



## Research article

## ICP-OES assisted determination of the metal content of some fruit juices from Yemen's market

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## ABSTRACT

The levels of Cd, Cr, Cu, Pb, Zn, Sn, and Fe of 37 samples of 6 types of fruit juices (orange, mango, guava, pineapple, peach, and mixed fruit) marketed by different brands and of easy access in Sana'a food stores, Yemen (2019) were evaluated using the inductively coupled plasma-optical emission spectrometry (ICP-OES) technique. Traces of chromium were detected in two fruit juices and cadmium in seven juices. One sample presented a highly elevated Pb-content. High level of tin, iron and zinc were detected in some fruit juices. Metal content in some fruit juices sold on the Yemeni market exceeded the permissible limits set by health organizations for drinking water. The origin of metal contamination could be likely linked to war condition even though it is difficult to be totally affirmative, so far. Fruit juices available on the Yemeni market are globally safe, nonetheless, further risk-based surveillance studies must be carried out to decrease child exposure to toxic metals from fruit juice sources.

## 1. Introduction

Fruit juices are made from the extraction or pressing of one type -or mix of- mature, fresh, chilled or frozen fruits. Fruit juices from concentrate are prepared from juices whose water content has been partially removed. Fruit juices are consumed everyday by everyone including children. They are also an important source of water-soluble vitamins and minerals, including Fe, Ca, and Mg, presenting beneficial health effects (Caswell, 2009). Those benefits have led Canada or US food-guides to recommend the consumption of 1/2 to 1 cup of fruit juice on a daily basis (Fathabad et al., 2018). In a similar way, the French National Nutrition and Health Program, aimed at improving the general health of the french population (Herberg, 2011), recommends a daily consumption of 5 portions of fruit or vegetable, one portion being possibly replaced by a fruit juice.

If fruit juices provide beneficial elements to humans, they may also contain harmful elements as Hg, Sn, Pb, As, and Cd which can cause severe problems for human health even in low levels (Bhattacharya

et al., 2016). Packaging is a possible source of contamination by metal (Conti, 2006). Nevertheless, metal in fruit juices often comes from fruit itself. Element content in fruit is influenced by the nature of the fruit. Soil mineral composition is an obvious source of metals for any vegetal material. However, elements found in plant parts may also originate from numerous sources such as fertilizers, pesticides, and various types of chemicals transported through air and/or water (Fathabad et al., 2018). Consumption of heavy metals in high concentrations through fruit juices (or from any other sources) can lead to chronic diseases resulting from damages in vital organs or mutagenesis, carcinogenesis, and teratogenesis. Several of these chronic diseases affect children more severely. In addition, some elements, as Fe or Cu, may also catalyze oxidative processes, through free radical oxidative deterioration, leading to a reduced shelf life of food or possibly lowering the nutritive value of fruit juice (Kilcast and Subramaniam, 2011).

Trace element content determination is a performant method that has been successfully used to evaluate the quality, as well as safety, of food in

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general (Mohammed et al., 2018, 2019a, 2019b) and fruit in particular (Soylak et al., 2013).

The war in Yemen is now in its fifth year and signs of rapid improvement are rare. During these years, thousands of Yemenis (combatants and civilians) have been killed. The country's infrastructure have also been severely damaged (Sharp, 2019). Humanitarian crisis in Yemen is worst in the world, United Nations reports (Sharp, 2019). About 65% of the Yemeni population is food insecure; half of this population suffers from extreme levels of hunger (Sharp, 2019). Fighting that has been going on for several years around Sa'dah, Ibb, and Taiz, regions where orange, guava, and particularly mango are grown and used to produce juices, may have dramatically changed the soil's mineral composition. Similarly, the soil composition of the peach orchards and vineyards located around Sana'a has possibly been impacted by the frequent and violent fighting around the Yemeni capital.

Presently, children in Yemen are frequently fed fruit juices that provide them with carbohydrates, vitamins and microelements. However, children are not necessarily given juice on a daily basis because of difficulty of supply. Indeed, due to war conditions, locally produced fruit juices are becoming scarce. They also present the risk of having a high level of toxic elements. Imported fruit or fruit juices, due to the economic state of Yemen, are necessarily very cheap and generally of uncontrolled quality.

Fruit juice is particularly popular with children who often consume more fruit juice relative to their body weight than adults. Children may also have, for some metals, greater susceptibility. Therefore, it is important to get a precise picture on the safety of fruit juice consumption in Yemen.

Before the war, Yemen was a major player of the international mango trade (UNCTAD, 2006). Currently, mangoes grown in Yemen are mainly consumed in the form of fresh fruit or used to prepare fruit juice sold on the domestic market. Mango juice is particularly popular with Yemeni children. The goal of this research was to detect and assess the concentrations of Cr, Cd, Pb, Cu, Zn, Sn, and Fe in mango juice as well as other popular fruit juices (peach, orange, guava, pineapple, and mixed juices) purchased on Sana'a's market, Yemen in 2018. Permissible limits set by health organizations for drinking water were used as limits of reference even though daily fruit juice consumption is lower than water consumption.

## 2. Materials and methods

### 2.1. Chemicals and reagents

All reagents were of analytical grade. Nitric acid 69.5% and hydrogen peroxide 35% were reagent grade solvents (Merck, Darmstadt, Germany). Working standard solutions (blanks) were prepared by dilutions of a multi-element (1000 mg/L) Certipur ICP standard accredited according to DIN EN ISO/IEC 17025 (Merck, Darmstadt, Germany). Millipore system (Bedford, MA, USA) was used to prepare aqueous solutions. All glassware and plastic bottles were cleaned with a 10% (v/v) HNO<sub>3</sub> solution and rinsed several times with deionized water and filtered when necessary.

### 2.2. Sample preparation, digestion, and instrumentation

For mineral analysis, 0.5 mL of juice samples was measured directly in PTFE tubes, 5 mL of concentrated 69.5% HNO<sub>3</sub> (Fluka, TraceSelect™, Buchs, Switzerland) and 2 mL of 35% H<sub>2</sub>O<sub>2</sub> (Aldrich, Milan, Italy) were added and the tubes were heated in oven at 200 °C for 20 min (close to dryness).

After digestion, the solutions were transferred to 50 mL falcon tubes and deionized water was added to a final volume of 50 mL. Metal content was measured by inductively coupled plasma - optical emission spectrometry (ICP-OES) using a spectrometer with axial viewed plasma (Norwalk, CT, USA). Operating conditions were: power 1300 W; plasma

flow gas 15 L/min; auxiliary gas flow 0.2 L/min; nebulizer gas flow 0.8 L/min. All analyses were performed in triplicate.

### 2.3. Quality control

Accuracy of the measurements was established standard samples. For each quantified element, limit of detection (LOD) and limit of quantification (LOQ) were calculated using the formula:  $LOD = Xb1 + 3.3Sb1$ ,  $LOQ = Xb1 + 10Sb1$  (where  $Xb1$  is the mean concentration of the blank and  $Sb1$  is the standard deviation of the blank), respectively (Table 1).

### 2.4. Statistical analysis

The data determined in fruit juices were studied as statistical variables and the mean values of three independent replicates per fruit juice type were compared using the least significant difference (LSD) test at  $P < 0.05$  that was considered to be statistically significant.

## 3. Results and discussion

Thirty seven samples of fruit juices were purchased from different food stores spread throughout Sana'a city. Evaluated samples in this study included five orange juices (three in carton packaging, two in glass bottles, and one canned juice), sixteen mango juices (six canned juices, three in glass bottles, six in carton packaging, and one in a PET bottle), two peach juices (both canned), three guava juices (two in carton packaging, one in PET bottle), three pineapple juice (one canned juice and two in carton packaging), two grape juices (one canned and one in carton packaging), and six mixed fruit (two canned juice and four in carton packaging). These samples were evaluated for assessment of seven heavy metals: Cr, Cd, Zn, Pb, Cu, Sn and Fe using acid digestion and optical emission spectroscopy.

### 3.1. Chromium quantification

Chromium has oxidation states ranging from chromium(II) to chromium(VI). In humans, chromium(III) is an essential nutrient. It plays a role in glucose, fat, and protein metabolism. Nonetheless, exposure to chromium(VI) via ingestion may cause adverse health effects including respiratory and gastrointestinal problems (Wilbur et al., 2012). A maximum value below 0.05 mg/L is recommended for drinking water (WHO, 1996). Of the thirty-seven samples included in this study, chromium was detected in two fruit juices (Table 2). In both cases, Cr was detected at very low levels ( $0.02 \pm 0.01$  mg/L), a value below the critical value of 0.05 mg/L allowed for drinking water (Table 2). Both fruit juices presenting a quantifiable chromium content were mango-based (pure or mixed) juices produced on the domestic market. Mango fruit is known to easily accumulate chromium when mango trees are grown in a chromium-rich environment (Mausi et al., 2014). In Yemen, mango orchards are essentially located in the provinces of Taiz, Al Hudaydah and Lahij, three provinces that have not been spared by the fighting. Even though preliminary, our results suggest that some mangoes introduced in the mango juice process have grown in mango orchards chromium-contaminated.

The levels of chromium in mango juice detected in our study are not necessarily alarming for the consumer health, so far. Because of the lack of traceability, our study does not provide sufficient proofs to affirm that all three provinces are equally concerned by a chromium contamination. However, a special care should be taken to follow the evolution of the chromium content in Yemeni mango-based juices in the next years.

### 3.2. Cadmium quantification

Oral ingestion of cadmium results in increases in hematological, liver, kidney, gastrointestinal, neurological, and testicular effects (Faroon

**Table 1.** Analytical figures of merit (mg/L) of ICP-OPES determination of trace elements in fruit juices previously digested in an oven.

|    | Blank sample concentration<br>measured (average) | SD     | RSD% | LOD    | LOQ   |
|----|--|--------|------|--------|-------|
| Cr | 0.0024, 0.0026, 0.0024 (0.002)                   | 0.0001 | 4.68 | 0.0023 | 0.003 |
| Cd | 0.0015, 0.0014, 0.0013 (0.001)                   | 0.0001 | 7.14 | 0.0013 | 0.002 |
| Pb | 0.020, 0.021, 0.022 (0.02)                       | 0.001  | 4.76 | 0.0233 | 0.03  |
| Cu | 0.0020, 0.0022, 0.0022 (0.002)                   | 0.0001 | 5.41 | 0.0023 | 0.003 |
| Zn | 0.0013, 0.0015, 0.0014 (0.001)                   | 0.0001 | 9.49 | 0.0013 | 0.002 |
| Sn | 0.031, 0.033, 0.030 (0.03)                       | 0.002  | 4.89 | 0.0366 | 0.05  |
| Fe | 0.0013, 0.0012, 0.0014 (0.001)                   | 0.0001 | 7.69 | 0.0013 | 0.002 |

**Table 2.** Mean concentration ( $\pm$ SD) of Cr, Cd, Pb, Cu, Zn, Sn, and Fe (mg/L) in the evaluated fruit juices purchased on the Yemeni market.

|                    | Cr              | Cd              | Pb              | Cu              | Zn              | Sn               | Fe              |
|--------------------|-----------------|-----------------|-----------------|-----------------|-----------------|------------------|-----------------|
| <b>Orange</b>      |                 |                 |                 |                 |                 |                  |                 |
| Orange1            | bdl             | 0.02 $\pm$ 0.01 | n.d             | n.d             | 0.04 $\pm$ 0.01 | n.d              | 0.35 $\pm$ 0.01 |
| Orange2            | bdl             | bdl             | nd              | 0.02 $\pm$ 0.01 | 0.44 $\pm$ 0.03 | nd               | 1.35 $\pm$ 0.12 |
| Orange3            | nd              | nd              | n.d             | n.d             | 0.07 $\pm$ 0.01 | n.d              | 0.84 $\pm$ 0.02 |
| Orange 4           | nd              | nd              | nd              | nd              | 0.03 $\pm$ 0.01 | nd               | 0.23 $\pm$ 0.03 |
| Orange5            | nd              | nd              | n.d             | n.d             | 0.04 $\pm$ 0.01 | 2.95 $\pm$ 0.10  | 2.91 $\pm$ 0.12 |
| <b>Mango</b>       |                 |                 |                 |                 |                 |                  |                 |
| Mango1             | nd              | nd              | n.d             | 0.62 $\pm$ 0.10 | 1.42 $\pm$ 0.13 | n.d              | 0.13 $\pm$ 0.01 |
| Mango2             | nd              | nd              | 8.07 $\pm$ 1.65 | nd              | 0.15 $\pm$ 0.03 | nd               | nd              |
| Mango3             | bdl             | bdl             | nd              | 0.13 $\pm$ 0.03 | 0.02 $\pm$ 0.01 | nd               | 0.17 $\pm$ 0.03 |
| Mango4             | nd              | nd              | nd              | 0.03 $\pm$ 0.01 | 0.03 $\pm$ 0.01 | nd               | 1.23 $\pm$ 0.10 |
| Mango5             | nd              | nd              | nd              | 0.13 $\pm$ 0.02 | 0.10 $\pm$ 0.02 | 0.33 $\pm$ 0.03  | 0.67 $\pm$ 0.07 |
| Mango6             | nd              | nd              | n.d             | n.d             | 0.02 $\pm$ 0.01 | 0.02 $\pm$ 0.01  | 1.07 $\pm$ 0.12 |
| Mango7             | bdl             | 0.02 $\pm$ 0.01 | nd              | 0.16            | nd              | 0.45 $\pm$ 0.03  | 0.21 $\pm$ 0.02 |
| Mango8             | bdl             | 0.03 $\pm$ 0.01 | nd              | 0.02 $\pm$ 0.01 | 0.42 $\pm$ 0.03 | 0.19 $\pm$ 0.02  | 0.44 $\pm$ 0.01 |
| Mango9             | bdl             | bdl             | nd              | 0.14 $\pm$ 0.02 | 0.49 $\pm$ 0.03 | nd               | 0.89 $\pm$ 0.06 |
| Mango10            | bdl             | bdl             | nd              | 0.35 $\pm$ 0.04 | 0.24 $\pm$ 0.03 | 18.65 $\pm$ 1.65 | 0.35 $\pm$ 0.03 |
| Mango11            | bdl             | 0.02 $\pm$ 0.01 | nd              | 2.47 $\pm$ 0.10 | 5.38 $\pm$ 0.23 | nd               | 9.12 $\pm$ 0.72 |
| Mango12            | bdl             | bdl             | nd              | 0.07            | 3.13 $\pm$ 0.95 | 1.75 $\pm$ 0.85  | 1.38 $\pm$ 0.92 |
| Mango13            | bdl             | bdl             | 0.20 $\pm$ 0.03 | nd              | 0.32 $\pm$ 0.04 | nd               | 0.09 $\pm$ 0.01 |
| Mango14            | 0.02 $\pm$ 0.01 | bdl             | nd              | 0.42 $\pm$ 0.03 | 0.16 $\pm$ 0.06 | nd               | 1.46 $\pm$ 0.14 |
| Mango15            | bdl             | bdl             | nd              | nd              | 0.47 $\pm$ 0.04 | 8.24 $\pm$ 2.10  | 11.5 $\pm$ 2.6  |
| Mango16            | bdl             | bdl             | nd              | 0.88 $\pm$ 0.05 | 0.91 $\pm$ 0.07 | nd               | 1.61 $\pm$ 0.14 |
| <b>Guava</b>       |                 |                 |                 |                 |                 |                  |                 |
| Guava1             | nd              | nd              | nd              | 0.09 $\pm$ 0.01 | 0.17 $\pm$ 0.02 | 0.21 $\pm$ 0.02  | 0.26 $\pm$ 0.02 |
| Guava2             | bdl             | bdl             | nd              | 0.02 $\pm$ 0.01 | 0.12 $\pm$ 0.02 | 0.24 $\pm$ 0.01  | 0.04 $\pm$ 0.01 |
| Guava3             | bdl             | bdl             | nd              | 0.06 $\pm$ 0.01 | 0.38 $\pm$ 0.02 | nd               | 0.44 $\pm$ 0.02 |
| <b>Pineapple</b>   |                 |                 |                 |                 |                 |                  |                 |
| Pineapple1         | nd              | nd              | nd              | 0.07 $\pm$ 0.01 | 0.34 $\pm$ 0.03 | 0.23 $\pm$ 0.03  | 0.81 $\pm$ .05  |
| Pineapple2         | nd              | nd              | nd              | 0.09 $\pm$ 0.01 | 0.36 $\pm$ 0.05 | nd               | 0.81 $\pm$ 0.06 |
| Pineapple3         | nd              | nd              | nd              | 0.06 $\pm$ 0.01 | 0.03 $\pm$ 0.01 | 0.04 $\pm$ 0.01  | 0.43 $\pm$ 0.03 |
| <b>Mixed fruit</b> |                 |                 |                 |                 |                 |                  |                 |
| Mixed 1            | nd              | nd              | nd              | nd              | 2.01 $\pm$ 0.16 | 0.35 $\pm$ 0.04  | 2.01 $\pm$ 0.12 |
| Mixed 2            | nd              | nd              | nd              | 0.05 $\pm$ 0.01 | 0.37 $\pm$ 0.04 | 0.79 $\pm$ 0.04  | 5.77 $\pm$ 0.92 |
| Mixed 3            | nd              | nd              | nd              | 0.03 $\pm$ 0.01 | 0.07 $\pm$ 0.02 | nd               | 1 $\pm$ 0.09    |
| Mixed 4            | nd              | nd              | nd              | nd              | 0.07 $\pm$ 0.01 | nd               | 0.82 $\pm$ 0.03 |
| Mixed 5            | bdl             | 0.03 $\pm$ 0.01 | nd              | nd              | nd              | 1.59 $\pm$ 0.14  | nd              |
| Mixed 6            | 0.02 $\pm$ 0.01 | 0.03 $\pm$ 0.01 | nd              | 0.05 $\pm$ 0.01 | 0.35 $\pm$ 0.04 | 1.06 $\pm$ 0.10  | 2.56 $\pm$ 0.17 |
| <b>Peach</b>       |                 |                 |                 |                 |                 |                  |                 |
| Peach1             | nd              | nd              | n.d             | 0.54 $\pm$ 0.05 | 1.42 $\pm$ 0.10 | nd               | 0.13 $\pm$ 0.01 |
| Peach2             | nd              | nd              | n.d             | n.d             | 0.12 $\pm$ 0.01 | nd               | 1.57 $\pm$ 0.13 |
| <b>Grape</b>       |                 |                 |                 |                 |                 |                  |                 |
| Grapes1            | nd              | nd              | nd              | nd              | 0.05 $\pm$ 0.01 | nd               | 0.80 $\pm$ 0.05 |
| Grapes2            | bdl             | 0.02 $\pm$ 0.01 | nd              | 0.05 $\pm$ 0.01 | 0.06 $\pm$ 0.01 | nd               | 0.62 $\pm$ 0.07 |

Bdl: below detection limit; nd: not detected.

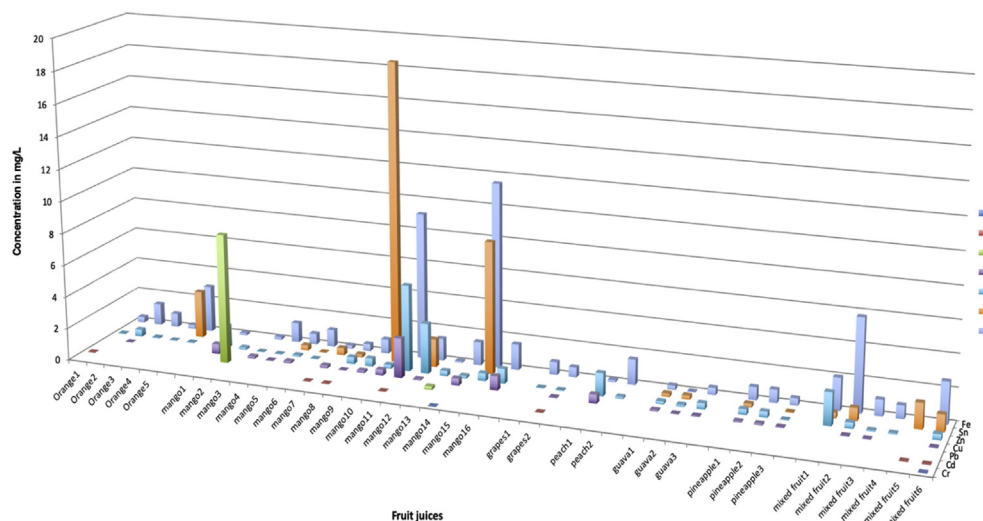


Figure 1. Distribution of Cr, Cd, Pb, Cu, Zn, Sn, and Fe in 37 fruit juices sold on the Yemeni market.

et al., 2019). Consequently, the maximum Cd level permitted for Cd is 0.003 mg/L in drinking water (WHO, 1996).

In seven out of the thirty-seven fruit juices evaluated, Cd concentration was above the recommended value of 0.003 mg/L for drinking water. However, in drinking water, a Cd-level of 0.04 mg/L is also considered safe by the United States Environmental Protection Agency (US EPA) for an exposure no longer than 10 consecutive days for a 10-kg child consuming 1 L of water per day (EPA, 2018). In the seven samples presenting a detectable amount of Cd, the content oscillated between 0.02 and 0.03 mg/L (Table 2). The four juice samples presenting a concentration in Cd of 0.02 mg/L came from grape, orange, mango (2 samples). The three samples presenting a Cd content of 0.03 mg/L were two mixed juices and one mango juice. Fruit juices containing some amount of Cd were sold in a large variety of packaging : 3 fruit juices were in carton packaging, an equal number were canned juices, and one juice was sold in glass bottle. This suggest that packaging was not the source of the contamination.

Yemeni orange and grape orchards are located around Sa'dah and Sana'a, respectively. These places have been the scene of violent fighting and cadmium levels detected in fruit juice could witness a soil contamination. So far, the level of cadmium detected in the samples does not present any direct health concerns for Yemeni population. Nevertheless, as for chromium, a special care should be taken in a near future regarding the evolution of Cd content in fruit juices sold on the Yemeni market and determine if the detected Cd content reflect a slowly spreading Cd contamination.

### 3.3. Lead quantification

As Cr and Cd, Pb is another highly toxic element (Abadin et al., 2019). The main symptoms of lead poisoning are of three types: gastrointestinal, neuromuscular, and neurological (Pearce, 2007). Gastrointestinal absorption of water-soluble lead appears to be higher in children than in adults (Mushak, 1991). For drinking water, the maximum level of lead is set at 0.01 mg/L (WHO, 1996). Two fruit juices examined presented an inappropriate level of Pb. Both juices were mango juices. One juice sample presented a lead content of 0.2 mg/L, a value twenty times higher than the recommended level. This sample was sold in a carton packaging and the Yemeni origin of the fruit used for its preparation could not be ascertained. The second sample was a canned juice whose Pb level reached the extremely high level of  $8.07 \pm 1.65$  mg/L, a value 800 times higher than the recommended value. This juice was prepared from mangoes picked up in Yemen. The precise reason for this important lead contamination is unknown, but two explanations can be put forward:

either the high Pb content is a consequence of a regretful and undetected accident during the juice preparative process, or the fierce fighting that took place a few years ago in the Tihama region, where mango trees mainly grow, has resulted in a soil strongly polluted by the lead in some places. Other metals quantified in this specific mango juice sample did not present an abnormal value (Table 2). Finding a such elevated Pb-content in a fruit juice sample evidences the potential risks encountered by the Yemeni population.

### 3.4. Copper quantification

Copper is an essential nutrient for which one of the most commonly reported adverse health effect of is gastrointestinal problems: nausea, vomiting, and/or abdominal pain. Copper level in drinking water is tolerated until a maximum concentration of 2 mg/L (WHO, 1996). Copper was detected in twenty five out of the thirty seven evaluated fruit juices. Only one sample displayed a copper-value slightly above the level acceptable for drinking water (2.47 mg/L). It was a mango juice sold in glass bottle. This sample also displayed a high zinc and iron content (*vide infra*) suggesting, as already described for lead, soil contamination. Considering the amounts of copper found in the examined fruit juices, copper contamination through juice fruit consumption does not present a specific risk for the health of the Yemeni population, so far.

### 3.5. Zinc quantification

As copper, zinc is an essential nutrient for humans. One of the most commonly reported adverse health effect of zinc is gastrointestinal distress (Roney et al., 2005). Maximum level of zinc accepted for drinking water is 3 mg/L (WHO, 1996). Presence of Zn in food is not necessarily dangerous but unexpected high levels of Zn may alert on the possible presence of metal contamination. One of our evaluated fruit juices presented a Zn-level of 5.38 mg/L (Table 2). This sample was the mango juice containing an elevated level of copper (*vide supra*) and iron (*vide infra*). Another mango juice sample presented a Zn content slightly superior to the limit recommended for water (3.13 mg/L). This sample also presented a high level of tin and iron.

### 3.6. Tin quantification

Tin toxicity is poorly documented. Ingestion of tin could induce gastrointestinal troubles as well as respiratory concerns (Harper et al., 2005). In view of its low toxicity, the presence of tin in drinking-water does not represent a hazard to human health. Two of our evaluated

fruit juices presented a particularly high tin-content. Both were mango juices. One sample presented a tin content of 18.65 mg/L and the second had a tin-content of 8.24 mg/L (Table 2). The former sample presented acceptable levels regarding the other metal evaluated whereas the latter sample presented also a high (2.91 mg/L) iron-content (*vide infra*). In addition, an orange juice sample presented a tin content of 2.95 mg/L (Table 2). Observed high level of tin in some fruit juices does not necessarily represent a health risk for the Yemeni population but its origin would need to be identified to possibly prevent a contamination.

### 3.7. Iron quantification

Iron is an essential element in human nutrition. The presently recommended limit for iron in drinking water is 0.3 mg/L. This limit is based on taste and appearance rather than on any detrimental health effect (WHO, 1996). Five fruit juices displayed an elevated Fe-content. Among those, three were mango juices. The highest Fe-content (11.5 mg/L) was found in a mango juice that simultaneously presented Sn-content of 8.24 mg/L (Table 2). Another mango juice displayed an iron content that reached the value of 9.12 mg/L (Table 2). This fruit juice also presented high levels of Cu (2.47 mg/L) and Zn (5.38 mg/L) attesting of a global contamination by various metals. Another mango juice sample presented an iron content of 1.38 mg/L (Table 2). Its Zn content was calculated to be 3.13 mg/L, and its Sn content 1.75 mg/L (Table 2). Mango juices were not alone to present high Fe-content. An orange juice displayed a Fe content of 2.91 mg/L together with a Sn content of 2.95 mg/L (Table 2). Finally, three mixed fruit juices presented Fe-content of 5.77, 2.56 and 2.01 mg/L (Table 2). One of these samples had a high level of Sn and the other a high level of Zn. If elevated levels of Fe are not necessarily detrimental for the health of consumers, it could catalyze oxidative process reducing the shelf life of fruit juices.

### 4. Conclusion

It must be kept in mind that due to the war conditions in Yemen, it is difficult to evaluate daily serving sizes of fruit juices given to children. For the same reasons, the conditions for preparing local fruit juices are sometimes changeable and are frequently adapted to external conditions. Also, imported product quality is not always as effectively controlled as it should be.

We evaluated seven types of fruit juices (Figure 1). Among those, peach, guava and pineapple juices presented very low levels of metals and their consumption could be presented as totally safe for children. However, the study of a larger number of samples could reveal failures that were not detected in this study. We were only able to introduce two samples of peach juices and three of pineapple and guava juices in our study as those juices are not very common on the Yemeni market. Two samples of grape juices were evaluated. Their content in metal was also low but highly toxic Cd was detected in one of the two samples. Such observation could be attributed to a regrettable manufacturing accident or reflect the introduction of contaminated fruit in the preparation of the fruit juice. Interestingly, heavy metal content of pineapple juice sold on the Jordan market has been recently investigated (Massadeh and Al-Massaedh, 2018), providing a point of comparison. Zn-content of pineapple juices sold on the Jordan and Yemeni markets were found to be both around 0.3 mg/L, whereas Cu-content in pineapple juices purchased on the Yemeni market was found to be much lower than that of pineapple juices purchased on the Jordan market. In Yemen, pineapple juice is exclusively an imported product and our results suggest that imported pineapple juice is of satisfactory quality. Regarding orange, mango, and mixed fruit juices, they were found to be of heterogenous quality with regard of their metal content. One out of six orange juices displayed a unexpected high content in tin and iron; one sample contained some amount of Cd. Three juices could be qualified as safe for child consumption, with respect of their metal content. In the mixed juice group, one sample presented a high content in iron and one sample contained

chromium and cadmium. Some mango juices contained very high tin, iron, and zinc contents. In addition, one sample presented a unacceptable Pb-content. Analysis of the origin of the metal content of fruit juices sold on the Yemeni market is not necessarily easy as no data are available before the war. Scarce data regarding metal contents in Yemeni food regard only molluscs (Szefer et al., 1999, 2006) and are hence useless for comparison purposes with our study. Consequently, the origin of the high content in metal observed for several fruit juices cannot be unambiguously linked to war-associated soil contamination. However, very few industrial activities are developed in Yemen, not to mention rural areas where orchards are established. It is therefore difficult to identify an industry that could be a direct source of pollution or, even an indirect source by absence of effective pollution control systems. Additional and repeated in a timely manner studies are needed to confirm observed excessive values in metal content over time and to unambiguously identify their origin.

### Declarations

#### Author contribution statement

Faez Mohamed: Conceived and designed the experiments; Analyzed and interpreted the data.

Dom Guillaume: Analyzed and interpreted the data; Wrote the paper.  
Nada Abdulwali, Karem Al-Hadrami, Maher A. Al. Maqtari: Performed the experiments.

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#### Competing interest statement

The authors declare no conflict of interest.

#### Additional information

No additional information is available for this paper.

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