Beer as a potential source of macroelements in a diet: the analysis of calcium, chlorine, potassium, and phosphorus content in a popular low-alcoholic drink

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Abstract

The human body needs minerals to function properly. Since mineral deficiency leads to numerous serious disorders, it is imperative for a diet to ensure the correct supply of minerals. Due to the fact that beer is one of the most popular drinks in the world, a decision was made to determine whether this type of beverage can be considered as an important source of macroelements in a diet. For the purpose of this study, 52 types of bottled beer were analyzed. The beers were imported to Poland from Mexico (four bottles), China (six bottles), Czech Republic (four bottles), Ukraine (four bottles), Thailand (eight bottles), Vietnam (six bottles), Ireland (four bottles), Germany (four bottles), Armenia (four bottles), Italy (four bottles), and Portugal (four bottles). The analysis was performed by means of X-ray fluorescence (XRF), and the results were subjected to statistical analysis (*U* Mann–Whitney test). The study showed that beer is a good source of calcium and that one bottle (500 ml) covers up to 12% of the daily norm of the National Food and Nutrition Institute in Warsaw, Poland (IŻŻ), and up to 15.5% in reference to US norms. The rest of the studied elements (chlorine, potassium, phosphorus) cover up to 3% of the daily need.

Keywords Beer · Calcium · Chlorine · Diet · Potassium · Phosphorus

Introduction

Apart from proteins, fats, carbohydrates, and vitamins, the human organism also requires minerals to function properly. Minerals play regulatory and building functions [1], and their insufficiency or excess in a diet may be the reasons for the development of numerous diseases, including: arterial

hypertension, ischemic heart disease, cancers, obesity, diabetes, anemia, or osteoporosis [2].

Many minerals that are soluble in water pass to water environments via the surrounding soil. Other sources of elements include waste and industrial discharge released to local waters. Moreover, chemical compounds that include such elements as sodium, phosphorus, calcium, zinc, or fluorine are used for processing, the establishment of pH, and water purification. All mineral sources in water are characteristic for a given region, and this fact relates to the specific mineral content of waters in a given area [3].

Beer is the most commonly consumed alcoholic drink in the world, as well as the third most commonly consumed drink by humans, right after water and tea [4]. The study of Public Opinion Research Center (TNS OBOP) in Poland regarding the amount of alcohol consumed in Poland shows that beer is the most commonly consumed alcoholic drink in the studied population (it was chosen by 87.6% of interviewees) [5]. The basic ingredient that is used to make beer is water. The mineral content of water influences the chemical changes in the production of beer, which condition the

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beverage's taste, color, and durability [6]. Beer labels do not include mineral content because the current regulations do not provide information on the acceptable concentration of specific elements, and there is no obligation to inform customers about the levels of the elements [6]. Therefore, it can be supposed that the concentrations of specific elements in water (and in consequence—in beer) may differ significantly depending on the region of production. The differences may be conditioned by the different chemical compositions of the local materials used to produce beer, especially water, but also yeast, malt grain, and hops [7]. Malt is the main source of elements such as magnesium and potassium in beer. The malt delivers 130 mg/L of magnesium and 500 mg/L of potassium to beers. Magnesium and manganese can activate many enzymes such as decarboxylases, dehydrogenases, kinases, oxidases, peroxidases, and peptidases, which negatively affect the colloidal stability of beer. In contrast, potassium in concentrations increase more than 10 mg/L inhibits the activity of enzymes during mashing. However, on the other hand, the use of such high concentrations of potassium causes a salty taste of beer [6]. Zinc is very important for yeast as a cofactor for many enzymatic processes. It is involved in the metabolism of yeasts, what positively affect on the course of fermentation. In the wort, zinc concentration should be between 0.04 and 0.15 mg/L and should not exceed 0.6 mg/L because of its negative effect on the colloidal stability of beer. However, iron is also important because of its negative influences on the development and activity of yeast in concentration above 0.1 mg/L. In concentrations above 1 mg/L, this element causes degradation of yeast and stopped the fermentation proces [6]. Consumers often select national products, but imported beers are becoming increasingly popular [8]. Because of this fact, it seems reasonable to determine the content of elements in beers imported from various regions of the world and available on the local market. The aim of the study is to provide an answer to the question whether beer is a significant source of minerals for humans, and if there are differences if we compare the drinks imported from different countries.

Materials and methods

Samples

52 bottled beers imported to Poland from different breweries from Asia (China—6 Pilsner beers, Thailand—6 Lager beers and 2 Porter beers, Vietnam—6 Lager beers, Armenia—4 Lager beers), South America (Mexico—4 Pilsner beers), and European countries (Italy—4 Lager beers, Portugal—2 Lager beers and 2 Porter beers, Czech Republic—2 Lager beers and 2 Porter beers, Ukraine—2 Lager beers and 2 Pilsner beers, Germany—2 Pilsner beers and 2 Kolsch

beers, Ireland—2 Stout beers and 2 Lager beers) were used for the purpose of this study. The drinks were purchased in 2017 in the stores of Zachodniopomorskie and Wielkopolskie voivodeships. After degassing, beer samples were collected into plastic 20 ml tubes. Subsequently, the samples were described and stored at -20°C until labeling.

Analysis of mineral content in beer samples

The elemental analysis of the liquid samples was investigated by energy dispersive X-ray fluorescence (EDXRF) spectrometer EPSILON3 purchased from Panalytical B.V. XRF is an analytical technique that can be used to determine the chemical composition of a wide variety of sample types including solids, liquids, slurries, and loose powders. It can analyze elements from beryllium (Be) to uranium (U) in concentration ranges from 100 wt% to sub-ppm levels. In addition, Panalytical's Omnian software is ideal when there is no convention calibration established for materials that require analysis. Designed to provide fast and reliable quantification, the software Omnian's advanced fundamental parameter algorithm automatically deals with the analytical challenges posed by samples of widely differing types.

The liquid samples were placed in cups P1 type, diameter 28 mm with Prolene thin-film 4 μm (C3H6, 0.9 mg/g). The volume of the samplers was equal to 6 ml. Measurements were performed in helium during 480 s. The software OMNIAN was applied for quantitative analysis.

Detection limit (LLD [%]) was calculated for each sample and each element during the analysis and carried out: for P—0.001–0.0009%, for Cl—0.002–0.001%, for K—0.0009–0.0006%, for Ca—0.001–0.0009%.

The statistical analysis

The statistical analysis was performed using Statistica 12.5 program (StatSoft, Poland). The visual representation of the results was prepared using Excel 2007 in Windows 7. The arithmetic means (AMs) and standard deviations of the AM (SDs) were calculated for each studied group. The Shapiro–Wilk test was performed to determine the arrangement of the analyzed data. As the distribution in most cases deviated from normal, non-parametric test was used—the Mann–Whitney U test for comparisons between groups. The results were verified at the level of statistical significance p value ≤ 0.05 .

Results

The aim of the work was to investigate the levels of calcium, chlorine, potassium, and phosphorus in beer and whether beers can be a good source of these elements for humans.

Clear differences in terms of calcium concentration were observed in the studied beer samples depending on their country of origin. The most statistically significant differences were noted between Armenian, German, and Mexican beer compared to other examined countries. The best sources of calcium were German beers, with the average calcium concentration of 0.31 g/L (SD=0.15), and Armenian beers, with the average calcium concentration of 0.28 g/L (SD=0.013). The concentration of this element in these beers was higher in comparison to all other studied beverages. The lowest concentration of calcium was observed in Portuguese beers, with the average concentration not exceeding 0.05 g/L (SD=0.01) (Fig. 1).

Chlorine was the next element analyzed in the beers. Its highest concentration was observed in Ukrainian beverages (0.100 g/L $\pm$ 0.083). A high concentration of this element was also observed in Portuguese (0.066 g/L $\pm$ 0.003), Irish (0.054 g/L $\pm$ 0.003), and Thai beers (0.048 g/L $\pm$ 0.005). The lowest concentration was observed in Czech

(0.023 g/L $\pm$ 0.001), German (0.023 g/L $\pm$ 0.006), and Mexican beers (0.024 g/L $\pm$ 0.001). The statistical analysis showed significant differences in terms of Cl concentration in beers coming from different countries (Fig. 2). There were no statistically significant differences between Ukrainian beers compared to Thai Irish and Portuguese and between Thai compared to Vietnamese.

The highest concentration of potassium was observed in Portuguese (0.191 g/L $\pm$ 0.001), Irish (0.189 g/L $\pm$ 0.003), Ukrainian (0.175 g/L $\pm$ 0.061), and Armenian (0.168 g/L $\pm$ 0.003) beers, whereas the lowest concentration of this element was present in Czech (0.064 g/L $\pm$ 0.005) and Mexican (0.081 g/L $\pm$ 0.005) beverages. In this case, the statistical analysis also showed significant statistical differences in the content of this element in beers between all of the analyzed countries (Fig. 3).

The next element subjected to analysis was phosphorus. The concentration of this element was the highest in Portuguese (0.036 g/L $\pm$ 0.0001), Italian (0.031 g/L $\pm$ 0.001), and

Fig. 1 **a** Mean calcium concentration [g/L] in beers origin from different countries; SD standard deviation. **b** U Mann–Whitney test for calcium concentration in beers from different countries; * $p \leq 0.05$; minimum value; maximum value and coefficient of variation

Fig. 2 **a** Mean chloride concentration [g/L] in beers origin from different countries; *SD* standard deviation. **b** *U* Mann–Whitney test for calcium concentration in beer from different countries; * $p \leq 0.05$; minimum value; maximum value and coefficient of variation

Armenian beers ($0.031 \text{ g/L} \pm 0.001$). The lowest concentration was observed in Mexican ($0.012 \text{ g/L} \pm 0.003$), Chinese ($0.012 \text{ g/L} \pm 0.001$), and Czech beers ($0.013 \text{ g/L} \pm 0.001$), and these values were significantly lower in comparison to all other studied drinks (Fig. 4). There were no statistically significant differences between German and Irish, Armenian and German beers, Chinese and Mexican beers, Czech compared to Mexican and Chinese and Italian compared to German and Armenian beers.

Discussion

Beer is considered as a refreshing drink that is good at quenching thirst by many consumers. This fact can be associated with the properties of the drink that include high energy value, the content of vitamins soluble in water, as

well as the necessary microelements [9]. The contents of the extract are well absorbed because they partially occur in the form of colloids [9].

Calcium, which is the most common element in the organism in comparison to other elements, mostly occurs in hard tissues (99%). It is known that calcium absorption from food depends on many factors: fiber and caffeine reduce absorption [10, 11], whereas lactose, some amino acids, and vitamin D increase this process [12–14]. Calcium deficiency in the diet of adults may lead to osteomalacia [15] and osteoporosis [16]. The decrease in the concentration of calcium in blood serum results in the mobilization of its deposits initially from bones as a result of the activity of PTH (parathormone) [15]. On the other hand, the cases of hypercalcemia are very rare because the excess of this element in physiological conditions is mainly deposited in bones [17, 18]. The main causes of hypercalcemia include primary

Fig. 3 a Mean potassium concentration [g/L] in beers origin from different countries; *SD* standard deviation. **b** *U* Mann–Whitney test for calcium concentration in beer from different countries; * $p \leq 0.05$; minimum value; maximum value and coefficient of variation

hyperparathyroidism and cancers, which may lead to the formation of calcium salts' aminodeposits in other tissues and tissue disorders [17, 19, 20]. Other symptoms may include the weakening of muscles, tiredness, constipation, and the weakening of nerve transmission [17]. In brewing, calcium is used for the removal of oxalates which are deposited in insoluble form. In addition, calcium in beer is needed for flocculation of yeast. Flocculins bind mannans on the surface of adjacent cells in the presence of calcium ions [21, 22]. In the study, calcium levels ranged from 0.04 to 0.31 g/L, while in Spanish beers from 0.2 to 0.83 g/L. On the basis of the results achieved in this study, it can be concluded that the analyzed beers may serve as a significant source of calcium for humans. According to Polish nutritional norms, the daily need (RDA) for calcium is between 700 and 1300 mg/day depending on sex and age (Food and Nutrition Institute in Warsaw) [23]. The US recommended adequate intake levels (AI) for calcium are about 1000 mg/day for adults (dietary reference intakes recommended by the National Academy of

Sciences, Food and Nutrition Board, USA) [24]. This means that 500 ml of beer (1 bottle), depending on its origin, covers from 1.9 to 12% of the daily norm established by Food and Nutrition Institute in Warsaw [23], and from 2.5 to 15.5% of the daily norm in the USA [24].

Studies carried out by Rajkowska et al. on Polish beers indicated significantly higher contents of potassium (from 0.172 to 0.518 g/L) [6] in comparison to Spanish beers (0.406 g/L) [25] and other beverages analyzed in our study (from 0.064 to 0.191 g/L). The differentiated level of potassium may result from the different quality of resources, as well as from a different class of yeasts used in the production, which are a significant source of potassium ions and phosphorus ions [25]. During the technological processes used in the production of beer, potassium passes from malt to wort in the concentration between 0.3 and 0.5 g/L, influencing color and taste [6]. However, its level has to be strictly controlled because too high amounts can inhibit the activity of enzymes and lead to a salty taste of beer, significantly

Fig. 4 a Mean phosphorus concentration [g/L] in beers origin from different countries; *SD* standard deviation. **b** *U* Mann–Whitney test for calcium concentration in beer from different countries; * $p \leq 0.05$; minimum value; maximum value and coefficient of variation

reducing its quality [6]. Potassium is the main intracellular cation responsible for the regulation of the proper activity of nerves and muscles. Along with sodium ions, it participates in the functioning of Na^+/K^+ -ATPase and in the formation of the electrochemical gradient on both sides of cell membranes [1, 26]. The deficiency of this element may lead to the weakening or paralysis of muscles, whereas excessive amounts could cause cardiac arrest or small intestine ulcers [26]. According to the Polish and US recommendations, the intake of potassium for humans should be about 4.7 g a day. Therefore, one bottle of beer produced in Portugal or Ireland (the countries that had the highest concentration of this element) may cover 2% of the daily need for this element [23, 24].

The quality of beer, its color, and taste are also strongly influenced by the content of phosphorus. The appropriate level of this element is strictly regulated during the whole process of beer production [14]. Phosphorus is necessary for the formation of ATP, the formation of a dual phospholipid membrane around the yeast cell and buffering the pH change

[21]. Phosphate deficiency causes problems with fermentation and reduces cell growth. The study carried out by Alcazar et al. [27] on Spanish beers indicated phosphorus content in those beers at the level of 0.218 g/L, while studies performed by the American Society of Brewing Chemists, the European Brewery Convention, and the Brewery Convention of Japan [28] showed phosphorus content in the analyzed beer samples at the level between 0.159 and 0.465 g/L. In our work, the highest level of phosphorus was 0.036 g/L and it referred to Portuguese beers. Comparing these values to the norms of phosphorus intake which are 700 mg/L per day according to Poland and US standards, it turns out that a single bottle of beer may cover 2.6% of the daily requirement in terms of this element.

Similarly to calcium, phosphorus is a constituent of hydroxyapatites—the main building material of hard tissues [29]. Phosphorus is a constituent of nucleic acids, ATP, and phosphorylated metabolites in many metabolic pathways. Deficiencies of this element cause rickets in children and osteomalacia in adults [30]. However, excessive amounts

of phosphorus also have a negative impact on the human organism. Low Ca:P is the cause of secondary hyperparathyroidism and, in consequence, may also be the cause of bone mass loss [30]. This is why it is so important to cover the daily need for this element.

Chlorine plays an important role in the human organism. Most of all, it takes part in water and electrolyte transformation, as well as in the process of stomach acid creation. In beer, chloride limits the yeast's flocculation and improves clarification and colloidal stability [21]. The studies carried out by the American Society of Brewing Chemists, the European Brewery Convention, and the Brewery Convention of Japan [28] indicated a high differentiation in terms of the content of this element in beers, which was between 0.060 and 0.362 g/L [28]. One of the main causes of chlorine's presence in water is the fact that it is used in water purification to prevent the development of pathogenic microorganisms. Unfortunately, the chlorination of water leads to the formation of numerous different compounds, such as: trihalomethanes, haloacetic acids, haloacetonitriles, haloketones, chloral hydrate, or chloropicrin, all of which have a negative influence on human health [31]. Due to these hazards, many industrialized countries try to apply different methods of water purification, such as sedimentation, filtration, disinfection using UV light, or ozonisation which do not use chlorine [32]. Our studies showed that the highest concentration of chlorine was present in Ukrainian beers, and it was at the level of 0.1 g/L. While comparing the acquired results with the daily needs, it was observed that one 500 ml bottle covers between 0.5 and 2.8% of the daily requirement of chlorine (according to Polish and US norms) [8].

Large quantities of microelements and macroelements are present in malt. Studies by Svetlana and Özcan [33] showed that malt includes 4514 mg/kg of Ca, 6370 mg/kg of K, 2383 mg/kg of Mg, and 8865 mg/kg of P. However, the studies also show that the elements remain in spent grain after the separation from wort, which does not increase the pool of minerals in the beer [33, 34].

The available literature includes studies that show the positive influence of low-percentage alcohols on the mineral density of bones [35]. The density is influenced by both low doses of ethanol, as well as the additional ingredients of alcoholic drinks, such as resveratrol (in wines) which has antioxidative effects [35], or silicon which in the form of orthosilicic acid has a positive influence on the process of bone formation. In addition, small doses of alcohol may increase the concentration of HDL in serum via the increased synthesis of apoA1 and changes in the activity of the protein that transports cholesterol esters [26]. There are also significant amounts of beta glucans and arabinoxylans in beers. They are released by the enzymatic and thermal hydrolysis of the grain used to make beer. They have an

inhibitory effect on postprandial glucose concentration in the blood, insulin response, and lower elevated blood cholesterol levels [36, 37]. However, it has to be remembered that despite the significant amount of the elements in beer, we should consider this drink as a potential supplement of these elements in our diet. The consumption of beer and the alcohol it includes, for a prolonged time may lead to addiction and the development of alcoholism. Excessive alcohol consumption may lead to a growing storage of fatty acids in the liver (which come from endogenic synthesis), and their esterification into triacylglycerols, which might lead to the development of alcoholic fatty liver, inflammation, cirrhosis, or even cancer [26]. Furthermore, the synthesis of cholesterol increases as a result of the inhibition of Krebs cycle activity [26].

To summarize, on the basis of the study it can be concluded that beer is a good source of calcium ions, but it is a poor source of chlorides, potassium, and phosphorus. However, if we compare the results of our studies with the results achieved by other researchers, it has to be mentioned that various types of beer are characterized by significant differences in mineral content, which is a result of the type of water, the resources used for the drinks' production, the class of yeast, and the technological processes applied during production. All of those factors might have a direct effect on the role of beer in the daily needs for minerals.

Compliance with ethical standards

Ethical approval This study was supported by the statutory budget of the Department of Biochemistry and Human Nutrition, Pomeranian Medical University in Szczecin, Poland.

Conflict of interest The authors declare that there is no conflict of interest.

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