ORGANIC PLANT PRODUCTS ARE OF MORE IMPROVED CHEMICAL COMPOSITION THAN CONVENTIONAL ONES

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Abstract: Considering the negative effects of conventional agricultural production, organic food production is a sustainable approach to production, which preserves the environment and protects human health. Organic products are products of high quality, without residues of pesticides and other harmful chemicals. Through the review of literature data, the authors of this paper presented a comparative study on the chemical compositions of organically vs. conventionally grown plants and their products. Dry matter, nitrates, sugars, vitamins, macro- and microelements, as well as, secondary metabolites have been singled out. The analysis of collected data revealed that organic products contained more dry matter, significantly fewer nitrates, fewer proteins and a higher proportion of amino acids, more sugars, vitamin C, numerous macro- and microelements (particularly Fe, Mg and P), more polyphenols and they had higher total antioxidant capacity than conventional products. Although many authors have been dealing for many years with the comparison of the nutritional composition of organic and conventional food products, a clear consensus whether organic products have an improved chemical composition compared to conventional products has not been reached yet, i.e. the conclusions are ambivalent. Therefore, further long-term studies are necessary to clarify the existing doubts.

Key words: organic production, conventional production, vitamins, minerals, secondary metabolites, nitrates

INTRODUCTION

Organic agricultural production can be most easily defined through its goals: the production of healthy and high-quality food through the preservation of the environment, soil and its fertility, biodiversity, agro- and ecosystem, with the simultaneous improvement of health and productivity of interdependent communities, life of land, plants, animals and people (Mirecki, Wehinger & Jaklić, 2011; Popović et al., 2016). The areas under organic plant production on a global level have been increasing, as well as, the organic products market (Popović, Golijan, Sečanski & Ćamdžija, 2017; Golijan & Dimitrijević, 2018). According to the Research Institute of Organic Agriculture (FiBL, 2020): „Organic agriculture is prac-
Organic plant products are of more improved chemical composition than conventional ones. The global sales of organic food and drink reached more than 96 million euros in 2018. Numerious abiotic and biotic factors affect food quality. Many pollutants with very harmful effects on human health entered into the food production chain (soil–plant–animal–human organism) from the environment as an abiotic factor (Figure 1). Some of these pollutants are heavy elements, pesticide residues, nitrogen compounds, mycotoxins, chlorinated biphenyls, aromatic hydrocarbons (e.g. benzo[a]pyrene), plant growth stimulators (e.g. choline chloride), antibiotics, hormones, radio-active isotopes and plastic substances (monomers) (Rembiałkowska, 2007). Today, agriculture is considered as one of the sources of increased greenhouse gas emissions, as well as a great polluter of the environment. Modern scientific knowledge integrated into sustainable production has reaffirmed those methods and technologies of the food production processes that favour the healing of disturbed ecosystems. Organic agriculture can be considered as one of the directions of this type of sustainable, safe and environmentally friendly production (Šeremešić et al., 2017).

Consumers in most countries have a positive attitude towards organically produced food. Considering that the system of organic production is fully legally regulated and the mandatory certification by competent certification institutions is required, consumers recognise organic products as safer and sounder to consume (Codron, Siriex & Reardon, 2006). In this regard, the most common motif for consuming organic products is taking care of their own health, because consumers believe that organic products are healthier and with a higher content of nutrients compared to conventionally produced foods (Marques Vieira, Dutra De Barcellos, Hoppe & Bitencourt da Silva, 2013; Golijan & Veličković, 2015).

Figure 1. Pollutants that affect food quality
Since the use of synthetic pesticides, i.e. fungicides in the control of pathogenic microorganisms is not allowed in organic production, the question of whether mycotoxins are more present in organic food production than in conventional ones has been the objective of studies performed by many researchers. Obtained results varied a lot. For instance, Lairon (2010) has stated that it was evident that food contamination with mycotoxins was widespread, but still at a low level, due to which was impossible to draw a general conclusion whether organic and conventional food production differed in terms of the level of mycotoxin contamination. Preventive protection measures in the organic mode of production, despite the exclusion of classical fungicides, provide the maintenance of a low level of infection, when present mycotoxins do not exceed the maximum tolerable concentrations. According to Golijan, Lekić, Vuković & Sečanski (2020), who observed the content of mycotoxins in organically and conventionally produced seed of maize, spelt wheat and soya bean, there was only one sample of organic maize contaminated with aflatoxin B1 (1.16 µg/kg) and deoxynivalenol (101.53 µg/kg), in concentrations bellow maximum tolerable values given in the Regulation on the maximum allowed quantities of residues of plant protection products in food and feed.

Numerous researchers throughout the world have been for many years engaged in comparative studies of differences in the chemical composition between organically and conventionally grown plants and their products. Some of them presented review papers based on a large number of experiments. Some authors applied the meta-analysis to at least several hundred studies and drew conclusions about the effects of organic and conventional production methods on the chemical compositions of plants (Woëse, Lange, Boess & Bogl, 1997; Worthington, 1998; Bourn & Prescott, 2002; Heaton, 2001; Worthington, 2001; Rembiałkowska, 2007; Baranski et al., 2014, and many others). According to them, organic food products contain significantly more amounts of dry matter, total sugars, essential amino acids, vitamin C, macro- and microelements (especially Ca, Mg, Fe, P, Zn), phenolic compounds and significantly fewer nitrates than conventional food products (Figure 2).

The majority of data refers to vegetables and fruits and much less to cereals. Previous scientific data indicate that there is an insufficient number of studies related to the observation of the vitamin levels, particularly of β-carotene and vitamin B complex (Golijan & Veličković, 2015). Moreover, most of the conducted studies compared the effects of organic and conventional fertilisers on the nutritive composition of products, but not the effects of the production system as a whole. A simple measurement of various nutrients in food does not reflect the food quality per se (Magkos, Arvaniti & Zampelas, 2003). Results obtained by many researchers point out

![Figure 2. Effects of organic and conventional production methods on the chemical compositions of plants (data compiled from Woëse, Lange, Boess and Bogl, 1997; Worthington, 1998; Heaton, 2001; Worthington, 2001; Bourn and Prescott, 2002; Rembiałkowska, 2007; Baranski et al., 2014, and many others)](image-url)
that differences in the nutritional composition between organically and conventionally produced food products vary depending on the production season, plant species, morphological parts of plants being analysed, as well as on tested nutrients, so it is very difficult to draw a final conclusion on the effect of the cultivation system on the nutritional composition of plants (Magkos et al., 2003). Furthermore, several studies have proven that organically grown fruits and vegetables have a potentially higher nutritional value compared to conventional ones. Other studies have proven the existence of small differences or absence of differences, while several studies have indicated a higher level of specific nutrients in conventionally produced food products. Since many types of research suggest that the nutritional value of organic food is higher than the food conventionally produced, a clear consensus has not been reached yet and therefore, further studies are needed.

The aim of this study was to analyse the relevant literature and to point out the effects of organic and conventional methods of production on differences in the chemical composition of plants and their products in order to clarify ambiguities about favouring organically produced food.

**DRY MATTER**

Studies on the difference in dry matter contents between organic and conventional food products are mainly related to vegetables and fruits. Although obtained results vary, there are data that organically cultivated crops had a higher content of dry matter than conventionally grown crops (Finesilver, Johns & Hill, 1989; Hornick, 1992; Woëse et al., 1997; Worthington, 1998). According to some researchers, organically grown leafy, root and tuber vegetables have a higher dry matter content than conventionally grown vegetables (Woëse et al., 1997; Bourn and Prescott, 2002; AFSSA, 2003), while no difference was detected in other types of vegetables and fruits. There are very limited data related to fruits, and they mainly refer to apples, strawberries, oranges, lemons, and pineapples. Higher content of dry matter was recorded in organic leafy vegetables, such as spinach, lettuce, chard, Savoy cabbage, and white cabbage than in conventional ones (Schuphan, 1974; Vogtmann, Temperli, Kunsch, Eichenberger & Ott, 1984; Bourn, 1994; Lecerf, 1995; Fjelkner-Modig, Bengtsson, Stegmark & Nystrom, 2000). On the other hand, according to Schuphan (1974), Reinken (1986), Termine et al. (1987), Rembialkowska (1998), the differences in this content were not recorded between organically and conventionally grown root vegetables, such as potatoes, leeks, turnips, and carrots. Stated differences in the dry matter content in two different production systems are related to the influence of nitrogen. As far back as 1972, Schuphan (1972) claimed that the increased application of nitrogen fertilisers could reduce the content of dry matter, methionine, total sugars, vitamin C, essential oils, as well as, numerous minerals. As a result, the differences between organically and conventionally grown fruits are not expected due to the low ability of fruits to absorb and assimilate nitrogen. Bordeleau, Myers-Smith, Midak & Szeremeta (2002) assumed that plants organically cultivated contained less dry matter than plants conventionally produced, because the low amounts of fertilisers are applied in organic production and due to it plants are less developed and contain less water and thus less dry matter. Studies on the yield, quality indicators, antioxidants and elemental composition of nine leek cultivars grown in greenhouses under organic or conventional systems in the Moscow region, carried out by Golubkina et al. (2018), showed that pseudo-stem dry matter and sugars were higher with organic management.

**NITRATES**

Nitrate (NO₃⁻) is the most important form of nitrogen (N), which is easily absorbed by the majority of vegetables and fruits in order to achieve higher yields (Colla, Cardona Suarez, Cardanelli & Rouphael, 2010). It is usually found in large quantities in green leafy vegetables such as lettuce and spinach, as well as, root vegetables such as celery, radishes and beets. When the intake of nitrate in the plant exceeds the assimilation, the nitrate is accumulated in the plant tissues. Higher concentrations of nitrates are accumulated in leaves, while the lower level of nitrates is accumulated in bulbs, seeds, fruits, roots and tubers. Therefore, leafy vegetables such as rocket, chard, spinach, lettuce, celery and parsley are considered to be nitrate-accumulating species (Santamaria, 2006). Factors that affect the accumulation of nitrates in plants are: lack of...
sunlight or water, variety, maturity and high levels of fertilisation (Wolff & Wasserman, 1972). In contrast to a smaller number of data on the comparative dry matter content between organically and conventionally produced food products, the multitude of data indicates a lower nitrate content in organic crops (Worthington, 2001; Hoogenboom et al., 2008; Dangour et al., 2009; Soltoft et al., 2010; Gastol, Domagala–Świątkiewicz & Krośniak, 2011; Kalinova & Vrchotova, 2011; Aires, Carvalho, Rosa & Saavedra, 2012; Gorenjak, Koležnik & Cencič, 2012; Koh, Charoenprasert & Mitchell, 2012; Lombardo, Pandino & Mauro-micale, 2012; Tuomisto, Hodge, Riordan & Macdonald, 2012; Ilić, Kapoulas, Sunic, Bekovic & Mirecki, 2014; Nuñez de González et al., 2015; Rossetto, Vianello, Saeki & Lima, 2015; Hallmann et al., 2017; Golubkina et al., 2018; Bender et al., 2020). It is of great importance to be aware of this fact, given that the harmful effects of nitrate on the human body are known. They can react with amines and form nitrosamines - carcinogenic and mutagenic substances that cause digestive tract cancer and leukaemia. Moreover, nitrates converted into nitrites cause methemoglobinemia (Fewtrell, 2004). The lower content of nitrates and a higher content of phenolic compounds and vitamin C in organic crops are vital for health because vitamin C interferes with the conversion of nitrate into toxic nitrites, which are the precursors of carcinogenic nitrosamines. Large amounts of polyphenols present in organically grown crops hinder the process of carcinogenesis (Rembialkowska, 2007).

Table 1 presents the comparative analysis of the nitrate and nitrogen content between organic and conventional systems. It is known that the use of organic fertilisers in crops can lead to lower nitrate levels in contrast to the application of nitrogen-rich mineral fertilisers (Leclerc, Miller, Joliet & Rocquelin, 1991; Rembialkowska, 1998; Bourn & Prescott, 2002). The content of nitrate in organic crops is lower, on average, by 49% than in conventional crops (Rembialkowska, 2000). According to the formula coined by Worthington (2001): (CONV-ORG) / ORG x 100%, conventional crops contain an average of 148.39% more nitrate than organic crops. Consequently, the highest levels of nitrate were found in red beetroots. This is because they exhibit the tendency of nitrate accumulation in roots. It is generally known that the application of fertilisers in plant production affects the composition of plant material.

The majority of studies indicate that when a higher amount of nitrogen is available to a plant, its intake is higher, which results in a higher content of nitrogen and nitrates in crops (Bourn & Prescott, 2002).

### Table 1
Comparative analysis of nitrate and nitrogen content in plants from organic and conventional systems

| Reference                          | Samples                               | Compounds analysed | Major conclusions                                      |
|------------------------------------|---------------------------------------|--------------------|--------------------------------------------------------|
| Worthington (2001)                 | Many organic and conventional crops    | Nitrate            | Organic crops had a lower content of nitrate than conventional crops. |
| Kramer, Reganold,                   | Apple orchard                         | N₂O, N₂, nitrate   | Soils under organic management had higher organic matter content, microbial biomass C and N. Annual nitrate leaching was 4.4–5.6 times higher in conventional than in organic fields. N₂O emissions were not significantly different among treatments. N₂ emissions were highest in organic fields. |
| Glover, Bohannan & Mooney (2006)   | Conventional, organic and sustainable farms | Nitrogen           | Soils from organic farms had improved soil chemical factors and higher levels of extractable C and N, higher microbial biomass carbon and nitrogen, and net mineralizable N. |
| Liu, Tu, Hu, Gumpertz & Ristaino (2007) | Lettuce, carrots, potatoes             | Nitrate            | Nitrate levels in organic lettuce were much lower than those in conventional, while organic carrots and organic potatoes showed a large variation. |
| Hoogenboom et al. (2008)           | Chinese cabbage, maize                | Nitrate            | Higher concentration of nitrate was found in organic production than conventional. |
| Lima, lopes, Rossetto & Vianello (2009) | Many organic and conventional crops    | Nitrogen            | Nitrogen content was higher in crops from conventional systems than organic. |
| Soltoft et al. (2010)              | Carrot                                | Nitrogen            | Higher concentration of nitrogen was detected in conventional carrot than organic. |
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| Reference                     | Samples                     | Compounds analysed | Major conclusions                                                                 |
|-------------------------------|-----------------------------|--------------------|-----------------------------------------------------------------------------------|
| Gastol et al. (2011)          | Apple, pear, blackcurrant, carrot, beetroot and celery | NH₄⁺, NO₃⁻      | NH₃N content was lower in organic vegetable juices than in conventional ones. The conventional farming method favoured greater NO₃⁻N accumulation for beetroot (846 mg NO₃⁻N kg⁻¹ f.w.) than for organic juice (229 mg NO₃⁻N kg⁻¹ f.w.) |
| Kalinova & Vrchotova (2011)   | Buckwheat                  | Nitrate            | The nitrate content was higher in conventional buckwheat compared with the organic buckwheat. |
| Gorenjak et al. (2012)        | Lettuce, dandelion          | Nitrate            | The mean nitrate contents in organic lettuce were considerably lower than those in conventional sample. No major differences were recorded between the dandelion samples. |
| Koh et al. (2012)             | 27 varieties of spinach     | Nitrate            | The mean levels of nitrate were significantly higher in the conventionally grown spinach compared to the organically grown spinach. The levels of nitrate correlated negatively with those of ascorbic acid, vitamin C, and total flavonoids and showed a positive correlation with the oxalate content. |
| Lombardo et al. (2012)        | Potato                      | Nitrate            | The nitrate content in the organic grown tubers was 34% less than in the conventional grown ones. |
| Tuomisto et al. (2012)        | Many organic and conventional crops | Nitrogen          | Nitrogen leaching per unit of area was 31% lower from organic farming compared to conventional farming. |
| Aires et al. (2012)           | 6 kinds of baby-leaf salads (red and green lettuces, rucola, corn salad, watercress, chard) | Nitrite, nitrates | The nitrate average levels were significantly higher in conventional products, while no significant differences in nitrite content. |
| Laursen et al. (2013)         | Potato                      | Nitrate            | There were no significant differences between farming systems, locations, or harvest years. |
| Baranski et al. (2014)        | Many organic and conventional crops | Total N        | Conventional crops had higher concentrations of total N. |
| Ilić et al. (2014)            | Tomato                      | Nitrates           | Lower nitrate contents were observed in organic products compared to conventional ones. |
| Rossetto et al. (2015)        | Raw and cooked: broccoli, collard greens, carrot, beets | Nitrate, polyamines | Nitrate contents showed significant difference between conventional and organic broccolis, carrots, and collard greens. Organic beets contained lower nitrate levels compared to conventional beets. Organic farming increased the polyamine levels and decreased nitrate content. |
| Nuñez de González et al. (2015) | Broccoli, cabbage, celery, lettuce, spinach | Nitrate and nitrite | There was no difference in the average nitrite contents of conventional vegetables compared to organic vegetables. In most cases, organic vegetables were numerically lower in nitrate content than their conventional counterparts. |
| Kapoulas, Koukoumaras, & Ilić (2017) | Lettuce, onion | Nitrate | In lettuce, the highest values of nitrate concentration were in organic production system in autumn. The nitrate concentration was significantly higher in green onion plants grown during the spring period compared to those grown in autumn, indicating that different growing seasons affect nitrate content. Onion from org. production system obtained higher nitrate concentration. |
| Hallmann et al. (2017)        | White cabbage (Brassica Oleracea L. var. Capitata) | Nitrites, nitrates | Organic fresh cabbage, compared to the conventional one, contained significantly fewer nitrites and nitrates. |
If a plant receives more nitrogen than it can "withstand" through the increased protein synthesis, the remaining excess will be accumulated as nitrate and be stored mainly in green leafy parts of the plant (Mozafar, 1993; Worthington, 2001). Reganold and Wachter (2016) indicating that lower nutrient pollution from organic compared with conventional systems can be explaining by differences in their nitrogen cycling and losses.

Studies point out that the nitrogen levels in vegetable crops are higher when nitrogen is applied at high rates in the inorganic form than when nitrogen is applied in the form of compost or other organic fertilisers such as manure (Vogtmann et al., 1984; Woëse et al., 1997; Worthington, 1998). These and other data provide a basis for conclusions that organic practices result in reduced nitrate and nitrite intake in humans by approximately 50%. Then, Vitamin C can afford protection from this conversion of nitrate to nitrite to nitrosamines. Due to it, the higher levels of nitrate in non-organic crops have often been linked with the lower vitamin C levels (DIouhy, 1977; Fischer & Richter, 1986; Lairon et al., 1986; Woëse et al., 1997; Worthington, 1998).

### PROTEINS

The majority of studies related to the difference in the protein content between organic and conventional crops refer to data on vegetables. Most authors have compared the contents of crude proteins and specific free amino acids. Few authors have studied protein quality, i.e. the composition of essential amino acids. Many authors have agreed that organically grown vegetables in comparison to conventionally grown vegetables, such as spinach, red beet, carrots, tomato and potato, had a lower content of crude proteins and free amino acids, and on the other hand had higher concentrations of several essential amino acids (Lairon et al., 1984; Millard, 1986; Reinken, 1986; Schuphan, 1974; Clarke & Merrow, 1979; Eppendorfer, Eggum & Bille, 1979; Bourn, 1994; Lecerf, 1995; Wawrzyniak, Kwiatkowski & Gronowska-Senger, 1997; Woese et al., 1997; Kumpulainen, 2001; Bourn & Prescott, 2002).

Pimpini, Giardini, Borin and Gianquinto (1992) compared the effects of the application of poultry manure and mineral fertilisers on the nutritional composition of potatoes, sugar beet, onion, tomatoes and spinach and have detected a lower content of crude proteins only in organically grown spinach. However, all differences in terms of quantity, type and quality of proteins in vegetable crops have very little practical significance, given their negligible (vegetables) or small (potatoes) contribution as a source of proteins.

Not much data are available on differences in protein contents between organic and conventional cereals and legumes. According to Woëse et al. (1997), organically grown cereals, especially wheat, contain fewer proteins than conventionally grown cereals. Organic cereals, such as wheat, maize and rye, tend to contain lower amounts of crude proteins and free amino acid, but higher amounts of essential amino acids (DIouhy, 1977; Chakhovskii, 1981; Starling & Richards, 1990; Starling & Richards, 1993; Bourn, 1994; Ragaatis & Kismanyoky, 2000; Magkos et al., 2003).

Comparative studies performed by Shier, Kelman and Dunson (1984) on differences in contents of crude proteins, moisture and ash among nine samples of wheat from organic and conventional trials showed that the protein content obtained in both production systems was similar. Lower protein content in organic wheat can be a consequence of lower nitrogen
availability (Starling & Richards, 1990). Storey, Hogan and Humphreys (1993) studied the stability of wheat varieties for organic production and determined a lower content of proteins in them. On the other hand, according to some authors, organic wheat is nutritionally and metabolically superior (Bourn & Prescott, 2002). The content of essential amino acid lysine was higher by 25-30\% in organically grown wheat (Wolfson & Shearer, 1981; Brandt, Brand & Cruywagen, 2000). Regarding organic and conventional fruits, differences in the concentration of crude proteins and free amino acids are not significant (Reinken, 1986; Woese et al., 1997; Magkos et al., 2003). Since fruit is an insignificant source of proteins, these results have no practical importance. Contents of proteins, total sugars, total and insoluble fibres of conventional goji berries were significantly higher (p≤0.05) than those of organic goji berries (Pedro et al., 2019). Protein content varied from 9.57\% in organic berries to 9.72\% in conventional berries.

The higher content of crude proteins in conventionally grown vegetables is probably a consequence of the application of conventional fertilisers, which provided the plant with greater nitrogen availability than organic manure. It is known that the increased application of nitrogen in crop growing increases the concentration of crude proteins, but due to it, the nutritional protein value is reduced, i.e. the content of essential amino acids is decreased (Locascio, Wilkbank, Gull & Maynard, 1984; Eppendorfer & Eggum, 1996; Worthington, 2001; Rembialkowska, 2007), in particular the lysine content (Worthington, 2001). The response of each amino acid to the application of each nitrogen acid differs in dependence on the crop variety. The application of greater amounts of nitrogen fertilisers in organically and conventionally grown maize increased the contents of lysine, methionine, histidine and threonine, and decreased the contents of isoleucine, leucine and phenylalanine in organic maize. The content of crude proteins increased in the conventionally grown crop, while no difference in the proportion of amino acids was detected (Lockeretz, Shearer & Kohl, 1981; Wolfson & Shearer, 1981).

The comparative analysis of the sugar contents between organic and conventional systems is presented in Table 2.

A higher content of total sugars, most often succharose, was found in organically grown vegetables (carrots, sugar beet, red beet, potato, spinach, Savoy cabbage) and fruits (apple, cherry, current) (Rembialkowska, 2000; Bordeleau et al., 2002). The higher content of total sugars in organically grown fruits affects the better consumers’ taste perception (Rembialkowska, 2000). Hogstad, Risvik and Steinsholt (1997) performed trials on 14 farms and compared the contents of dry matter, carotene, proteins, nitrates, sugars, as well as, sensory quality of carrots. These authors determined that organically grown carrots were much juicier, sweeter, and crispier, furthermore contained more total flavour strength than conventionally grown carrots. Organic carrots also had a significantly higher content of dry matter, true protein, total sugars and carotene. Although amounts of sugars were higher in organically grown crops (Bohn et al., 2014), some authors observed no effects of either organical or conventional management on the sugar content in crops (Zörb, Langenkämper, Betsche, Niehaus & Barsch, 2006; Langenkämper et al., 2006). According to Pither and Hall (1990), who compared the nutritional content of organic and conventional vegetables, conventionally grown carrots had a higher content of glucose, fructose, total sugars and vitamin C, the organic potato had a higher content of glucose, fructose, Ca, Fe and Zn, while conventional potato contained more dry matter and succharose.

Studying differences among nine leeks cultivars (Allium porrum) grown in greenhouses under organic and conventional systems, Golubkina et al. (2018) concluded that the contents of sugars and dry matter were higher in organic leek cultivars. A significant positive correlation was determined between dry matter and disaccharides, while the correlation between dry matter and monosaccharides was negative. The increased content of dry matter and sugar in organic leek may be a consequence of the enhancement of microbial biomass and activity leading to the synthesis of the organic compounds, which is in agreement with similar studies carried out in greenhouses (Caruso, Villari, Borrelli & Russo, 2012). Indeed, Ca-
ruso et al. (2012) performed a three-year study (2007-2009) on green asparagus under the tunnel in Campania, and reported that the level of residues and sugars were higher in organic asparagus whereas nitrate and fibres levels were lower. According to studies carried out - by Pedro et al. (2019), the contents of proteins, total sugars, total and insoluble fibres of conventional goji were significantly higher than those of organic goji. Both berries of organic and conventional goji are a great source of carbohydrates and important food in the diet.

Table 2.
Comparative analysis of sugar content in plants from organic and conventional systems

| Reference                          | Samples          | Compounds analysed                  | Major conclusions                                                                 |
|------------------------------------|------------------|-------------------------------------|-----------------------------------------------------------------------------------|
| Kumpulainen (2001)                 | Carrots, potatoes| Sugars                              | For organic acids and sugars, no clear difference was found.                       |
| Reganold, Glover, Andrews & Hinman (2001) | Apple            | Sugars                              | The ratio of soluble solids (sugar) content to acidity (tartness), an indication of sweetness, the highest in organic fruit. |
| Zörb et al. (2006)                 | Wheat grain      | Sugars, sugar alcohols, sugar phosphates | No significant differences in glucose, fructose, saccharose, maltose, and erythrose-4-P of organic and conventional wheat were detected. Though small differences were detected in myoinositol content which was reduced in grains from the conventional system. |
| Langenkämper et al. (2006)         | Wheat            | Fructan                             | Fructan-levels were equal in wheat from organic and conventional farming systems.  |
| Wang, Chen, Sciarrappa, Wang & Camp (2008) | Blueberries      | Sugars                              | Blueberry fruit grown from organic culture yielded significantly higher sugars (fructose and glucose) than fruit from the conventional culture. |
| Zörb, Niehaus, Barsch, Betsche & Langenkämper (2009) | Wheat ears       | Sugars, sugar alcohols              | In ears, no significant differences between the farming systems with regard to kestotetraose, kestopentaose, stachyose, maltose, 1-kestose, raffinose, and fructose were detected. Only a difference for sucrose and glucose was found with higher concentrations in ears from conventional agriculture. |
| Gastol et al. (2011)               | Beetroot         | Sugars                              | Higher total sugars were noted for organic than conventional beetroot (8.4% versus 5.9%). |
| Carillo, Cacace, De Pascale, Rapacciuolo & Fuggi (2012) | Potato           | Carbohydrate, starch                | Compared with organic potatoes, total carbohydrate and starch content were much higher in conventional potatoes. |
| Skrabule, Muceniece, & Kirchner (2013) | Potato           | Starch                              | No significant correlations with starch content were found between potatoes grown in organic and conventional fields. |
| Nunes-Damaceno, Muñoz-Ferreiro, Romero-Rodríguez & Vázquez-Odériz (2013) | Kiwi             | Sugars                              | Conventional kiwis showed a higher content of sugars than organic kiwis, and had the greatest soluble solids, glucose and fructose contents. Conventional kiwis were larger in size and weight, and had a sweeter taste than organic kiwis. |
| Bohn et al. (2014)                 | Soybeans         | Sugars                              | Organic soybeans showed the healthiest nutritional profile with more sugars, such as glucose, fructose, sucrose and maltose, significantly more total protein and less fibre than both conventional and GM-soy. |
| Kouřimská, Kubaschová & Sus (2014) | Carrot           | Sugars                              | Organic grown carrot had higher contents of glucose, fructose and saccharose than carrots grown in the integrated farming system. |
| Brazinskienė et al. (2014)         | Potato           | Starch                              | Potatoes from organic and conventional systems had similar starch content.          |
| Bach, Kidmose, Kristensen & Edelenbos (2015) | Carrot           | Sugars                              | Sugar concentration was similar between organic and conventional carrots.            |
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| Reference                  | Samples                     | Compounds analysed | Major conclusions                                                                                                                                 |
|---------------------------|-----------------------------|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| Suja, Byju, Jyothi, Veena, & Sreekumar (2017) | Taro | Sugars | Organic taro had higher starch (10.78%), total (31.55%) and reducing sugars (9.37%) than conventional crops.                                                                                  |
| Golijan et al. (2017a)    | Soybean, maize, spelt, buckwheat | Sugars | Conventionally growing cultivars soybean and spelt had higher sugars content. Organically maize and buckwheat contained more soluble sugars than conventional cultivars. |
| Golubkina et al. (2018)   | Leek | Sugars | When cultivated with organic procedures, all cultivars attained higher dry matter and sugar.                                                                                                    |
| Pedro et al. (2019)       | Goji berry                   | Sugars | The content of total sugars, total and insoluble fibres of conventional goji were significantly higher than that of organic goji. The content of fructose was greater in organic goji, while, the content of glucose was greater in conventional goji. |
| Reche et al. (2019)       | Jujube fruit                 | Sugars | Organic jujubes were smaller, with higher contents of sugars than conventional jujubes.                                                                                                      |
| Zhang et al. (2019)       | Wheat | Sugars | In this study, the contents of sugars and their derivatives, including glucose, maltose, trehalose, threitol, xylitol, and sorbitol, were higher in organic wheat grains than in conventional grown wheat grains. |
| Bender et al. (2020)      | Carrot | Sugars | There were no convincing effects of cultivation system on the total sugar content of carrots.                                                                                                  |
| Golijan (2020a)           | Maize, spelt, soya bean      | Total soluble sugars, individual sugars, starch | No effect of the cultivation method was observed on the content of total soluble sugars in maize and spelt. A higher amount of total soluble sugars was in conventionally grown soya bean. Starch was higher in organically soya bean. Organically grown maize had higher non-reducing disaccharides, while conventionally maize contained more monosaccharides. |

The content of available carbohydrates (total sugars) ranged from 67.85% in organic goji to 75.05% in conventional goji. Fructose was the most important soluble sugar identified in organic and conventional fruits (5.45 and 4.92 g/100 g, respectively), followed by glucose and sucrose. According to Zörb et al. (2006), who observed different types of metabolites and sugars in organically and conventionally grown wheat, there were no significant effects of the production methods on the amount of sugar in wheat. An inverse correlation between the amount of starch and protein in wheat grain has been established in the study performed by Konvalina, Stehno, Capouchová and Moudry (2011) according to which the increase in the starch amount in grain was caused by conditions unfavourable for the protein accumulation in grain. Organic potato has higher contents of glucose and fructose, while the conventionally grown potato contains higher amounts of saccharose (Warman & Harvard, 1998).

Kouřimská et al. (2014) stated that carrots grown in the organic farming system had higher contents of glucose, fructose and saccharose than carrots grown in the integrated farming system. Similar results have been gained by Golijan (2020a), who observed the effects of organic and conventional farming on the contents of total soluble sugars, individual sugars and starch in seeds of maize, spelt wheat and soya bean. In seeds of maize and spelt wheat, no effect of the cultivation method was observed on the content of total soluble sugars; the differences were seasonal. A higher amount of total soluble sugars was established in conventionally grown soya bean. Starch was higher in organically grown soya bean. Organically grown maize had higher non-reducing disaccharides, while conventionally maize contained more monosaccharides. Moreover, Golijan et al. (2017a) established higher contents of soluble sugars in seeds of organically grown maize and buck-
wheat in comparison to those grown conventionally.

Summarising the results of 150 studies related to the effects of organic and conventional farming systems on the chemical compositions of food products, Woëse et al. (1997) concluded that there was no difference in the content of total sugars, starch and monosaccharides. There was no difference in the contents of total organic acids, as well as, malic and oxalic acids in red beet, carrot, spinach, leek and celery. Furthermore, the absence of evidence of a significant difference in the contents of sugar and organic acids between organically and conventionally grown strawberries, apples and pineapples is in line with the report of Alvarez, Carracedo, Iglesias and Martinez (1993). Since the contents of acids, sugars and dry matter in fruits vary among species grown in the same farming system that is affected by microclimate, maturity/ripeness and other factors, it is very difficult to determine differences caused by different methods of fruit production (Bordeleau et al., 2002).

One of the reasons for higher sugar contents in organic foods is the effect of nitrogen. Namely, the higher amount of nitrogen that reaches the plant through the higher rates of nitrogen fertilisers applied in the conventional crop production reduces the amount of dry matter, total sugars, methionine, numerous mineral elements and vitamin C (Bourn & Prescott, 2002).

**VITAMINS**

A large number of studies refer to the differences in the vitamin contents between organic and conventional food products. However, a clear consensus does not exist yet. It can only be stated with certainty that organic food products contain higher quantities of vitamin C. The contents of vitamin C, all groups of secondary metabolites not including carotenoids and some other compounds such as anthocyanins, tocopherols and volatile substances, were higher in plants organically grown in comparison to plants conventionally grown. Table 3 presents the comparative analysis of the contents of vitamins and pigments between organic and conventional systems.

According to the meta-analysis of results referring to the contents of secondary metabolites and vitamins, it is obvious that these contents are higher in organically grown fruits and vegetables, particularly the vitamin C content, which is higher by 6% (Brandt, Leifert, Sanderson & Seal, 2011). Moreover, Smith-Spangler et al. (2012), based on the meta-analysis of 17 studies in humans and 223 studies of nutrient and contaminant levels in foods, have stated that there was strong evidence that organic foods were significantly more nutritious than conventional foods. These authors have not established significant differences for vitamin C (31 studies), β-carotene (12 studies) and α-tocopherol (5 studies). A similar report was submitted by Baranski et al. (2014). These authors established statistically significant differences for a small number of carotenoids and vitamins. Moreover, they stated that there were higher concentrations of xanthophylls and L-ascorbic acid and lower concentrations of vitamin E (higher concentrations of total carotenoids, carotenoids and lutein) in organic food products.

Summarising the findings of other authors, Worthington (2001) reported that the content of vitamin C contained in organic foods was higher by 27% than in conventional ones. Similar statements were also made earlier by Worthington (1998). It has been proven that the amounts of vitamin C are somewhat higher in organically grown leafy vegetables and potatoes. The higher vitamin C content has been determined in organic potatoes (Kolbe, Meineke & Zhang, 1995), tomatoes (Pither & Hall, 1990; Caris-Veyrat et al., 2004), celery and kale (Leclerc et al., 1991). Contrary to findings suggesting that the vitamin C content is higher in organic food products, many researchers reported no differences in the vitamin C content between organically and conventionally grown vegetables (Lairon et al., 1986; Warman & Havard, 1996; Warman & Havard, 1998; Rembialkowska, 1998; Fjelkner-Modig et al., 2000).

On the other hand, Auclair, Zee, Karam and Rochat (1995) have stated that organically grown vegetables contained a lower amount of this vitamin. Some studies reported higher vitamin C levels in conventional products (Clarke & Merrow, 1979; Hansen, 1981). According to studies carried out by Weibel, Bickel, Leuthold and Alfeldi (2000), a significantly higher P content (31.9%), higher technical and vital quality (14.7% and 65.7%, respectively), were established in apples in orga-
nic farming. Furthermore, these apples contained more phenolic compounds (18.6%) and were of better taste (15.4%). On the other hand, contents of minerals K, Ca, Mg and Se, as well as vitamins C and E, did not significantly differ, neither did animals show feeding preference, nor did the fruits degrade faster. No difference in the contents of vitamins C, B1 and B2, minerals, carbohydrates, proteins and free amino acids, as well as, organic acids were found between organic and conventional fruits (apples, pineapples and strawberries) (Alvarez et al., 1993; Woëse et al., 1997). Regarding the contents of vitamins in cereals, differences in the vitamin B complex content between organic and conventional farming systems have not been established (Woëse et al., 1997). In contrast, higher vitamin C levels were observed by many authors (Leclerc et al., 1991; Warman & Havard, 1996; Woëse et al., 1997; Warman & Havard, 1998; Worthington, 1998; Xu, Wang, Mridha, Goyal & Umemura, 2000; Worthington, 2001).

The content of vitamin C in fruits and vegetables depends on many factors, such as a genotype, weather conditions before harvest, cropping practices, harvest method and treatments after harvest (Lee & Kader, 2000). The accumulation of vitamin C is related to the impact of stress factors on plants that induce oxidative stress in plant tissues, such as high temperatures and increased light, drought, and low nitrogen availability in the soil (Brandt & Mølgaard, 2001). The higher content of vitamin C in the organic crop may be caused by the crop insufficient maturity at harvest. Since the level of vitamin C is affected by numerous factors, one should be careful when interpreting results as well as drawing any conclusions. For instance, light is an important factor that affects the content of vitamin C in tomatoes. It has been shown that the fruits exposed to direct sunlight had higher vitamin C levels compared to those with shaded leaves (Clarke & Merrow, 1979). In addition, the effects of nitrogen on vitamin C content are known. The extensive use of nitrogen fertilisers increases the contents of nitrates and thus reduces the contents of vitamin C in vegetables and fruits (Mozafar, 1996; Bourn & Prescott, 2002). Numerous studies are indicate that fertilisation tends to decrease vitamin C levels (Lee & Kader, 2000) and to increase β-carotene levels (Mozafar, 1993). Mineral nutrition with nitrogen fertilisers is positively correlated with β-carotene levels (Brandt & Mølgaard, 2001). Nitrogen from conventional mineral fertilisers affects the contents of vitamin C and nitrates in plants. Namely, when the plant is supplied with high amounts of nitrate, it increases protein production, but, simultaneously, it decreases sugar production. As vitamin C is known to be synthesised from sugar, nitrates will reduce the synthesis of vitamin C. If the plant is supplied with more nitrogen than it can "withstand" through the increased protein synthesis, the remaining excess will be accumulated in the form of nitrates and be stored mainly in green leafy parts of the plant (Mozafar, 1993; Worthington, 2001). According to some studies, reduced amounts of nitrogen can result in an increased accumulation of phenolic compounds, but, on the other hand, higher amounts of nitrogen fertilisers improve the formation of chlorophylls and carotenoids (Schreiner, 2005).

There is a large body of data on the differences in the vitamin C content between organic and conventional food products. Data on the contents of other vitamins, such as β-carotene (precursor of vitamin A), B1 and B2 are contradictory; hence a general conclusion cannot be drawn. Higher levels of vitamin E were found in organic olive oil (Gutierrez, Arnaud & Albi, 1999). Regarding contents of vitamins A, B1 and B2, no significant differences were observed between organic and conventional vegetables (Clarke & Merrow, 1979; Bourn, 1994; Leceer, 1995; Warman & Havard, 1996; Woese et al., 1997; Warman & Havard, 1998; Kumpulainen, 2001; Bourn & Prescott, 2002), fruits (Magkos et al., 2003) and cereals (Woëse et al., 1997). For instance, according to the report by Kumpulainen (2001), no significant differences were established in the contents of β-carotene, vitamins B1 and B2 in organic carrots and potatoes whereas Leclerc et al. (1991) detected higher levels of β-carotene and vitamin B1 in organic carrots.

According to Golubkina et al. (2018), the ascorbic acid content was higher in all nine organic leek cultivars than in conventional ones. Ribes-Moya, Raigón, Moreno-Peris, Fita & Rodriguez-Burruezo (2018) carried out studies on 37 accessions of Spanish landrases and introduced material of hot peppers and other
species grown within organic and conventional systems, in order to evaluate ascorbic acid, total phenolics and total red and yellow/orange carotenoids, considering both ripening stages. A significant genotypic variation was established for the studied traits within each ripening stage and growing condition. According to these authors, differences in carotenoids were not attributed to growing conditions but principally to the genotype factor.

Crops treated with mixed fertilisers were found to have more β-carotene and minerals but lower levels of B vitamins than crops grown organically (Williams, 2002). Ismail and Fun (2003) have analysed the contents of β-carotene, vitamin C and riboflavin in vegetables (Brassica juncea, Brassica albovaglabra, Lactuca sativa, Amaranthus viridis, Ipomoea aquatica) and found that only Ipomoea aquatica grown organically had the highest contents of β-carotene, riboflavin and vitamin C among the entire samples studied. Organic tomato contains more β-carotene (Caris-Veyrat et al., 2004). β-carotene is contained within chloroplasts and acts as an antioxidant, performing specific roles during the process of energy transfer. During fruit development, light leads to an increase in the contents of carotenes and carotenoids (McCollum, 1956), and care must be taken when interpreting results. Moreover, the β-carotene content is reduced under conditions of reduced chloroplast proliferation, which usually occurs when the availability of nitrogen is limited. In plants such as carrots or pumpkins in which carotenoids perform the function of colourants in certain plant organs, their contents reach the maximum values under conditions that are optimal for the growth of these plants (Brandt & Mølgaard, 2001).

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### Table 3.

**Comparative analysis of vitamins and pigments levels in plants from organic and conventional systems**

| Reference                        | Samples                        | Compounds analysed       | Major conclusions                                                                 |
|----------------------------------|--------------------------------|--------------------------|-----------------------------------------------------------------------------------|
| Worthington (2001)               | Many organic and conventional crops | Vitamin C                | Vitamin C contained in organic foods was higher by 27% than in conventional ones. |
| Kumpulainen (2001)               | Carrots, potatoes              | β–carotene, vitamins B1, B2 | No significant differences were established in the contents of β-carotene, vitamins B1 and B2 in organic carrots and potatoes. |
| Carbonaro, Mattarella, Nicoli, Bergamo & Cappelloni (2002) | Peaches, pears               | Ascorbic acid, tocopherols | Ascorbic acid was higher in organic compared to conventional peaches. Higher tocopherol levels were found in organic pears than in those produced under conventional system. |
| Asami, Hong, Barrett& Mitchell (2003) | Marionberry, strawberry, corn | Ascorbic acid            | Levels of ascorbic acid in organically grown and sustainably grown samples were consistently higher than the levels for the conventionally grown crops. |
| Lombardi-Boccia, Lucarini, Lanzi, Aguzzi & Cappelloni (2004) | Yellow plums                  | Ascorbic acid, vitamin E, β-carotene | Ascorbic acid, alpha-, gamma-tocopherols, and beta-carotene were higher in organic plums grown on soil covered with natural meadow. |
| Chassy, Bui, Renaud, Van Horn & Mitchell (2006) | Tomatoes, bell peppers         | Ascorbic acid            | Ascorbic acid (16%) was higher in organic tomatoes. |
| Koh, Wimalasiri, Renaud & Mitchell (2007) | Marinara pasta sauces          | Vitamin C, β-carotene    | The content of total vitamin C was not statistically different between organic and conventional samples. Conventional pasta sauces demonstrated a significantly higher level of all-trans-β-carotene. |
| Reganold et al. (2010)           | Strawberries                   | Ascorbic acid            | Organic strawberries had higher ascorbic acid (9.7%) than conventional berries. |
| Brandt et al. (2011)             | Many organic and conventional crops | Vitamin C                | Vitamin C was higher in organic than conventional samples. |
| Reference                          | Samples                      | Compounds analysed | Major conclusions                                                                                                                                                                                                 |
|-----------------------------------|------------------------------|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Koh et al. (2012)                 | 27 varieties of spinach      | Vitamin C          | No significant difference was reported between the spinaches on vitamin C contents.                                                                                                                                |
| Lombardo et al. (2012)            | Potato                       | Ascorbic acid      | Ascorbic acid level in conventionally grown potatoes was 23% higher than that in organic potatoes.                                                                                                             |
| Skrabule et al. (2013)            | Potato                       | Vitamin C, vitamins B1, B2 | The vitamin B1 concentration of potato genotypes grown in the organic field exceeded that of potato genotypes grown in the conventional field.                                                                 |
| Hallmann, Lipowski, Marszalek & Rembialkowska (2013) | Tomato juice                 | Vitamin C, β-carotene | The organic tomato juice contained significantly more β-carotene compared to the non-organic tomato juice. Non-organic tomato juice was characterized by a significantly higher content of vitamin C (19.30 mg/100 g f.w.) in comparison with the organic juice (16.80 mg/100 g f.w.). |
| Oliveira et al. (2013)            | Tomato                       | Vitamin C          | Higher vitamin C were detected in organic compared to conventional tomatoes at harvest.                                                                                                                         |
| Tõnutare, Keert, Szajdak & Moor (2014) | Strawberry                   | Ascorbic acid, vitamin E | There is no evidence supporting that organically harvested strawberries have more bioactive compounds compared with conventional strawberries.                                                                   |
| Vinha, Barreira, Costa, Alves & Oliveira (2014) | Tomato                       | Ascorbic acid      | Tomato produced from organic systems was higher in ascorbic acid (+30%) than those from conventional systems.                                                                                                       |
| Baranski et al. (2014)            | Many organic and conventional crops | Vitamins (B, C, E) | Higher concentration of vitamin C was measured in organic crops, while conventional crops were higher in vitamin E.                                                                                               |
| Kazimierczak, Hallmann & Rembialkowska (2015) | Rosemary, peppermint, lemon balm, sage | Vitamin C          | Organic medicinal plants contained significantly higher vitamin C than the conventional plants.                                                                                                                  |
| Khalil & Hassan (2015)            | Strawberries and oranges     | Ascorbic acid, β-carotene | Organic strawberries had higher level of β-carotene as well as ascorbic acid compared with conventionally grown ones. Same for oranges.                                                                            |
| Freedman & Mira-Brishami (2015)   | Oranges                      | Vitamin C          | Vitamin C content was similar in juice from organically and conventionally grown oranges.                                                                                                                        |
| Assumpção et al. (2015)           | Grape seed oils              | Tocopherol         | No differences were found for grape seed oil between conventional and organic products.                                                                                                                          |
| Lee et al. (2016)                 | Perilla leaves (Perilla frutescens var. japonica Hara) | Vitamin C, vitamin E, β-carotene | Organically grown perilla leaves had vitamin E 49% greater than the conventional perilla leaves. Other components were not showed the differences.                                                                  |
| Kurubas, Maltas, Dogan, Kaplan & Erkan (2018) | Lettuce                      | Ascorbic acid      | The highest ascorbic acid content was obtained in lettuce from the organic production system.                                                                                                                     |
| Ribes-Moya et al. (2018)          | Peppers                      | Ascorbic acid      | Organic peppers had higher content of ascorbic acid than conventional ones.                                                                                                                                       |
| Golubkina et al. (2018)           | Leek (Allium porrum)         | Vitamin C          | Organic management resulted in higher vitamin C in leek pseudo-stems compared to conventional management.                                                                                                        |
| Marti et al. (2018)               | Tomato                       | L-ascorbic acid    | Organic farming increased L-ascorbic acid contents, though this increase again was cultivar and site depended.                                                                                                   |
| Bender et al. (2020)              | Carrot                       | Vitamin C          | Carrots managed organically had 10.0% higher vitamin C content than those managed conventionally.                                                                                                                  |
| Barcanu-Tudor, Vinatoru, Zamfir, Bratu & Draghici (2020) | Bell peppers                 | β-carotene         | Higher levels of β-carotene and lycopene registered in the organic bell peppers.                                                                                                                                  |
MACRO- AND MICRO-ELEMENTS

The results obtained in studies on differences in the contents of macro-and microelements between organically and conventionally grown vegetables, fruits and cereals differ very much. For instance, based on the meta-analysis, Heaton (2001) has summarised 400 papers dealing with comparisons of differences in chemical contents of food products produced organically and conventionally and has revealed that organic products had the higher contents of Ca, Mg, Fe and Cr. Other authors, also applying the meta-analysis, submitted similar reports. Thus, according to Rembialkowska (2007), the contents of Fe and Mg in organically produced food products were higher by 21% and 29%, respectively. Table 4 presents the comparative analysis of the contents of minerals between organic and conventional systems.

Worthington (1998) has summarised results presented in 34 publications in which organical and conventional food products were compared and have found that the contents of Ca, Mg, Fe and Zn were higher by 44.7%, 37.8%, 42.9% and 25%, respectively. In 2001, the same author summarised 41 papers, stating that organic food products contained the higher content of 21 elements (Fe - 21.1%, Mg - 29.3%, P - 13.6%, B, Ca, Cr, Cu, J, Mn, Mo, K, Se, Na, V, Zn). On the other hand, the contents of toxic heavy metals Pb, Cd, Hg and Al were lower. According to Worthington (2001), the majority of data related to the comparative mineral contents refer to lettuce, spinach, carrot, potato, and cabbage. As reported by the Agence Française de Sécurité Sanitaire des Aliments (AFSSA, 2003) the higher contents of Fe and Mg were detected in organically grown potatoes, carrots, red beets, lettuce, kale, leeks, beets, onions, celery and tomatoes. Organic carrots and potatoes were found to have higher contents of K and Na (Kumpulainen, 2001), and then of P and Ca, while differences in contents of Mg and K were not recorded (Leclerc et al., 1991). A similar report has been submitted by Warman and Harvard (1998), who observed the differences between organically and conventionally grown potatoes and sweet maize. On that occasion, they determined the higher contents of P, Mg and Na, and lower contents of Mn in tubers of organically grown potatoes whereas contents of Mg, B and Cu were higher and contents of B and Fe were lower in leaves of potatoes and sweet maize.

According to a report by Smith (1993), organic apples, pears, potatoes and wheat contained more mineral elements by 90% than conventional food products. Although there are numerous studies aimed at the determination of the existence of qualitative and quantitative differences in contents of nutrients between organically and conventionally grown cereals, the obtained results are still variable (Baranski et al., 2014). Worthington (2001) has stated that organically grown cereals contained significantly higher contents of Fe, Mn and P compared to conventional cereals. According to Ciolek, Makarska, Wesolowski and Cierpiła (2012) the production method has no effect on the contents of microelements in barley, while seeds of organic wheat contained significantly

| Reference                          | Samples                        | Compounds analysed | Major conclusions                                                                 |
|-----------------------------------|--------------------------------|--------------------|-----------------------------------------------------------------------------------|
| Kopczyńska et al. (2020)          | Courgette                      | Chlorophylls, carotenoids, vitamin C | Both chlorophylls content was significantly higher in organic fruits vs conventional. The production system significantly impacted the carotenoids (sum), β-carotene and lutein content in plants and had no effect on zeaxanthin. Higher concentrations of carotenoids were found in organic compared to the conventional courgette fruits, except for zeaxanthin which was not affected by the agronomic system. Content of L-ascorbic acid and the vitamin C (sum of L-ASC and DHA) in courgette fruits was not influenced by the cultivation system. Content of DHA was found to be higher in conventional fruits. |
| Hallmann & Sabala (2020)          | Ocimum basilicum L., Allium ursinum L., Origanum majorana L., O. vulgare | β-carotene          | Conventional herbs contained significantly higher concentrations of carotenoids, including beta-carotene. |
increased contents of Fe, Zn, Ca and Mg. In accordance with Ryan, Derrick and Dann (2004), higher amounts of Mn and P were found in conventionally grown wheat, while the amount of Zn and Cu were smaller. On the other hand, N, K, Mg, Ca, S and Fe showed small differences between organically and conventionally grown wheat. Contents of Ca, Cu and Zn recorded in organically grown barely were higher than in conventionally grown barley (Alföldi et al., 1996). Biel, Ga-węda, Jaroszewska and Hury (2018) reported increased Mn contents in organic soya bean, while contents of P, K, Ca, Mo, Cu and Ni were higher in conventional soya beans. The Mg content did not vary significantly.

Pedro et al. (2019) were among the first ones to perform a comparative analysis and characterize the differences between organic and conventional goji berries. Organic goji berries ensure the safety of factory-made food products, due to their lower content of heavy metals (Cd, Hg and Pb). Conventional berries contain Hg and Pb in more than the maximally acceptable tolerance limits by the Codex Alimentarius.

According to Wang et al. (2020), Mn, Zn, Cu and Mo were significantly higher in spelt wheat flour than in common wheat flour (31, 64, 35 and 24% respectively), organic than conventional flour (51, 45, 43 and 70% respectively) and whole-grain than white flour (216, 111, 49 and 43% respectively). Fe concentrations were also significantly higher in organic than conventional flour (16%) and whole-grain than white flour (63%). Furthermore, significant two-way interactions were established for Mn, Zn and Cu between farming systems and flour type, with concentrations significantly higher in organic than conventional whole grain, but not white flour. The Cu concentration was significantly higher in organic than conventional common wheat flour, but not spelt wheat flour.

Mäder et al. (2007) have performed a 21-year trial and found no effect of organic and conventional farming systems in wheat related to the contents of P, K, Zn, Mo and Co. The studies carried out on the contents of macro- and microelements in grains of organically and conventionally grown maize, spelt wheat, soya bean and buckwheat, showed that organically grown maize was characterised by a higher content of zinc (Golijan, Kostić, Dojčinović & Lekić, 2018a; Golijan, Kostić, Dojčinović& Lekić, 2018b; Golijan et al., 2019a). Moreover, a higher Se content was determined in grains of organically grown maize, spelt wheat and soya bean compared to the grains of conventionally grown corresponding crops (Golijan, 2020a).

Some researchers indicated that conventionally grown plants and plant-based products contain higher concentrations of heavy metals, whereas other researchers stated the opposite. There is no clear difference in the content of heavy metals between organic and conventional crops (Rembiàlkowska, 2007). Toxic heavy metals, such as Cd, Pb, As, Hg etc., may be found in crops, which have very harmful effects on human health. They accumulate in foods and crops through industry, transport, municipal waste and agriculture. Cadmium, a highly toxic element (as well as Pb and Hg), accumulates in the human body (especially in the liver and kidneys). Consequently, the intake of this element in the diet must be as small as possible. The European Commission has set maximum residue levels (MRL) in foods for Cd (European Commission, 2008). In conventional agricultural production, the soil and crops can be contaminated with Cd as a result of the application of phosphate fertilisers (Rembiàlkowska, Zalecka, Badowski & Ploeger, 2012). Golijan (2020a), studying the contents of macro-and microelements in organically and conventionally grown maize, spelt wheat and soya bean pointed out the presence of potentially toxic elements, particularly Cd and Sr, in grains of the crops. This study has shown that there was no regularity that would confirm which of the two methods of production - organic or conventional - would provide a better grain composition in terms of macro and microelements. Furthermore, similar results were presented in another two papers published by Golijan et al. (2017b; 2019b), in which the authors reported that some toxic elements, such as Al, Sr, Cd, As and Pb, could be found in grains of organically and conventionally produced maize, spelt wheat, soya bean and buckwheat.

Although a number of researchers found that organically grown vegetables contain elevated level of minerals, some believe that differences do not exist (Clarke & Merrow, 1979; Lairon
et al., 1984; Lairon et al., 1986; Termine et al., 1987; Perez-Llamas, Navarro, Marin, Madrid & Zamora, 1996; Warman & Havard, 1996; Tan, Wang & Lee, 1998; Fjelkner-Modig et al., 2000). This statement also refers to differences between organically and conventionally grown fruits (Alvarez et al., 1993; DeEll & Prange, 1993; Bourn, 1994; Woëse et al., 1997; Alvarez, Ortega, Fernandez & Borges, 2001; Bourn & Prescott, 2002), which is in agreement with the AFSSA report (2003).

There is a difference in soil fertility maintenance in organic and conventional agricultural production, which further affects the soil dynamics and plant metabolism, due to which plants have different nutritive compositions. Mineral fertilisers, mainly consisting from nitrogen, phosphorus and potassium, do not improve the soil structure and do not stimulate the activities of microorganisms. On the other hand, good organic production practice requires the use of organic fertilisers, preservation of the soil structure, the increase of the community of microorganisms, due to which nutritive substances are gradually released during the long period, and the soil is more fertile. The abundance of microorganisms in organic soils contributes to the formation of specific compounds (such as citrates and lactates), which combine with soil minerals making them easily available for absorption via plant roots. This is one of the facts that explains the existence of a trend of the higher contents of macro-and microelements in organic crops (Worthington, 2001). It is obvious that fertilisers with easily available phosphors are used in conventional farming, which increases the intake of phosphorus in all parts of the plant. On the other hand, it disrupts mycorrhiza, which results in the reduced Zn uptake, but also in the increased Mn uptake (Mäder et al., 2007). Potassium fertilisers reduce the content of Mg in plants (and then of P - indirectly, because the absorption of P depends on Mg, so the plant will have less P), due to which plants absorb less Mg from the soil. Potassium fertilisers are differently added to plants in organic and conventional production. Conventional potassium fertilisers are easily dissolved in the soil, due to which conventionally grown plants have a higher K content. The soil, used in organic farming, contains moderate amounts of K and Mg, due to which it is expected that plants contain higher amounts of Mg and P in comparison to plants conventionally grown (Worthington, 2001).

Table 4. Comparative analysis of mineral content in plants/food grown in organic and conventional systems

| Reference          | Samples                                      | Compounds analysed | Major conclusions                                                                 |
|--------------------|----------------------------------------------|--------------------|-----------------------------------------------------------------------------------|
| Worthington        | Many organic and conventional crops          | Ca, Mg, K, Na, Fe, Cu | Organically grown cereals contained significantly higher contents of Fe, Mn and P compared to conventional cereals. |
| Kumpulainen        | Carrots, potatoes                            | K, Na              | Organic carrots and potatoes were found to have higher contents of K and Na.        |
| Ryan et al. (2004) | Wheat                                        | N, P, K, Mg, Mn, Ca, S, Fe | N, K, Mg, Ca, S and Fe showed small differences between organically and conventionally grown wheat. Organic wheat displayed higher levels of copper and zinc and lower levels of P and Mn compared with conventional grown. |
| Lombardi-Boccia    | Plums                                        | P, K, Ca, Mg, Zn, Na, Fe, Cu | The organic plums showed higher P, K, Ca, Mg, Zn content and lower Na, Fe, Cu content compared with the conventionally plums. |
| Harcz et al. (2007)| Winter wheat                                 | Hg, Cd, Pb         | The concentrations of Cd and Hg showed no significant difference, but lead content were higher in organic cereals compared with conventional. |
| Liu et al. (2007)  | Conventional, organic and sustainable farms  | Ca, Mg, Na, Mn, Zn, Cu, P, K | Ca, Mg, Mn, P, Zn, and Cu were greater in soils under organic production.          |
| Mäder et al. (2007)| Wheat                                        | P, K, Ca, Mg, Mn, Zn, Cu, Mo, Co | No effect of organically and conventionally grown wheat on the contents of P, K, Zn, Mo and Co. |
| Dangour et al.     | Many organic and conventional crops          | Mg, Ca, P, K, Zn, Cu | Organically produced crops were higher in phosphorus than conventional samples.     |
| Reference | Samples | Compounds analysed | Major conclusions |
|-----------|---------|--------------------|------------------|
| Hoefkens et al. (2009) | Potatoes, carrot, tomato, and lettuce | Cd, Pb | No significant variation for the heavy elements Cd and Pb between conventional and organic potatoes. |
| Roussos & Gasparatos (2009) | Apple | K, Ca, Mg, Na, Mn, Fe, Cu, B, Zn | Organic apple showed higher K, Ca, Mg, Na, Mn content than the conventionally grown ones, while conventionally grown apple showed more Fe, Cu, B, Zn. |
| Reganold et al. (2010) | Strawberry | N, P, K, Ca, Mg, B, Zn, S, Mn, Cu, Fe | Leaf P and fruit P and K concentrations were significantly higher in conventionally grown strawberry plants than in organically grown plants; leaf Mg and fruit N were also notably higher in conventionally grown strawberry plants. All other strawberry and leaf nutrient concentrations were similar. |
| Laursen et al. (2011) | Wheat, barley, faba bean, potato | K, Mg, P, S, Ca, Fe, Mn, B, Zn, Cu, Mb, Sr, Na | No differences in mineral levels. |
| Vrček & Vinković Vrček (2012) | Wheat flour | Al, As, Cd, Cr, Pb, Fe, Mg, Mo, Ni, V | The significant differences among conventional vs. organic wheat flours were obtained for As, Cd, Cr, Fe, Mg, Mo, Ni and V. Toxic metals (Al, As, Cd and Pb) input was higher in conventional compared with organic wheat flours. |
| Ciolek et al. (2012) | Wheat, bulled and naked barley, oat | Ca, K, Mg, Cu, Mn, Fe, Zn | Organic wheat grain was characterized by a higher content of Mn, Fe, Zn, Ca and Mg compared to conventional grain. Lower content of Fe and Zn was determined in organic barley and oat. |
| Gąstoł & Domagała-Świątkiewicz (2013) | Fruit and vegetable fields producing organic and conventional crops | Cu, B, Fe, Mn, Zn, Ni, Pb, Cd, Ca, P, Mg, S, Na | Higher amounts of all elements in organic produced crop. |
| Ilić et al. (2014) | Tomato | Zn, Pb, Cu, Cr, Ni, Co, Cd | Significantly higher amounts of Pb, Zn, Cu, and Ni were found in conventional tomatoes. The contaminants levels were lower than the maximum limits. |
| de Souza Araújo et al. (2014) | Lettuce, peppers, tomatoes | Cd, Ni, Pb, Cr, Cu, Fe, K, Mg, Mn, Zn, Na | Pb and Cd contents displayed no significant difference between conventional and organic lettuces. Organic lettuces contained significantly higher amount of Ni compared to the conventional lettuces. Twice as much as nickel was detected in conventional peppers compared to organic ones. Organic lettuce had significantly higher levels of Cr, Cu, Fe, K and Mg, whereas conventional samples had higher levels of Mn and Zn. The organic peppers showed higher mineral levels (Cr, K, Mg, Na, and Zn) when compared to the conventional samples. Organic and conventional tomatoes exhibited high levels of Mn, Fe, Cu and Cr. |
| Vinković Vrček et al. (2014) | Wheat flour | K, Mg, Ca, Fe, Mn, Zn, Al, Mo, Ni, Cr, Cd, Pb, Se, V, Co, Cu, Sr, As | Organic wheat flour had more K, Mg, Zn, Ni, Mo than conventional. |
| Bohn et al. (2014) | Soybeans | Ba, Cu, Fe, Mn, Mo, Se, Zn | The content of Zn was significantly higher in organic samples compared to the conventional and organic samples. Other differences were relatively small. |
| Zhang, Jiao, Li & Lei (2014) | Black sesame | K, Mg, Ca, Na, P, Cu, Fe, Cr, Si, Sr, Al, Ba, Ti | Organic black sesame had 58%–132% richer content of K, Mg, Ca, Na, P, and 21%–554% richer contents of Cu, Fe, Cr, Zn, Si, Sr as well as richer Al (40%), Ba, (485), Ti (566%) than the conventional. |
| Reference                      | Samples                          | Compounds analysed                  | Major conclusions                                                                                                                                                                                                 |
|--------------------------------|----------------------------------|-------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Uckoo, Jayaprakasha & Patil (2015) | Lemons                           | P, K, Ca, Mg, Na, Zn, Fe            | Organic lemons showed the highest P content, whereas the conventionally grown showed the lowest. Conventional lemons showed higher K, Ca, Mg, Na, Zn, Fe levels compared with the organic. |
| Suja et al. (2017)              | Taro (Colocasia esculenta)       | pH, P, K, Ca, Mg, Fe, Mn, Zn, Cu, organic C, ash | Cormel quality was better under organic management, with higher P, K, Ca and Mg contents. Organic plots showed significantly higher pH (+1.2 unit) and available P and higher soil organic C (+39%), exchangeable Ca, Mg, Fe, Mn, Zn and Cu status. Conventionally produced taro had higher ash content than taro from organic systems (20.07%). |
| Dos Santos et al. (2017)        | Sweet potato, carrot, okra, cabbage, eggplant brinjal | Ca, Cu, Fe, K, Mg, Mn, P, Na         | Samples of organic cultivars showed higher concentrations of minerals, such as Ca, Cu, Fe, K, Mg, Mn and P.                                                                                                           |
| Kapoulas et al. (2017)          | Lettuce, onion                    | N, P, K, Ca, Mg, B, Mn, Zn, Fe, Cu   | Organically grown green onions had higher contents of all macro and microelements (except Cu) compared to the conventionally grown onions. Lettuce from convential systems contained more Ca, Mg, Mn, Fe, Cu than that from organic production. |
| Yu, Guo, Jiang, Song & Muminov (2018) | Corn grain                       | P, K, Mg, Fe, Zn, S, Mn             | The organic corn grains were rich in K (30%), P (30%), Mg (20%) and Fe and Zn, although the differences were not significant. Conventional corn grain exhibited higher S (15%) and Mn (17%) content. |
| Biel et al. (2018)              | Soybean                          | P, K, Mg, Ca, Mo, Mn, Cu, Ni        | The contents of P, K, Ca, Cu and Ni were found to be significantly higher in conventional soybean seeds.                                                                                                           |
| Golubkina et al. (2018)         | Leek (Allium porrum)             | Al, As, B, Ca, Cd, Co, Cr, Cu, Fe, Hg, I, K, Li, Mg, Mn, Na, Ni, P, Pb, Si, Sn, Sr, V, Zn | Among the mineral elements, only K was significantly affected by the management system, showing a higher content in organically grown pseudo-stems.                                                        |
| Golijan et al. (2017b)          | Maize, wheat, spelt, soybean, buckwheat | Ca, Mg, P                            | The content of Ca, Mg and P differs between maize, spelt, soybean and buckwheat in different years of production and in both production systems, as well.                                                               |
| Golijan et al. (2018a)          | Maize, spelt, buckwheat, soybean | Fe, Zn                               | The highest Zn concentration was detected in organic (19.92 μg/g) and conventionally (25.05 μg/g) produced soybean seed from 2016. The highest Fe content was found in the seed of organic (122.55 μg/g) and conventionally (94.33 μg/g) grown buckwheat seed from 2016. |
| Golijan et al. (2018b)          | Spelt seed                       | Fe, Zn                               | Quantity of Fe and Zn was higher in conventionally grown spelt seed compared to organically grown seed.                                                                                                                                 |
| Dutra, Rodrigues, de Oliveira, Pereira & Lima (2018) | Grape juices and wines           | Cu, Fe, Mn                            | No significant differences were observed on Cu, Fe and Mn minerals.                                                                                                                                                 |
| Pedro et al. (2019)             | Goji berry                       | K, Na, P, Ca, Mg, Fe, Zn, Cu, Mn, Cd, Hg, Pb | Organic fruits exhibited significantly higher levels of K, Na, Ca, Fe, Zn and Cu elements than conventional goji. Organic goji berry showed concentrations of the toxic elements Cd, Hg and Pb within the limits established by the Codex Alimentarius, while conventional fruits had levels of Hg and Pb above the established maximum levels. |
Produced food products are organic acids and antioxidantolic acids, as additional polyphenols in cereals are commonly found in the bound form (Benbrook et al., 2015). Polyphenols in plants may range from several grammes per kilogrammes, whereby the concentration is higher in the skin/peel and the coat than in the fruit (Benbrook, 2005). Polyphenols exhibit antioxidant activity, antiviral, antibacterial, hypoglycaemic, anticancer, antiarthritic as well as anti-inflammatory activities, and are used in the treatment and prevention of chronic diseases (Owen et al., 2000).

There are many studies related to the comparison of contents of polyphenols and other antioxidants between organically and conventionally grown plants and plant-based products. The comparative analysis of secondary metabolites, organic acids and antioxidant activity between organic and conventional systems is presented in Table 5.

A larger number of data are available for vegetables and fruits, and a slightly smaller number for cereals. Numerous studies state that organically produced food products are richer in the content of organic acids and polyphenolic compounds with antioxidant properties. However, Dangour et al. (2009) reported that organic and conventional production systems did not significantly affect nutritive differences and the content of polyphenols in food products.

The results of testing the content of polyphenols and the antioxidant activity in organic and conventional leek point out that the cultivation method did not significantly affect the polyphenol concentration (Golubkina et al., 2018). Similar results were reported by Brazinskiene et al. (2014) for potato, Valverde et al. (2015) for broccoli, Lee et al. (2016) for buckwheat, and Kapoulas et al. (2017) for lettuce and onion, Dutra et al. (2018) for grape juices and wines.

According to Benbrook, Zhao, Yañez, Davies and Andrews (2008), organically produced food products in comparison with conventional ones have an antioxidant capacity higher by 88%, as well as amounts of total polyphenols, quercetin and kaempferol higher by 72%, 87% and 55%, respectively. As reported by Rombiakowska (2007), organically produced foods have twice the amount of polyphenols compared to conventional ones. According to Benbrook (2005), organic products have an an-
tioxidant capacity higher by approximately 30% than conventional ones.

Baranski et al. (2014) performed the meta-analysis of 342 publications related to differences between conventionally and organically grown crops regarding the contents of numerous secondary metabolites, as well as macro- and micronutrients and have reported that organically grown plants contained significantly higher amounts of antioxidants, primarily polyphenols, such as flavanones flavones, flavonols, stilbenes and anthocyanins. It should be emphasised that the observed differences were more credible because the data were gained on the same crops cultivated in numerous trials performed in many growing seasons on the same areas under various climatic and weather conditions. According to Levite, Adrian and Tamm (2000), organic wine contains a higher amount of resveratrol.

Table 5. Comparative analysis of secondary metabolites, organic acids and antioxidant activity in plants/food from organic and conventional systems

| Reference                      | Samples                                      | Compounds analysed                                                                 | Major conclusions                                                                                                                                 |
|--------------------------------|----------------------------------------------|-----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| Mikkonen et al. (2001)         | Black currant                                | Flavonols (quercetin, myricetin and kaempferol)                                   | No consistent differences in the contents of flavonols were found between the same black currant cultivars grown in organic and conventional systems.       |
| Carbonaro et al. (2002)        | Peach, pear                                  | Polyphenols, ascorbic and citric acids                                            | A parallel increase in polyphenol content and polyphenoloxidase activity of organic peach and pear as compared with the corresponding conventional samples was found. Ascorbic and citric acids were higher in organic than conventional peaches. |
| Asami et al. (2003)            | Marionberry, strawberry, corn                | Total phenolics                                                                   | Higher amounts of total phenolic compounds were found in organic foods compared to the conventional food.                                                                                                  |
| Lombardi-Boccia et al. (2004) | Yellow plums                                 | Total polyphenols, phenolic acids, flavonols                                       | Total polyphenols content was higher in conventional plums. Quercetin was higher in conventional plums, but myrecitin and kaempferol were higher in organic plums. |
| Dimberg, Gissén & Nilsson (2005) | Oats                                         | Avenanthramide, hydroxycinnamic acid, ruxinic acid                                | No difference resulting was observed for cropping system.                                                                                                                                               |
| Young et al. (2005)            | Leaf lettuce, collards, pac-choi             | Phenolic acids (caffeic acid, gallic acid) and aglycone or glycoside flavonoids (apigenin, kaempferol, luteolin, quercetin)                         | No significant difference was shown for polyphenolic concentrations between conventional and organic lettuce and collard samples. Organic pac choi had significantly higher phenolic content compared to conventional pac choi. |
| Chassy et al. (2006)           | Tomatoes, bell peppers                       | Total phenolics, flavonoid aglycones quercetins, kaempferols, luteolins            | Organic tomatoes had higher levels of polyphenols and flavonoids compared with conventional tomatoes.                                                                                                    |
| Olsson, Andersson, Oredsson, Berglund & Gustavsson (2006) | Strawberry, strawberry extracts             | Flavonols, ellagic acid, anthocyanins                                              | The antioxidant levels in the organic strawberries were higher compared to the conventional ones. The ratio of ascorbate to dehydroascorbate was significantly higher in the organically cultivated strawberries. Organic strawberries extract showed higher antiproliferative activity compared with conventional strawberries. |
| Mitchell et al. (2007)         | Tomatoes                                     | Quercetin, kaempferol                                                            | Ten-year mean levels of quercetin and kaempferol in organic tomatoes were 79 and 97% higher than those in conventional tomatoes, respectively.                                              |
| Koh et al. (2007)              | Marinara pasta sauces                        | Flavonoids                                                                       | The flavonoid content was not statistically different between organic and conventional samples. The content of lycopene was not statistically different between organic and conventional samples. |
| Reference                  | Samples                          | Compounds analysed                              | Major conclusions                                                                                     |
|----------------------------|----------------------------------|--------------------------------------------------|--------------------------------------------------------------------------------------------------------|
| Wang et al. (2008)         | Blueberries                      | Antioxidant activity (ORAC), total phenolics, total anthocyanins | Fruit grown under organic cultivation yielded significantly higher malic acid, total phenolics, total anthocyanins, and antioxidant activity (ORAC) than fruit from the conventional culture. The organic culture also yielded fruits with higher contents of myricetin 3-arabinoside, quercetin 3-glucoside, delphinidin 3-galactoside, delphinidin 3-glucoside, delphinidin 3-arabinoside, petunidin 3-galactoside, petunidin 3-glucoside, and malvidin 3-arabinoside than conventional culture. |
| Lamperi et al. (2008)      | Apples                           | Total polyphenols contents, polyphenols composition, antioxidant property | Production method did not significantly contribute to the polyphenol content. Apple peels of both cultivars of organic fruits showed higher radical scavenging properties than corresponding ones from integrated production. |
| Dangour et al. (2009)      | Many organic and conventional crops | Titratable acidity | Organically produced crops were higher in titratable acidity than conventional samples. |
| Riahi et al. (2009)        | Tomato                           | pH, titratable acidity, lycopene, total phenolic | The production system affected fruit soluble solids, pH, titratable acidity and firmness only in some cultivars. Tomato lycopene and total phenolic contents were similar between organic and conventional production systems. |
| Soltoft et al. (2010)      | Onion, carrot, potato             | Flavonoids, phenolic acids                       | In onions and carrots, no statistically significant differences between growth systems were found for any of the analysed polyphenols. A significantly higher content of phenolic 3-caffeoylquinic acid was found in the organic potatoes as compared to the conventional growth system, |
| Reganold et al. (2010)     | Strawberries                     | Antioxidant activity, total phenolics            | Organic strawberries had higher antioxidant activity (8.5%) and phenolics (10.5%) than conventional berries. Specific polyphenols, such as quercetin and ellagic acid, showed mixed or no differences. |
| Brandt et al. (2011)       | Many organic and conventional crops | Secondary metabolites, carotene | Organic samples had 12% more secondary metabolites than conventional samples. All groups of secondary metabolites, except carotene and non-defence compounds, were higher in organic than conventional samples. |
| Gastol et al. (2011)       | Apple, pear, blackcurrant, carrot, beetroot and celery | Organic acids, polyphenols, antioxidant activity | Higher organic acids content was shown in apples, pears, and especially blackcurrants grown organically. Organic juices had slightly higher antioxidant activity and similar levels of polyphenols and ascorbic acid as conventional juices. |
| Koh et al. (2012)          | 27 varieties of spinach          | Flavonoids, oxalate                             | The mean levels of flavonoids were significantly higher in the organically grown spinach compared to the conventionally grown spinach. No significant effects were observed in the oxalate content of spinach from either production system. |
| Lombardo et al. (2012)     | Potato                           | Total phenolics                                  | The mean total phenolic content of organic grown tubers exceeded that of the conventional grown ones by 18%, although this advantage was cultivar dependent. |
| Oliveira et al. (2013)     | Tomato                           | Antioxidants, enzymes, phenolic compounds        | Higher activity of phenylalanine ammonia lyase, total phenolics, citric acid, yellow flavonoids, were detected in organic compared to conventional tomatoes at harvest. Cell membrane lipid peroxidation degree was 60% higher in organic tomatoes. SOD activity was also dramatically higher in the fruits from organic farming. |
| Hallmann et al. (2013)     | Tomato juice                     | Polyphenols, lycopene                           | More total phenolic acid, chlorogenic acid, rutin, p-coumaric acid, gallic acid, quercetin 3-O-gluicoside, total flavonoids, and quercetin was found in organic tomato juice compared with conventional. The organic tomato juice contained less lycopene compared to the non-organic tomato juice. |
| Reference                          | Samples          | Compounds analysed                          | Major conclusions                                                                                                                                 |
|-----------------------------------|------------------|---------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|
| Nunes-Damaceno et al. (2013)      | Kiwis            | Organic acids (oxalic, quinic, malic, citric acids), pH | Significant differences existed only for citric acid among kiwis of different origins. Organically grown kiwis had higher citric acid levels than the others, pH was the lowest in conventionally grown fruit, although the between-origin differences in pH and titratable acidity were minimal but significant. |
| Kazimierczak et al. (2014)        | Beetroots        | Total phenolic acids, flavonoids             | The content of total phenolic acids was significantly higher in conventional beetroots compared with the organic ones, while the level of flavonoids was similar. |
| Baranski et al. (2014)            | Many organic and conventional crops | Many secondary metabolites, pigments        | Higher concentrations of total flavonoids, total phenolic acids, flavanones, stilbenes, flavones, flavonols, kaempferol, xanthophylland total anthocyanins were found in organic compared to conventional crops. |
| Brazinskie et al. (2014)          | Potato           | Phenolic acids                               | Potatoes from organic and conventional systems had similar phenolic acid content.                                                                     |
| Vinha et al. (2014)               | Tomato           | Total phenolics and flavonoids, antioxidant activity | Tomato produced from organic systems were higher in antioxidant activity, total phenolics and flavonoids, than those from conventional systems. Tomato produced from organic systems was higher in lycopene (+20%) than those from conventional systems. |
| Anton et al. (2014)               | Tomato           | Polyphenols                                  | Higher contents of apigenin acetylhexoside, caffeic acid hexoside I, and phloretin dihexoside were found in all organic samples. The content of polyphenols was more dependent on year and cultivar than on cultivation conditions. |
| Kazimierczak et al. (2015)        | Rosemary, peppermint, lemon balm, sage | Phenolic acids, total flavonoids, carotenoids | Organic medicinal plants contained significantly more phenolic acids and total flavonoids than the plants from conventional production. Conventional medicinal plants had significantly higher amounts of carotenoids compared to the organic counterparts. |
| Granato, Margraf, Brotzakis, Capuano & Van Ruth (2015) | Purple grape juices | Total phenolics                             | No differences in polyphenols content.                                                                                                              |
| Khalil & Hassan (2015)            | Strawberries and oranges | Total phenol content                        | Total phenol content was significantly higher in organic strawberries compared to conventional ones.                                                   |
| Valverde et al. (2015)            | Broccoli         | Total phenolics and flavonoids, glucosinolates | Levels of total phenolics and total flavonoids showed a significant year-on-year variation. They were not significantly different between organic and conventional production systems. Levels of the indolyl glucosinolates glucobrassicin and neoglucobrassicin were higher under organic compared to conventional management. |
| Cuevas et al. (2015)              | Plum cultivars   | Organic acids, total polyphenols, total anthocyanins, total carotenoids, antioxidant capacity | The organic plums had significantly higher polyphenol and anthocyanin concentrations and a greater antioxidant capacity. Organic plums had greater concentrations of malic, succinic, tartaric, and shikimic acids than those from conventional orchards. The culture system affected all the studied parameters except for total carotenoid content. |
| Lee et al. (2015)                 | Onion            | Total phenolics, total flavonoids, pyruvic acid | Total phenolic compounds were significantly higher in conventional than organic onions. There were no significant differences in pyruvic acid and flavonoids content between conventional onions and organic onions. |
| Assumpção et al. (2015)           | Grape seed oils  | Carotenoids                                  | No differences were found for grape seed oil between conventional and organic products.                                                               |
### Reference | Samples | Compounds analysed | Major conclusions
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De Pascale, Maggio, Orsini & Barbieri (2016) | Tomato | Lipophilic antioxidant capacity, titratable acidity, carotenoids | Lipophilic antioxidant capacity was increased under organic soil fertility management (25%) then conventional. Titratable acidity was 20% higher in conventional than organic tomatoes. Carotenoid levels were increased under organic soil fertility management (14%) then conventional.
Lee et al. (2016) | Perilla leaves (Perilla frutescens var. japonica Hara) | Total phenol, total flavonoid, GABA, caffeic acid, rosmarinic acid | Differences between the organic and conventional production in analysed components were not showed.
Suja et al. (2017) | Taro (Colocasia esculenta) | Total phenols, dietary fibres | Conventionally produced taro had higher total phenols (6.04%) and fibres (19.78%) than organic taro.
Kapoulas et al. (2017) | Lettuce, onion | Total phenols content, total antioxidant capacity | No significant difference in total phenols content (TPC) was observed between production systems and growing season in lettuce. TPC in green onion was higher compared to lettuce. Similar trend was observed for total antioxidant capacity.
Ren et al. (2017) | Onion | Total flavonoids, total anthocyanins, individual flavonols, individual anthocyanins, antioxidant activity | Antioxidant activity (DPPH and FRAP), total flavonol content, and levels of quercetin 3,4′-diglucoside and quercetin 3-glucoside were higher in onion varieties under organic compared to conventional management.
Hallmann et al. (2017) | White cabbage (Brassica Oleracea L. var. Capitata) | Polyphenols, flavonoids, chlorophylls, carotenoids | Organic fresh cabbage, compared to the conventional one, contained significantly less total flavonoids and several flavonoid compounds. The organic sauerkraut, compared to the conventional one, contained significantly more total polyphenols as well as several flavonoids. Organic fresh cabbage, compared to the conventional one, contained significantly less total chlorophylls and carotenoids.
Golubkina et al. (2018) | Leek (Allium porrum) | Polyphenols, antioxidant activity | Management system did not affect polyphenol levels.
Kurubas et al. (2018) | Lettuce | Antioxidant activity, titratable acidity, total phenolic contents | The highest antioxidant activity was obtained from the organic production system. The conventional production system had higher total soluble solids, titratable acidity, and total phenolic contents.
Dutra et al. (2018) | Grape juices and wines | Phenolic profile, antioxidant activity | Conventional products presented higher anthocyanins content, and no significant differences were observed on other phenolic compounds and antioxidant activity.
Rubes-Moya et al. (2018) | Peppers | Total phenolics, total red and yellow/orange carotenoids | Organic peppers had more total phenolics than conventional. Organic peppers had higher content of total red and yellow/orange carotenoids than conventional.
Martí et al. (2018) | Tomato | Polyphenols | Organic farming significantly increased the levels of caffeic acid by 20%, but reduced those of ferulic acid and naringenin by 13% and 15% respectively.
Reche et al. (2019) | Jujube fruit | Organic acids, flavonoids, phenols, antioxidant activity, chlorophylls, carotenoids | Organic jujubes had higher contents of chlorophylls, carotenoids, organic acids, and total volatile compounds, but lower flavonoids than conventional jujubes. Organic and conventional jujubes had similar contents of total phenols and antioxidant activity.
Picchi et al. (2019) | Plums | Polyphenols | Organic management resulted in a lower content of neo-chlorogenic acid compared to the conventional management.
Carrillo, Wilches-Pérez, Halman, Kazmierczak & Rembiałkowska (2019) | Beetroot | Phenolic compounds, total antioxidant capacity, betalains | Organic and conventional growing systems had similar average levels of the flavonoids kaempferol-3-O-glucoside and luteolin in the final products. The organic beetroot showed significantly higher contents of total betalains, total polyphenols and higher total antioxidant capacities, when compared to the conventionally grown samples.
Reference | Samples | Compounds analysed | Major conclusions
--- | --- | --- | ---
Ponder & Hallmann (2019) | Raspberry cultivars | Polyphenols, anthocyanins | The organic samples contained significantly more dry matter, total anthocyanins and cyanidin-3,5-di-O-glucoside, phenolic acid and flavonoids, including myrcetin, queretin, luteolin and queretin-3-O-rutinoside.
Pedro et al. (2019) | Goji berry | Organic acids | Citric acid was greater in conventional goji than organic.
Barcanu-Tudor et al. (2020) | Bell peppers | Lycopene | Higher level of lycopene registered in the organic bell peppers.
Guilherme, Aires, Rodrigues, Peres & Pereira (2020) | Sweet peppers (green and red) | Phenolic composition, antioxidant activity | Meta-coumaric acid, ortho-coumaric acid and quercetin-3-O-rhamnoside were more abundant in green conventional peppers and chlorogenic acid, caffeic acid and rutin were found in higher levels in red organic peppers. Green conventional peppers showed the highest DPPH, ABTS•+ and total reducing capacities, while red conventional peppers had higher TEAC values.
Kopećyńska et al. (2020) | Cougette | Polyphenols | Organic cougette fruits were characterised by their significantly higher content of phenolic acids and flavonoids when compared to the conventionally grown.
Hallmann & Sabala (2020) | Ocimum basilicum L., Allium ursinum L., Origanum majorana L., Origanum vulgare | Total polyphenols, flavonoids, phenolic acids, chlorophylls | Organic herbs contained significantly higher concentrations of total polyphenols, flavonoids, and phenolic acids compared to conventional herbs. Conventional herbs contained significantly higher concentrations of chlorophylls.
Anjos et al. (2020) | Raspberry | Phenolic profile | Under organic agricultural practices, the polyphenols levels increased for the ‘Kweli’ cultivar but decreased for the ‘Tulameen’ cultivar. ‘Tulameen’ cultivar grown under conventional agricultural practices contained higher anthocyanins levels than grown under organic agricultural practices, while for the ‘Kweli’ cultivar no significant differences were observed between the two agricultural practices.
Santarelli et al. (2020) | Apples | Polyphenols, antioxidant activity | Organic and conventional apples showed a different profile in free and conjugated polyphenols. Total phenolic content and antioxidant activity were similar in organic and conventional apples.
Wang et al. (2020) | Triticum aestivum vs T. aestivum flour; (wholegrain vs white flour) | Total phenolics and total flavonoid content, total antioxidant activity | Phenolic/antioxidant concentrations and activity were found to be between 10 and 33% higher in organic vs conventional flour and between 2 and 4.3 times higher in wholegrain flour compared with white flour.

It is a polyphenol that is naturally found in the skin of red grapes, berries, plums, peanuts and other plants. As a natural antioxidant, it acts in the body by reducing the aggregation of red blood cells and affects the patency and elasticity of blood vessels, which is of great importance for the healthy functioning of the cardiovascular system.

Winter and Davis (2006) summarised studies comparing organic and conventional foods with respect to nutrient levels, stating that organic production led to the increase of nutrients in plants, especially of organic acids and polyphenolic compounds. Numerous authors reported that organically grown fruits had higher contents of secondary metabolites: polyphenols (Lucarini et al., 1999) and flavonoids (Heaton, 2001) in apples, polyphenol oxidase enzyme activity, total phenolics, organic acids in peaches and pears (Carbonaro et al., 2002), phenolics and ascorbic acid in marionberries and strawberries (Asami et al., 2003), phenolics in organic apple pulp (Vebere et al., 2005), polyphenols, anthocyanins and total antioxidant activity in oranges (Ta-
rozzi et al., 2006). In contrast to these authors, Hakkinen and Torronen (2000) claimed that the organic cultivation did not affect the level of phenolic acids and flavonols in strawberries. Similarly, organic production did not significantly affect the level of flavonols in black currants (Mikkonen et al., 2001).

As for vegetables, summarising 400 papers comparing the composition of organically and conventionally produced foods, Heaton (2001) stated that organic potatoes contained higher contents of polyphenols, which is in accordance with the report submitted by Hamouz, Lachman, Vokal and Pivec (1999), while organic tomatoes contained higher contents of lycopene, which is consistent with findings of Caris-Veyrat et al. (2004) that organic tomatoes had more polyphenols, carotenoids and vitamin C. The higher content of polyphenols in organic peppers was found by Pérez-López, López-Nicolas, Núñez-Delicado, Del Amor and Carbonell-Barrachina (2007). In a ten-year study about organically and conventionally grown tomatoes for a period from 1994 to 2004, Mitchell et al. (2007) estimated statistically higher levels of quercetin and kaempferol aglycones in organic tomatoes. The mean value of quercetin in organic tomatoes amounted to 115.5 mg/g d.m., which was higher by 79% than values in conventional vegetables (64.6 mg/g d.m.).

The corresponding value of kaempferol amounted to 63.3 mg/g d.m. which was higher by 97%. Furthermore, levels of flavonoids improved over time in samples organically grown. This improvement was consistent with the increasing amounts of organic matter in the soil that had been accumulated in organic plots, but also with the decreased application of manure once the soil used for organic farming reached equilibrium levels of organic matter. No significant difference in polyphenol contents was found between organically and conventionally grown lettuce and collard (Young et al., 2005).

Results gained by Ren, Endo and Hayashi (2001), indicated that organically grown vegetables contained by 30-100% more flavonoids than conventionally grown vegetables. Moreover, the antioxidant capacity of organic spinach was 2.2 fold-higher than that of conventional spinach, and in some types of onions and Chinese cabbage it was higher by 20% to 50%. According to Baxter, Graham, Lawrence, Wiles and Paterson (2001), soups made from organically grown vegetables had a higher content of salicylic acid. Gutierrez et al. (1999) found a higher content of polyphenols in organic olive oil.

According to Golijan and Kostić (2016), cereals contained an abundance of polyphenols and other antioxidants, and due to their unique phytochemical composition, the health benefits of consuming cereals and cereal-based products have been confirmed by numerous medical studies. Maize contains a number of bioactive components with antioxidant and anticancer activities, such as polyphenols of white-seeded maize: ferulic and ρ-coumaric acids with their derivatives (Panady, Singh, Maurya, Singh & Singh, 2013). It is known that the antioxidant activity is the strongest in maize and then in wheat and oats (Del Pozo-Insfran, Brenes, Saldivar and Talcott, 2006), whereas buckwheat is considered the best source of polyphenols (Golijan, Živanović & Kostić, 2017c). Red-, purple- and blue-seeded maize varieties inhibit colorectal carcinogenesis, exhibit antimutagenic activity as well as ability to remove free radicals, which is further associated not only with the contents of polyphenols but also their associated activity with anthocyanins (Lopez-Martinez et al., 2009). According to Koh et al. (2012) organic cropping practices applied in spinach production resulted in decreased levels of nitrates and increased levels of flavonoids and ascorbic acid.

Langenkämper et al. (2006) did not find significant differences in the content of total polyphenols in either organically or conventionally cultivated wheat. However, these authors reported that levels of polyphenols in grains of non-fertilised plants were elevated, suggesting that the increased levels of these compounds could occur under stressful nutrient deficiencies to which the plants had been exposed. A previously performed study on soya bean (Balisteiro, Rombaldi and Genoves, 2013) showed that the distribution of iso-flavonoids differed between organically and conventionally grown plants, whereby there was no unique effect not even within the same class of polyphenolic compounds. According to results obtained by Golijan (2020b), there was no significant difference in the content of total free polyphenols between maize grains grown organically and conventionally, while a higher
content of free flavonoids was recorded in organic grains. In a similar study conducted with grains of organically and conventionally grown soya bean, Golijan et al. (2018c) found higher content of free polyphenols and flavonoids in conventional grains.

According to Winter and Davis (2006), there are two main hypotheses that explain the increased content of polyphenols and organic acids in organic comestibles in comparison to conventional ones. One hypothesis refers to the effects of various methods of fertilisation on plant metabolism. In conventional farming, synthetic fertilisers are mainly used, providing more accessible nitrogen source to the plants as compared to organic fertilisers. High amounts of nitrogen, easily available through synthetic fertilisers, accelerate the growth and the development of plants, i.e. nitrogen is used for the needs of the plant growth, and as a result, the production of secondary metabolites (organic and amino acids, chlorophyll, polyphenols) is reduced in plants. The second hypothesis refers to the responses of plants to stress conditions of the environment, such as attacks of insects, pathogenic microorganisms, and the presence of weeds. Under conditions of such stress factors, the plant accumulates very important defence secondary metabolites - phytoalexins. Since the use of synthetic pesticides is forbidden in organic farming, with the limited use of permitted chemical substances, plants, in order to increase the level of their protection, consume larger amounts of resources for the synthesis of their own chemical defence mechanisms. The increased production of antioxidants, such as polyphenols, is one of the types of chemical defence mechanisms in plants.

Rembiąlkowska (2007) cites hypotheses that explain differences in the metabolite content in plants. The first, carbon-nitrogen balance hypothesis asserts that when nitrogen is easily available to the plant, the plant will first synthesise nitrogen-containing compounds, such as proteins needed for the plant growth and secondary metabolites that contain nitrogen, such as alkaloids, glucosinolates and non-protein amino acids. Under conditions of reduced availability of nitrogen, the metabolism is redirected to the synthesis of carbon-based compounds, such as starch, cellulose and secondary metabolites without nitrogen, such as polyphenols and terpenoids. According to the second, somewhat newer hypothesis (growth-differentiation balance hypothesis - GDBH), the plant permanently monitors the accessibility of available resources and accordingly directs building blocks towards the synthesis of molecules needed for the growth or differentiation, whereby the differentiation is considered to be the synthesis of compounds with a defensive role including many secondary metabolites, as well as, the synthesis of compounds necessary for the maturation of reproductive organs.

CONCLUSIONS

Differences in chemical compositions between organically and conventionally produced foods vary in dependence on a plant species, production season, morphological parts of the plant, as well as on observed nutrients, which makes it difficult to draw a single conclusion on the impacts of production methods on the chemical composition of plants and plant-based products. Numerous authors have pointed out that organically grown fruits and vegetables have an improved chemical composition and a higher nutritive value than conventionally grown ones. Their results showed that organic products have significantly less nitrates and proteins, but significantly more dry matter, essential amino acids, sugars, vitamin C, numerous macro-and microelements (particularly Fe, Mg and P), secondary metabolites and a higher total antioxidant capacity. Contrasting results reported in other studies have indicated the existence of small differences or the absence of differences, while some researchers have pointed out a higher content of some components in conventional products. Moreover, the lack of a large number of studies related to differences in contents of vitamins, especially β-carotene and the vitamin B complex, is evident.

Considering the multitude of studies suggesting that the nutritive value of organic food is higher compared to comestibles conventionally produced, a clear consensus does not exist yet, and therefore further research is needed.

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ORGANSKI BILNI PROIZVODI IMAJU BOLJI HEMIJSKI SASTAV OD KONVENCIONALNIH PROIZVODA

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Sažetak: S obzirom na negativne efekte do kojih dovodi konvencionalna poljoprivredna proizvodnja, organska proizvodnja hrane predstavlja održiv pristup proizvodnje, koji čuva životnu sredinu i zravlje ljudi. Organski proizvodi su proizvodi visokog stepena kvaliteta, bez ostataka pesticida i drugih štetnih hemikalija. U ovom radu je kroz pregled literaturnih podataka dat prikaz poređenja hemijskog sastava organskih i konvencionalnih biljaka i njihovih proizvoda. Izdvojeni su: suva materija, nitrati, proteini, šećeri, vitamini, makro- i mikroelementi, kao i sekundarni metaboliti. Podaci ukazuju da organski proizvodi u odnosu na konvencionalne imaju više suve materije, znatno manje nitrata, manje proteina uz veći udeo esencijalnih aminokiselina, više šećera, vitamina C, brojnih makro- i mikroelemenata (naročito Fe, Mg i P), kao i veći sadržaj polifenola i ukupni antioksidativni kapacitet. Međutim, iako se brojni autori širom sveta već dugi niz godina bave komparacijom nutritivnog sastava organskih i konvencionalnih namirnica, jasan konsenzus da su organski proizvodi boljeg hemijskog sastava od konvencionalnih do danas nije postignut, tj. odgovori su ambivalentni. Zbog toga su neophodna dalja dugogodišnja ispitivanja, kako bi se postojeće nedoumice razjasnile.

Ključne reči: organska proizvodnja, konvencionalna proizvodnja, vitamini, minerali, sekundarni metaboliti, nitrati

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