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Review

Developments and strategies in the spectrochemical elemental analysis of fruit juices

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ABSTRACT

Information on the concentration of major, minor and trace elements in fruit juices is very important because the popularity of these beverages and the rate of their consumption have rapidly increased in the past 20 years. For the overwhelming majority of cases, the elemental analysis of fruit juices is carried out using spectrochemical analytical methods, which normally require samples of fruit juices to be prepared by decomposing their organic matrix and releasing elements in a form suitable for measurement. This review covers different aspects of the elemental analysis of fruit juices and the societal implications related to the presence of various elements in these beverages. We review in detail sample-preparation procedures executed before the elemental analysis together with calibration strategies used, and quality assurance and quality control of results.

Contents

1. Introduction

A diet rich in fruit juices is recognized to be a good source of a wide range of physiologically and nutritionally important compounds, including carbohydrates, proteins, vitamins, carotenoids, pectins, flavonoids, glucarates, coumarins, monterpenes, limonids, triterpenes, phenolic acids and macroelements [1–10]. Due to the presence of all these functional and bioactive phytochemicals, fruit juices are very popular beverages that offer great taste, flavor and color, while their intake provides many beneficial health effects, primarily antioxidative properties and other bioactivities [1–3,5,7,9,11–15]. Fruit juices are widely consumed all over the world by different age groups and their intake has rapidly increased in the past two decades because they are acknowledged to reduce the risks of many chronic and degenerative diseases [10,15,16]. In tropical and Mediterranean countries, they are the most widely consumed beverages, so they naturally help to maintain and reinforce the health of the inhabitants of these regions [8,15,17].

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1.1. Fruit juices as valuable sources of different elements

As can be seen from Tables 1 and 2, which give the concentration ranges of different elements in commercially-available and freshly-prepared fruit juices, the contribution of these beverages to the total human diet cannot be neglected. Containing large amounts of essential and physiologically-important elements, fruit juices often prove to be rich sources of nutrients and valuable dietary supplements in cases of deficiencies of macroelements (e.g., Ca, K, and Mg) and other minor and trace elements (e.g., Cr, Fe, Mg, Mn, Mo and P) [3,4,8,10,12,13,16,18,19]. For this reason, it is not surprising that they are a subject of great concern and interest for many researchers, food analysts and nutritionists, who want to determine their nutritional quality and safety [15].

Considering total concentrations of elements, certain studies related to the elemental analysis of fruit juices reveal that the daily consumption of fruit juices may markedly cover recommended daily allowances (RDAs) for some nutritionally-important elements required by infants, children and adults {i.e. 0.8–19% (Al), 0.6–32% (Ca), 9.2–87% (Cr), 1.5–35% (Cu), 0.4–26% (Fe), 0.3–55% (K), 1.6–22% (Mg), 0.4–23% (Mn), 0.4–12% (Mo), 0.1–14% (Na) and 0.5–21% (Zn) [13,16,18,20–22]. In extreme cases, drinking fruit juices may even contribute to an unnecessary increase in the intake of Na [5,12] that is detrimental to health. The degree of coverage of RDA values strongly depends on the variety of juice and its provenience (i.e. the type of fruits from which it is produced and the region of the production). The impact of both factors is so strong that, in some cases, the consumption of certain fruit juices can only represent <0.01–0.7% of recommended or permissible levels of some elements {e.g., Al, Co, Cr, Cu, Fe, Mn, Ni, Zn and Se [7,8,13,18,20,23,24]}, and such beverages may not contribute at all to the dietary intake of the elements mentioned.

Although concentrations of some minor and trace elements (e.g., Al, As, Cd, Co, Cu, Fe, Mn, Mo, Ni, Pb and Zn) in fruit juices are low, these elements can impose toxic effects when the share of the relevant beverages in the total diet is high [4,9,12,15,19,21,25–27]. When the content of Cd, Pb, As, Al, Co, Cr Cu, Hg and Ni in consumed fruit juices is low or not detectable at all, so conforming to national health and sanitary standards or food-policy regulations, it proves the high food safety and quality of these beverages [1,2,17,19,25,26,28–30]. Otherwise, when analyzed samples contain these elements above admissible levels stipulated in national and/or international safety standards, the contribution of certain fruit juices to the total dietary intake of As, Cd, Pb and other trace elements dangerously increases and becomes highly undesirable for consumers [12,21,26,31,32]. In this situation, it is understandable that regular examination, verification and tests of fruit juices with respect to the concentration of minor and trace elements are mandatory. The issue of the potability and the safety of fruit juices is especially crucial because the quality of harvested fruits is subject to seasonal variations provoked by climatic changes [4,12,22,26,29].

In view of this, it appears that the elemental analysis of fruit juices is significant for the beverage industry because it gives information about total concentrations of many elements and their average dietary intakes related to the consumption of these beverages [16].

However, fruit juices contain natural endogenous bioligands that can differentially bind elements and change their availability for the human body. Hence, the elemental analysis and the resultant information on total concentrations of elements can sometimes be less important than knowledge of ultimate physicochemical species that are available for the human body [16,33].

1.2. Sources of elements in fruit juices

The variability of concentrations of elements in fruit juices is great [5,12,16,20,21,23,26,34–37]. Even within juices made of the same kind of fruit, the variation of concentrations of elements is high [8,13,38]. Usually, commercial fruit juices contain much higher quantities of elements than freshly prepared juices of the same fruit [39]. Several factors may contribute to observed variations in the levels of elements, including the availability of elements for uptake by plants (strictly related to the characteristics of soils, their mineral composition and the soil pH), agricultural practices and procedures applied during the growth of fruit plants (i.e. application of fertilizers and water irrigation, and climatic conditions), and, finally, plant variation in addition to the type and the maturity of fruits at harvest [4,5,8,13,16,17,20,22,34,35,37–43].

The effect of the soil mineralization can be of primary importance for macroelements (i.e. K, Mg and S) and some minor and trace elements (i.e. B, Fe, Mn and Zn) [43]. The soil type is recognized to be responsible for most regional differences observed in the content of elements present in fruit juices [22,40]. It is because specific groups and types of soil and rootstock can possess elevated concentrations of Ca, B, K, Na and Rb, and this is reflected in higher levels of these elements in fruit juices coming from these regions [40]. The proximity of rivers and any increase in their salinity can affect the concentration of Na in juices [40]. Due to similar properties of some elements and their natural co-occurrence or common exposure sources, several linear relationships between concentrations of these elements in different juices are found, including a very high positive correlation for Cr–Fe and high positive correlations for Al–Cr, Al–Pb, Ca–Cd, Ca–Mg, Ca–Sr, Cd–Ni, Cd–Sr, Cr–Mn, Cu–Fe, Fe–Mn and Mn–Zn [37].

Agricultural practices and techniques applied during the growth of plants and fruits are also important. Organic farming, which excludes the use of synthetic chemicals, such as fertilizers or pesticides in order to keep or to improve the fertility of soils, is recognized to have a significant effect on subsequent concentrations of selected macroelements (i.e. Ca, K and Mg) and microelements (Cu, Fe, Mn and Zn) in fruit juices [9,15,38]. In this case, the content of elements in juices made from organic fruits is higher [15,38]. The use of agrochemical products, e.g., insecticides or fungicides, employed during the growth of fruit plants, is responsible for diminishing the quality and the safety of these products because of an increased risk of the exposure of humans to heavy metals (e.g., Cd and Pb) [1,4,17,19,25].

Fruits themselves, their storage, handling and processing conditions and practices, especially the extraction procedure used to retrieve juices, are important post-harvest factors that affect the chemical composition of juices [1,4,5,20,23,31,34,39,42,44,45]. During the manufacture of juices, tap water [40,44] (increased concentrations of Al, Ca, Cu, Fe, Mg, Na, Si, Sr), peels [40] (increased concentrations of B, Cu, Fe, Mn, Na, Ni, Si, Sr), seeds [45] (increased concentration of Ca, Co, Fe, Mg, Mn and Zn), technological processes [13,23] (increased concentrations of Cr, K and Mn), packing [21,23,31] (increased concentrations of As and Al) and, in case of cans over glass bottles and carton packages, additives, pipes and containers used for processing and storage [44] can be sources of contamination. However, the production process and its steps may also lead to some loss of different elements [13] {i.e. Ca (54–55% compared to the concentration in fruits), Cr (53–77%), Cu (50%), Fe (45%), Mg (28%) and Mo (64–75%), due to the methods used for separating juices from pulps.

Because the elemental profile of fruit juices varies according to differences in the chemical composition of fruits grown and collected in different areas of production, information on total concentrations of elements can be used for classification and