Essential elements like copper and zinc are required by the human body for various body functions but heavy metals like lead, arsenic, and cadmium are highly toxic to human beings due to their adverse effects and it needs to be controlled. Lead poses a significant health risk to human health. It is essential to

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further monitor the levels of elemental impurities on a regular basis in commercial and fresh fruit juices.

Keywords Commercial fruit juices · Elemental impurities · Fresh fruit juices · ICP-MS · FSSAI

Introduction

Fruit juices are popularly consumed throughout the world due to their nutritional benefits. Fruit juices are prepared from a single fruit or a combination of different varieties of fruits, either commercial or home-based or fresh fruit juices supplied by street vendors. Fruit juices are a good source of vitamins, particularly vitamin C, folic acid, and group B vitamins and minerals such as manganese, potassium, phosphorous, magnesium, calcium, zinc, and selenium (Kowalska et al., 2020). Fruit juices also contain fiber which helps in regulating metabolic activities (Lattimer & Haub, 2010). The advantages of fruit juices include antioxidant properties, improvement of cardiovascular health, and anti-inflammatory (Zheng et al., 2017). The scientific name of Aloe vera is *Aloe barbadensis* and it belongs to the Liliaceae family. The benefits of Aloe vera juice include emollient, antioxidant, anti-inflammatory, aphrodisiac, anti-microbial, and also in cosmetic purposes (Benzidia et al., 2019). The combination of aloe vera with fruit juices has been a popular choice among consumers. It has the potential to serve as a functional food product due to its good anti-oxidant, anti-microbial, and both benefits of aloe vera juice and fruit juices (Sonawane et al., 2021).

Fruit juices contain macro and microelements. The elements such as sodium, phosphorus, calcium, and potassium are essential elements but heavy metals such as lead, cadmium, arsenic, and mercury can cause toxic effects even at low levels (Dehelean & Magdas, 2013). The elements which are nontoxic if the concentration is below 100 ppm are nickel, chromium, tin, and aluminum (Williams et al., 2009). The elements such as copper, zinc, and iron are essential elements but can cause harmful effects at high levels. The source of elemental impurities in fruit juices could be attributed to the cultivation and agricultural conditions in which fruits are grown (Pohl et al., 2018). The bioaccumulative potential of metals can cause significant health risks to human beings. Therefore, it is important to estimate elemental impurities in fruit juices for safety as well as nutritive considerations. Food Safety and Standards Authority of India (FSSAI) safeguards public health by suitable regulations and guidelines for India. The regulation "Food Safety and Standards (Contaminants, Toxins and Residues) Regulations, 2011 dated 27.01.2022" describes limits for metal contaminants present in food which even includes fruit juices ("Food Safety and Standards (Contaminants, Toxins and Residues) Regulations, 2011," 27-01-2022).

The objective of the present study was to determine the content of lead, cadmium, arsenic, mercury, methyl mercury, nickel, chromium, tin, copper, and zinc in commercial (9 samples) and fresh fruit juices (8 samples) using inductively coupled plasma-mass spectroscopy (ICP-MS Agilent 7700 ×) with quadrupole mass analyzer was used to determine the element content of samples. Microwave-assisted sample digestion with 4 mL concentrated nitric acid and 1 mL hydrogen peroxide was performed for all the samples. The working standard solutions were prepared from single-element heavy metal certified reference material (lead, cadmium, arsenic, mercury, methyl mercury, nickel, chromium, tin, copper, and zinc) and linearity was carried out. The concentrations of the samples were obtained in parts per million (ppm). The results were compared with permissible limits as per FSSAI. Furthermore, we have carried out health risk assessment using statistical software. It is expected that our study would create awareness to manufacturers for the metal contamination in fruit juices and measures can be implemented to reduce the toxic effects of metals in humans. It also serves as a guide to consumers about the effects of metal contamination due to consumption of fruit juices.

Materials and methods

Sample procurement

Commercial fruit juice samples of different brands including combination of aloe vera and fruit juice were collected from retail stores in Ahmedabad city, India. Fresh fruit juice samples from street vendors were collected from various parts of the city. Home-based samples 10 and 11 were considered for the study. The investigation includes seventeen samples. The sampling date was between December 2018 and

October 2019. Details of the commercial fruit juices considered for the study are provided in Table 1. Details of fresh fruit juices considered for the study are provided in Table 2.

Chemicals and reagents

All reagents used for the analysis were of analytical grade and heavy metal free. Milli-Q ultrapure water (type-1) obtained from Merck Millipore; India was used. All reagents were at least of analytical purity grade. Distilled nitric acid ultrapure grade and hydrogen peroxide 30% (v/v) were procured from Merck, India.

The working standard solutions were prepared from single-element heavy metal certified reference material (lead, cadmium, arsenic, mercury, methyl mercury, nickel, chromium, tin, copper, and zinc) National Institute of Standards and Technology (NIST) Traceable procured from Sigma-Aldrich, India.

Validation

Validation was carried out using reported methods (Yüksel et al., 2023).

Sample Preparation

Fruit juice samples were digested based on microwave-assisted sample digestion.

A total of 0.5 g of fruit juice sample is weighed and added in a digester tube with 4 mL concentrated nitric acid, 1 mL hydrogen peroxide, and 5-mL Milli-Q water. Microwave digestion (multiwave GO plus microwave digester, Anton Paar) was performed. A

Table 1 Details of commercial fruit juices samples for the study

Sample number	Brand code	Description of samples
1	A	Orange fruit juice
2	B	Orange fruit juice
3	X	Aloe vera juice
4	Y	Combination of orange fruit juice and aloe vera pulp
5	Z	Combination of orange fruit juice and aloe vera pulp
6	A	Mixed fruit juice (apple, mango, banana, orange, guava, apricot, lime, passion fruit, pineapple)
7	B	Mixed fruit juice (apple, mango, guava, orange, banana, apricot, peach)
8	Y	Combination of mixed fruit juice and aloe vera pulp (orange, pomegranate, apricot, apple, banana, mango, peach, pineapple, litchi, guava)
9	Z	Combination of mixed fruit juice and aloe vera pulp (apple, banana, orange, peach, mango, guava, litchi, pineapple)

Table 2 Details of fresh fruit juices samples for the study

Sample number	Area of Ahmedabad from where fruit juices were collected	Description of samples
10	Home-based	Fresh orange juice
11	Home-based	Fresh mixed fruit juice (mixed fruit (apple, banana, orange, peach, mango, litchi, pineapple, pomegranate, lime, grapes, kiwi, raspberry))
12	Area 1	Fresh orange juice
13	Area 2	Fresh orange juice
14	Area 3	Fresh orange juice
15	Area 4	Fresh mixed fruit juice (pineapple, orange, grapes, lime)
16	Area 5	Fresh mixed fruit juice (pineapple, orange, grapes, kiwi, lime)
17	Area 6	Fresh mixed fruit juice (pineapple, orange, grapes, pomegranate)

blank sample without fruit juice sample was included in every digestion step.

Sample digestion is carried out in two stages.

Stage 1 Sample digestion Power: 1600 W, Temperature: 180 °C, Hold Time: 20 min, Cool time: 20 min

Stage 2 Sample digestion Power: 1600 W, Temperature: 200 °C, Hold Time: 20 min, Cool time: 20 min

The cooled digested solution was then filtered through Whatman Filter paper 1 and the final volume is made with 10-mL Milli Q water.

Determination of metallic impurities

The metallic content of lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg), methyl mercury, nickel (Ni), chromium (Cr), tin (Sn), copper (Cu), and zinc (Zn) was determined with inductively coupled plasma-mass spectrometry (Agilent 7700 ×) with quadrupole mass analyzer.

The plasma gas used for the determination was helium. The instrumental conditions maintained for ICP-MS are shown in Table 3.

Certified single-element standard solutions (1000 mg/L) were used for the calibration curve.

Health risk assessment

Health risk assessment was calculated by finding the daily intake (mg/day/person) of selected elemental impurities through consumption of fruit juices and comparing them to the reference oral dose (Yüksel, Arıca, & Söylemezoğlu, 2021).

Table 3 Instrumental operating conditions for ICP-MS

Name	Value with unit
Carrier gas	0.80 L/min
Plasma gas	15 L/min
Auxillary gas	0.90 L/min
Forward power	1548 W
Reflected power	53 W
Plasma frequency	28.04 MHz
He gas	0.25 mL/min
Cell entrance	−29.9 V
Cell exit	−49.8 V
Inlet temperature	34.6 °C
Internal temperature	43.7 °C

Estimated daily intake (EDI): The following equation was used to compute EDI:

$$\mathrm{EDI} = C \times 1$$

C metal concentration in fruit products
I daily intakes

Health risk index (HRI):

The health risk index (HRI) is a ratio between the estimated daily intake (EDI) of the metal, the reference oral dosage (RfD) for each metal, and the body weight (BW) of the consumers. Metals with an HRI less than 1 are considered safe for consumers (Topaldemir et al., 2023). The following equation was used to compute HRI:

$$\mathrm{HRI} = \sum \frac{n\left(c_{\mathrm{n}} \times \mathrm{Dn}\right)}{\mathrm{RfD} \times \mathrm{Bw}}$$

c_{n} mean metal concentration in specific fruit product on fresh fruit weight basis (mg/kg)
Dn Avg daily intake rate of a specific fruit product in a whole year
RfD showed safe level of exposure by oral intake for lifetime
Bw Avg. body weight

Target hazard quotient (THQ): THQ and HRI were used to assess non-carcinogenic health risk to humans. The following equation was used to compute THQ:

$$\mathrm{THQ} = \frac{C \times I \times 10^{-3} \times \mathrm{EFr} \times \mathrm{EDtot}}{\mathrm{RfD} \times \mathrm{Bw} \times \mathrm{ATn}}$$

C represents mean metals level in fruit product (mg/kg); *I* is the ingestion rate (g/day/person); EFr is the exposure frequency (days/year); Edtot is the total exposure duration (years); Bw is the average body weight adult (kg); and Atn is the averaging time, non-carcinogens (EDtot 365 days/year).

Hazard index (HI)

Hazard index (HI) is the sum of hazard quotients for metals and was computed by the following equation (Abbasi et al., 2020; Bayram Yüksel et al., 2023):

$$\mathrm{HI} = \mathrm{THQ1} + \mathrm{THQ2} + \ldots . + \mathrm{THQ}$$

THQ1-n is target hazard quotients for 1-n metals

Target cancer risk (TCR): TCR was used to assess non-carcinogenic health risk to humans. The following equation was used to compute TCR in fruit juices (Abbasi et al., 2020):

$$TCR = \frac{Cb \times I \times 10^{-3} \times CPS \times EFr \times EDtot}{BWa \quad \times ATc}$$

where ATc is averaging time carcinogens; carcinogens potency slope oral (μg/g/day) is CPS; EFr is the exposure frequency (days/year); EDtot is the total exposure duration (years); BWa is the average body weight; and Cb is metal concentration.

Results and discussion

As the consumption of fruit juices is very popular throughout the world, the determination of commercial and fresh fruit juices plays an important role in health and safety of the public. The present study involves the estimation of 17 fruit juice samples for their elemental content. The results of commercial fruit juices are mentioned in Table 4 and results of fresh fruit juices are mentioned in Table 5. The limits were considered as per FSSAI standards. Heavy metals are of major concern due to their toxic nature. Heavy metals such as lead, cadmium, arsenic, mercury, and methyl mercury were considered in the evaluation for commercial and fresh fruit juices. Other elements such as nickel, chromium, and tin on long-term exposure lead to toxicity. Elements such as copper and zinc have nutritive benefits but their limit should not be exceeded as per FSSAI guidelines.

Lead is a heavy metal that is highly toxic and carcinogenic which affects neurological, cardiovascular, renal, hematological, gastrointestinal, and other body systems ("Preventing disease through healthy environments Exposure to lead: a major public health concern,", 2019). The toxicity in children has higher impact on children as compared to adults as children have more soft tissues than adults. Long-term exposure can cause various health hazards like behavior problems, increase in blood pressure, and anemia. It may cause damage in the kidney and the brain that may result in death (Bozalan et al., 2019; Wani et al., 2015; Yuksel et al., 2017). Trace levels of exposure to lead can cause irreversible neurological damage. Lead was found to exceed the permissible limit of FSSAI in samples 1,2, 3, 4, and 5 commercial juices. Lead poisoning mainly occurs by ingestion of food and water contaminated with lead. It may occur through fruits and vegetables where soil is contaminated with high level of lead. The source of lead contamination in food is mainly affected by environmental factors, food processing and handling, equipment, and packaging used for food and industrial emission can cause deposition in crop plants (Gupta & Shaw, 2011). Water is also an important source of contamination in food ("Preventing disease through healthy environments Exposure to lead: a major public health concern,", 2019). To avoid lead contamination in fruit juices, good manufacturing practices should be

Table 4 Results of elemental impurities for commercial fruit juices

Element	Limits as per FSSAI (ppm)	Results (ppm)								
		Sample								
		1	2	3	4	5	7	8	9	10
Lead (Pb)	0.05	0.13	0.07	0.38	0.21	0.18	BLQ	BLQ	BLQ	BLQ
Cadmium (Cd)	1.5	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Arsenic (As)	0.2	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Mercury (Hg)	1.0	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Methyl mercury	0.25	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Nickel (Ni)	0.02	4.07	1.26	3.24	1.95	1.72	BLQ	BLQ	BLQ	BLQ
Chromium (Cr)	0.02	6.20	3.13	5.91	3.51	4.29	BLQ	BLQ	BLQ	BLQ
Tin (Sn)	250	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Copper (Cu)	5.0	4.10	1.53	5.23	1.90	1.19	1.06	0.69	0.76	0.82
Zinc (Zn)	5.0*	3.65	2.32	5.17	2.45	2.63	2.04	1.82	1.80	1.90

*Deleted as per Food Safety and Standards Authority of India updated guideline of Contaminants dated 31.08.2018

BQL below limit of quantification (quantification limit—0.05)

Table 5 Results of elemental impurities for fresh fruit juices

Element	Limits as per FSSAI (ppm)	Results (ppm)							
		Sample							
		6	11	12	13	14	15	16	17
Lead (Pb)	1.0	BLQ	BLQ	0.17	0.11	0.15	0.12	0.06	0.10
Cadmium (Cd)	1.5	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Arsenic (As)	0.2	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Mercury (Hg)	1.0	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Methyl mercury	0.25	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Nickel (Ni)	0.02	BLQ	BLQ	0.42	2.42	0.21	0.21	0.19	0.66
Chromium (Cr)	0.02	BLQ	BLQ	0.98	8.95	0.99	0.88	0.80	1.16
Tin (Sn)	250	BLQ	BLQ	7.14	6.75	6.74	6.37	6.24	7.18
Copper (Cu)	5.0	0.86	0.50	1.12	1.06	0.99	1.00	0.99	0.95
Zinc (Zn)	5.0*	1.11	0.90	17.07	18.54	19.49	14.81	13.13	13.83

*Deleted as per Food Safety and Standards Authority of India updated guideline of Contaminants dated 31.08.2018

BQL below limit of quantification (quantification limit—0.05)

followed. Limitations on industrial emissions, gasoline, and contaminated water can also reduce lead levels in fruit juices (Gupta & Shaw, 2011). Further fruits should be properly washed, peeled, and handled to reduce lead levels.

Cadmium is carcinogenic to humans and primarily accumulation takes place in kidneys and bones, affecting calcium metabolism and causing osteoporosis and osteomalacia, and in the lungs, causing acute pneumonitis and chronic obstructive pulmonary disease and also contributing to smoking-related lung disease. Cadmium causes lung cancer and may also cause kidney and prostate cancer therefore cadmium is classified in group 1 as carcinogenic by International Agency for Research on Cancer (Plangsombat et al., 2016). Cadmium causes genetic effects by alterations in DNA repair and tumor suppressor proteins and epigenetic and signal transduction processes (Straif et al., 2009). The source of cadmium contamination in food could be water contamination from wastewater, industrial processes like mining, smelting, and fossil fuel combustion, smoking, sewage sludge, and fertilizers cause contamination of cadmium in soil (Gautam et al., 2009; Sharma et al., 2011). To avoid cadmium contamination in food includes proper washing and peeling of fruits, reducing industrial emissions in water, safe handling and disposing of cadmium-containing waste in water, and reducing tobacco smoke and cadmium-containing fertilizers (Plangsombat et al., 2016). Cadmium was found to be below the quantitation limit in all samples of commercial and fresh fruit juices.

Arsenic is highly toxic and carcinogenic to humans. Arsenic is found in three forms that include inorganic, organic, and gaseous form. Inorganic arsenic compounds are found generally in water while organic arsenic compounds are found especially in seafood. Inorganic arsenic compounds are highly toxic than organic arsenic compounds(Yüksel et al., 2010). Inorganic arsenic causes skin pigmentation and lesions. Arsenic can cause cancers of the skin, bladder, and lungs, and thus arsenic is classified in group 1 as carcinogenic by International Agency for Research on Cancer (Kalumbi et al., 2020). Arsenic poisoning affects millions of people every year through occupational and environmental exposure. Arsenic causes alteration of DNA repair and causes genomic instability. Other effects include peripheral neuropathy, diabetes, black foot disease, and passes placenta barrier (Jaishankar et al., 2014). The primary source of arsenic toxicity includes soil, contaminated water, and food products. The sources of arsenic contamination could be natural such as volcanic eruption, industrial activities like mining, smelting, combustion, pesticide production, and its use, antifungal wood preservatives, and smoking. In food, fish and shellfish and mainly drinking water are a major concern for arsenic (Many countries do not pass the criteria of WHO for drinking water) (Mukhopadhyay et al., 2021).

To reduce arsenic contamination in food, measures to reduce arsenic concentration in drinking water (WHO recommends a value of 10 μg/L in exposed areas) such as arsenic removal systems, substitution of high arsenic sources and blending of low and high arsenic water, and regular testing (Alengebawy et al., 2021). Industrial processes like smelting, mining, combustion, and usage of pesticides should be reduced (Alengebawy et al., 2021). Arsenic was below the quantitation limit in all tested samples of commercial and fresh fruit juices.

Mercury is a highly toxic heavy metal and it occurs in various forms (i) elemental or metallic, (ii) inorganic (mercuric chloride), and (iii) organic (methylmercury, ethylmercury) (Roy et al., 1971). Methyl mercury is generated from inorganic mercury and occurs in aquatic environments by microbial action (Mandal et al., 2000). Elemental mercury is in liquid form which vaporizes rapidly in the atmosphere and then settles in aquatic environments altering in the form of methyl mercury and absorbed by fishes, sharks, zooplankton, etc (Zhu et al., 2010). Methyl mercury is toxic to the nervous system (central and peripheral), digestive, kidney, liver, and reproductive organs ("Joint, F. A. O. W. H. O. Expert Committee on Food Additives World Health, Organization Food, Agriculture Organization of the United, Nations Evaluation of certain food additives and contaminants: sixty-first report of the Joint FAO/WHO Expert Committee on Food Additives,", 2004). The kind of mercury, the amount, and the pace of exposure all affect how dangerous it is to humans. The brain is the primary organ that inhaled mercury vapor targets. The severity of the toxicity depends on the dosage, for example, prolonged acute exposure to elemental mercury vapor causes severe pneumonitis, which in severe cases can be fatal (Bernhoft, 2012).

Mercury toxicity causes neurological and behavioral disorders causing tremors, neuromuscular, memory loss, etc. The source of mercury and methylmercury contamination could be the consumption of tainted fish and shellfish, industrial emissions, dental amalgam outgassing, and inhaling mercury vapors (Roy et al., 1971). To prevent mercury exposure and facilitate clean energy use, discontinue mercury usage in gold mining and mining of mercury and phase out non-vital mercury-containing products (Mandal et al., 2000). Mercury and methyl mercury were found to be below the quantitation limit in all samples of commercial and fresh fruit juices. Therefore, fruit juices are safe for consumption for mercury and methyl mercury contamination.

Nickel occurs in the environment as nickel (II) compounds. Sources of nickel contamination include water as a primary source, industrial emissions, smelting and mining, use of fertilizers, and nickel leaching from stainless steel equipment or chromium or nickel-coated materials (Chain et al., 2020). IARC has classified inhaled nickel compounds as group I which is carcinogenic to humans but evidence for oral exposure is lacking ("Nickel in drinking-water,", 2021). Water treatments using conventional or ion exchange resins can reduce the contamination of nickel in water and food ("Chemical fact sheets: Nickel,", 2022).

Chromium occurs in the earth's crust and exists in mainly trivalent (naturally present in food) and hexavalent forms (by-product of stainless steel and production processes). Sources of chromium contamination include sewage wastewater, production processes, and electroplating and dye industries. Chromium (VI) is rapidly absorbed by chromium (III) in the GI tract but complete absorption is not possible which can lead to toxicity. IARC has classified chromium (VI) as group I which is carcinogenic to humans by inhalational route but data for the oral route is still not significant ("Chromium Geneva, World Health Organization (WHO Fact Sheet,", 2022. Chromium plays an important role in glucose, fat, and protein metabolism (Mohamed et al., 2020). Long-term exposure of Nickel and Chromium can cause serious health hazards. Nickel carbonyl and hexavalent chromium are categorized as carcinogens. Polluted water and food with high concentration of Ni and Cr are responsible for various health problems. Chromium toxicity can cause asthma, back pain, dermatitis, brochities, hypertension, metabolic syndrome, etc. High concentration of Nickel may cause dermatitis, epigenetic changes, and alteration in gene changes. Both Ni and Cr have ability to cross placenta (Yüksel, Ustaoğlu, & Arıca, 2021). Nickel was found to be above permissible limits as per FSSAI in 5 samples of commercial fruit juices and 6 samples of street-vended fruit juices. Chromium was found to be above permissible limits as per FSSAI in 5 samples of commercial fruit juices and all street-vended fresh fruit juices (6 samples).

Tin is primarily used for coating of equipment and other appliances in food industries and is also found in drinking water but in low concentrations which can be caused of human exposure. The tin coating could cause leaching in fruit juices. To control excessive leaching of Tin, pH, temperature, storage, additives, organic acids, preservatives, etc. should be monitored ("Guidance for Industry: Juice Hazard Analysis Critical Control Point Hazards and Controls Guidance, First Edition,", 2004). Tin could cause gastrointestinal irritation and has relatively low toxicity on long-term exposure ("Inorganic Tin Geneva, World Health Organization (WHO Fact Sheet,", 2022). Tin was found to be below the permissible limit in fresh fruit juices and below the quantitation limit in commercial fruit juices.

Copper is an essential element that is responsible for biochemical functions as it is part of some enzymes essential for the catalysis of metabolic oxidation, synthesis of hemoglobin, and maintenance of health in the human body (Sobhanardakani et al., 2017). Copper is found in nuts, legumes, chocolate, mushroom, shellfish, red meat, unrefined cereals, etc. (Alok et al.). Excess copper can cause membrane damage, anorexia, fatigue, premenstrual syndrome, depression, anxiety, migraines, learning disorders, gastrointestinal disturbance, hemolysis, renal and kidney necrosis, and other effects (Ackah et al., 2014; Alok et al.). Copper was found to be within the permissible limit of FSSAI standards, i.e, below 5 ppm in all the samples of commercial fruit juices as well as fresh fruit juices.

Zinc is an essential element that has an important role in biochemical and physiological functions such as it is part of some enzymes in hemoglobin synthesis, catalysis of metabolic oxidation, and protein synthesis (Jalbani et al., 2010). Zinc is found in milk, cheese, poultry, fish, eggs, nuts, cereals, and whole grains (Roohani et al., 2013). Overconsumption of zinc causes nausea, dizziness, lethargy, gastrointestinal troubles, low copper levels, etc. (Rahimzadeh et al., 2020). Zinc is above the permissible limit in street-vended fresh fruit juices and sample 3 of commercial juices.

Health risk assessment

Health risk assessment of elemental impurities in fruit juices was computed by estimation of health risk index (HRI), target hazard quotient (THQ), hazard index (HI), and target cancer risk (TCR). Statistical analysis was performed using GraphPad Prism version 10.

Health risk index (HRI)

HRI was computed to estimate noncarcinogenic health risks for commercial fruit juices and fresh fruit juices. The results of the health risk index of commercial fruit juice samples are provided in Fig. 1 and the results of the health risk index of fresh fruit juice samples are provided in Fig. 2. HRI values for all the elemental impurities concentration in commercial fruit juice samples and fresh fruit juice samples were found to be less than 1. Thus, it does not pose any serious health risk to consumers.

Target hazard quotient (THQ)

THQ was computed to estimate non-carcinogenic health risks for commercial fruit juices and fresh fruit juices. The results of target hazard quotient of commercial fruit juice samples are provided in Fig. 3 and results of target hazard quotient of fresh fruit juice samples are provided in Fig. 4. THQ values for all the elemental impurities concentration in commercial fruit juice samples and fresh fruit juice samples were found to be less than 1. Thus, it does not pose any serious health risk to consumers.

Hazard index

Hazard index (HI) was computed to estimate non-carcinogenic health risk for commercial fruit juices and fresh fruit juices. The results of hazard index of commercial fruit juice samples are provided in Fig. 5 and results of hazard index of fresh fruit juice samples are provided in Fig. 6. HI values for Sample 1 and Sample 3 of commercial fruit juices were found to be 1.027 and 1.207, respectively, which can cause serious risk to consumers. HI values for all the elemental impurities concentration in fresh fruit juice samples were found to be less than 1. Thus, it does not pose any serious health risk to consumers.

Target carcinogenic risk (TCR)

THQ and HI values were within the acceptable levels except for HI which was found in 2 samples. TCR value was assessed for heavy metals, i.e., lead, nickel, and chromium as it might pose carcinogenic risk to humans. Arsenic and cadmium were found below limit of quantification and thus were not considered

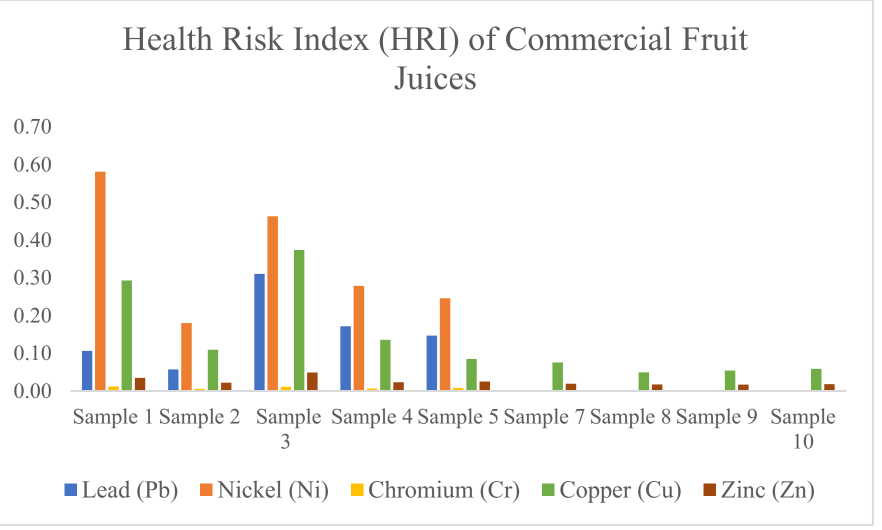

Fig. 1 Health risk index of commercial fruit juice samples

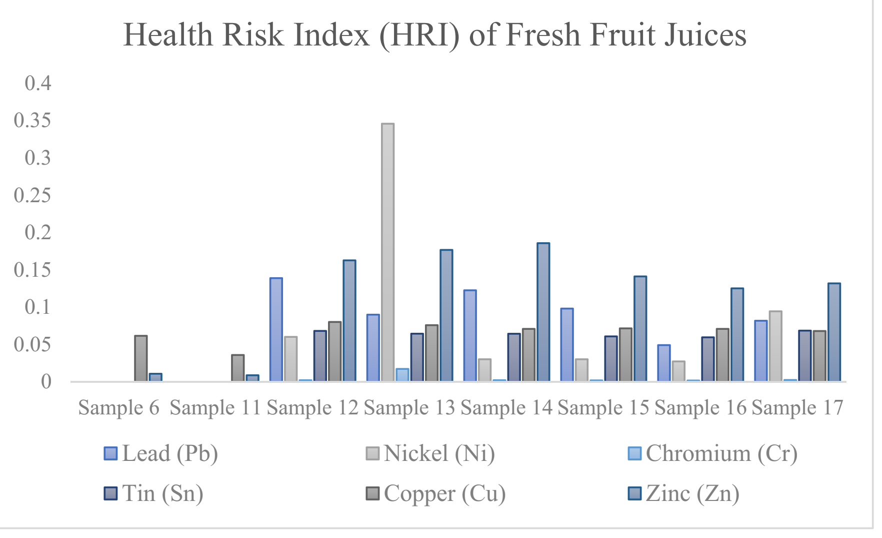

Fig. 2 Health risk index of fresh fruit juice samples

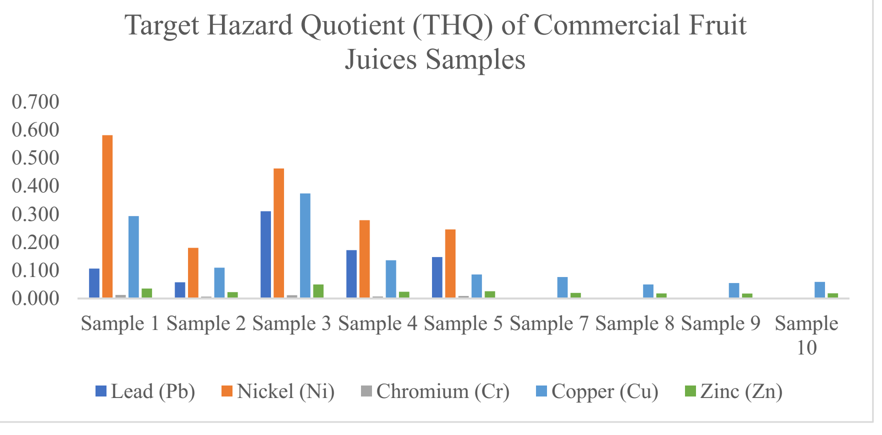

Fig. 3 Target hazard quotient of commercial fruit juice samples

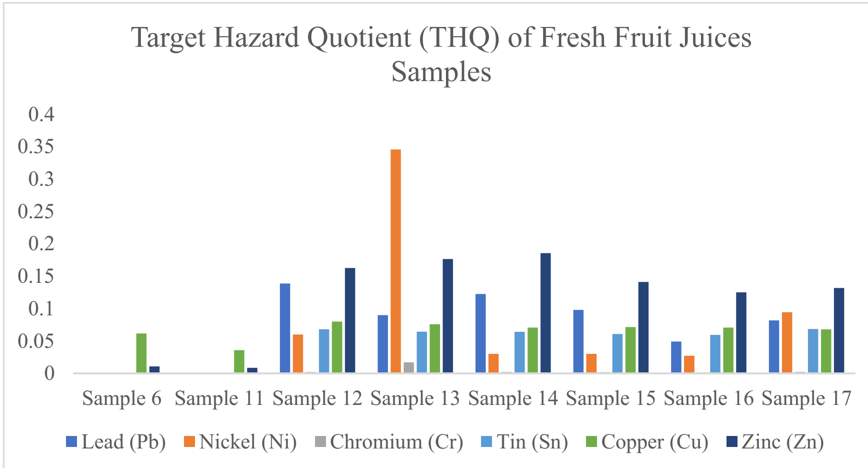

Fig. 4 Target hazard quotient of fresh fruit juice samples

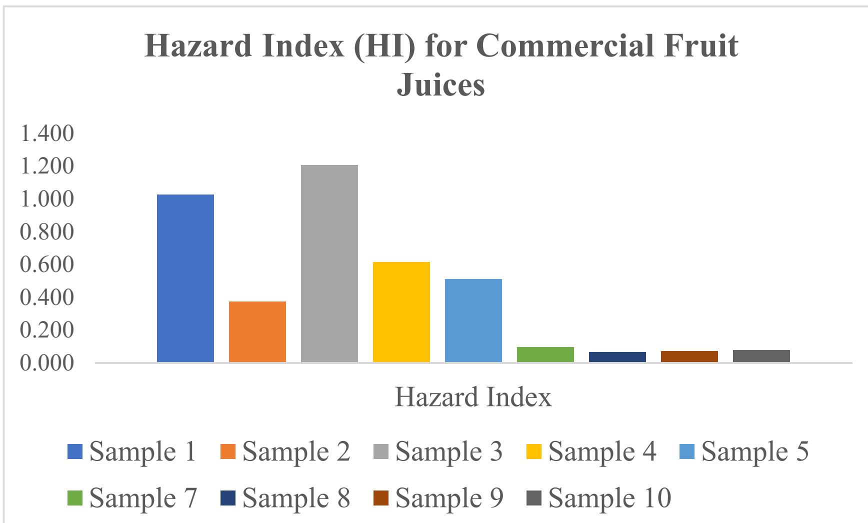

Fig. 5 Hazard index of commercial fruit juice samples

for the TCR value. The results of target carcinogenic risk of commercial fruit juice and fresh fruit juice samples are provided in Table 6. Acceptable TCR values for lead, nickel, and chromium are ranged from 1×10^{-4} to 1×10^{-6}. TCR values were within acceptable limits for lead, chromium, and nickel for commercial fruit juice and fresh fruit juice samples.

Conclusion

The study describes the estimation of elemental impurities in commercial fruit juices and fresh fruit juices (orange, multifruit, orange + aloe vera, and multifruit + aloe vera) available in the Indian market. Fruit juices are analyzed for metal contaminants which were carried out by the ICP-MS technique. The results were compared with FSSAI standards. The concentration of arsenic, tin, cadmium, mercury, and methyl mercury was below the limit of quantification and thus does not have any toxic effect. However, limits for lead exceeded per FSSAI limit in 5 commercial fruit juice samples. Lead poses serious health risks even at a trace level. Measures to monitor lead levels in fruit juices are vital for the safety and quality of fruit juices. Nickel and chromium were found to be above permissible limits in 5 samples of commercial fruit juices and 6 samples of fresh fruit juices. Health risk assessment was performed for elemental impurities. Target hazard quotient and health risk index for

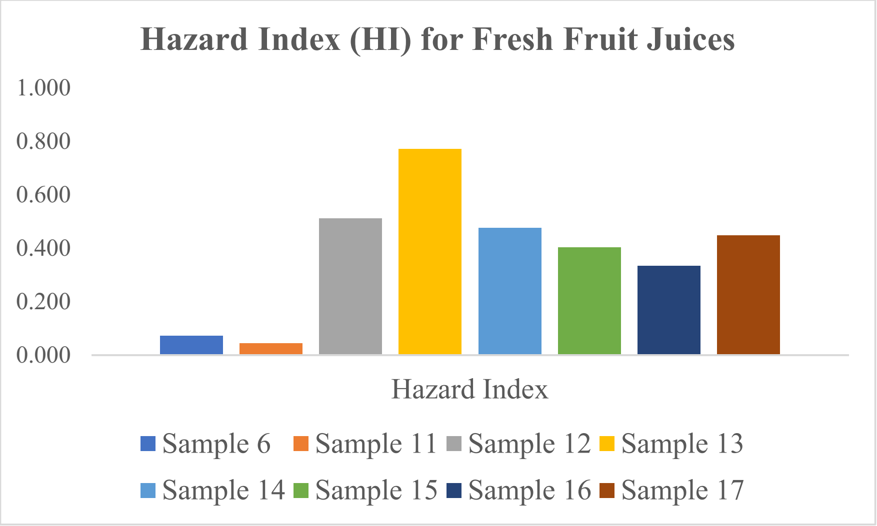

Fig. 6 Hazard index of fresh fruit juice samples

Table 6 Results of target carcinogenic risk (TCR) of commercial fruit juices and fresh fruit juice samples

Fruit juice samples	Sample number	Target carcinogenic risk (TCR) value		
		Lead	Nickel	Chromium
Commercial fruit juices	Sample 1	7.1×10^{-7}	9.8×10^{-5}	4.4×10^{-5}
	Sample 2	3.8×10^{-7}	3.1×10^{-5}	2.2×10^{-5}
	Sample 3	2.1×10^{-7}	7.8×10^{-5}	4.2×10^{-5}
	Sample 4	1.1×10^{-6}	4.7×10^{-5}	2.5×10^{-5}
	Sample 5	9.8×10^{-7}	4.2×10^{-5}	3.1×10^{-5}
Fresh fruit juices	Sample 12	9.2×10^{-7}	1.0×10^{-5}	7.0×10^{-6}
	Sample 13	6.0×10^{-7}	5.9×10^{-5}	6.4×10^{-5}
	Sample 14	8.1×10^{-7}	5.1×10^{-6}	7.1×10^{-6}
	Sample 15	6.5×10^{-7}	5.1×10^{-6}	6.3×10^{-6}
	Sample 16	3.3×10^{-7}	4.6×10^{-6}	5.7×10^{-6}
	Sample 17	5.4×10^{-7}	1.6×10^{-5}	8.3×10^{-6}

elemental impurities were found to be less than 1 which is considered safe for consumers. Hazard index for elemental impurities was found to be more than 1 in two samples which can cause serious non-carcinogenic risk to consumers. Target carcinogenic risk was found within acceptable levels for all elemental impurities in all samples of fruit juices. It is essential to further monitor the levels of chromium and nickel in fruit juices as it causes toxicity in humans. Fresh fruit juices do not exceed FSSAI limit for heavy metals, thus it causes less harm in comparison to commercial fruit juices. Homemade fresh fruit juices were within the FSSAI limits, thus making it safest for human consumption. Timely analysis of commercial and fresh fruit juices is required for quality and safety. Awareness among consumers about the careful intake of fruit juices for good health should be carried out. Measures should be taken by manufacturers of packaged fruit juices to reduce the content of metal contamination during all stages of processing, packaging, and storage. Street vendors should also be encouraged to use proper measures and hygiene to ensure fruit juice quality and safety are maintained.

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Data availability Not applicable.

Declarations

Consent for publication Not applicable.

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