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

Jelena M. Golijan*[1], Mile D. Sečanski[2]

[1]University of Belgrade, Faculty of Agriculture, 11080 Belgrade, Nemanjina 6, Serbia
[2]Maize Research Institute, 11185 Belgrade, Slobodana Bajića 1, Serbia

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, nitrites*

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 & Jaklič, 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 & Čamdžija, 2017; Golijan & Dimitrijević, 2018). According to the Research Institute of Organic Agriculture (FiBL, 2020): *„Organic agriculture is prac-*

Corresponding author: golijan.j@agrif.bg.ac.rs
Phone: +381631501988

tised in 186 countries, and 71.5 million hectares of agricultural land are managed organically by approximately 2.8 million farmers. The global sales of organic food and drink reached more than 96 million euros in 2018". Numerous 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, radioactive 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).

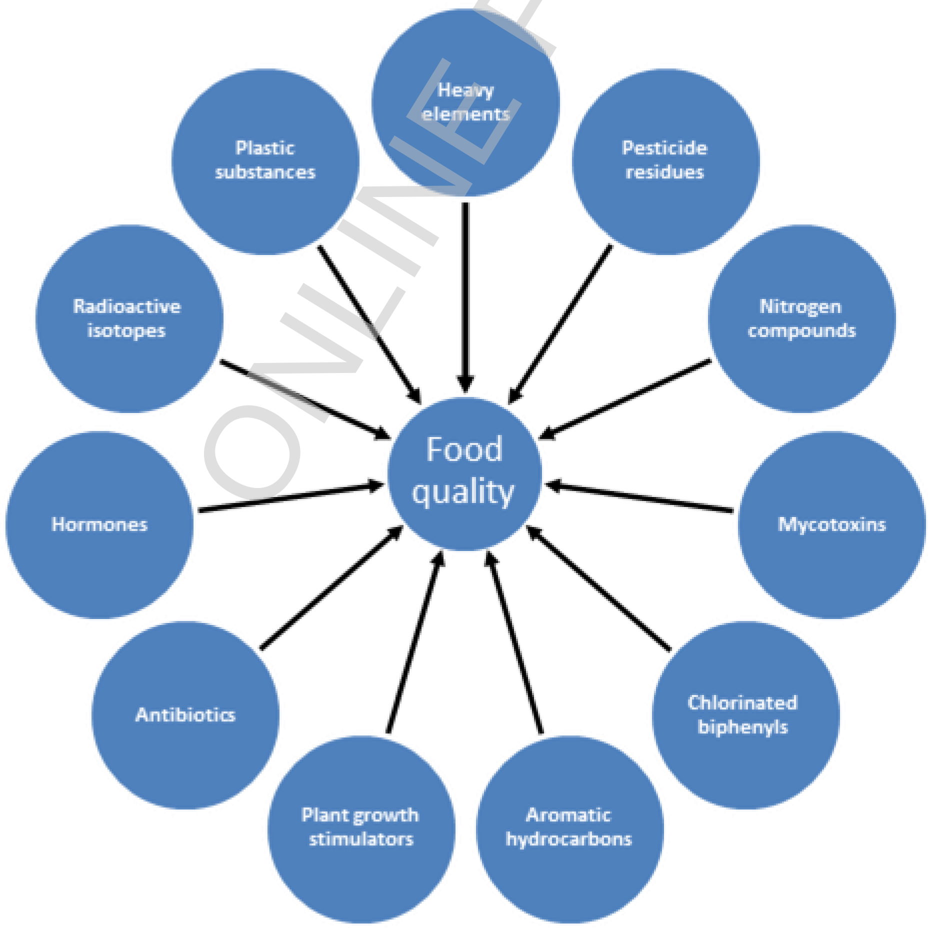

Figure 1. Pollutants that affect food quality

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 objecttive 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 protecttion 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

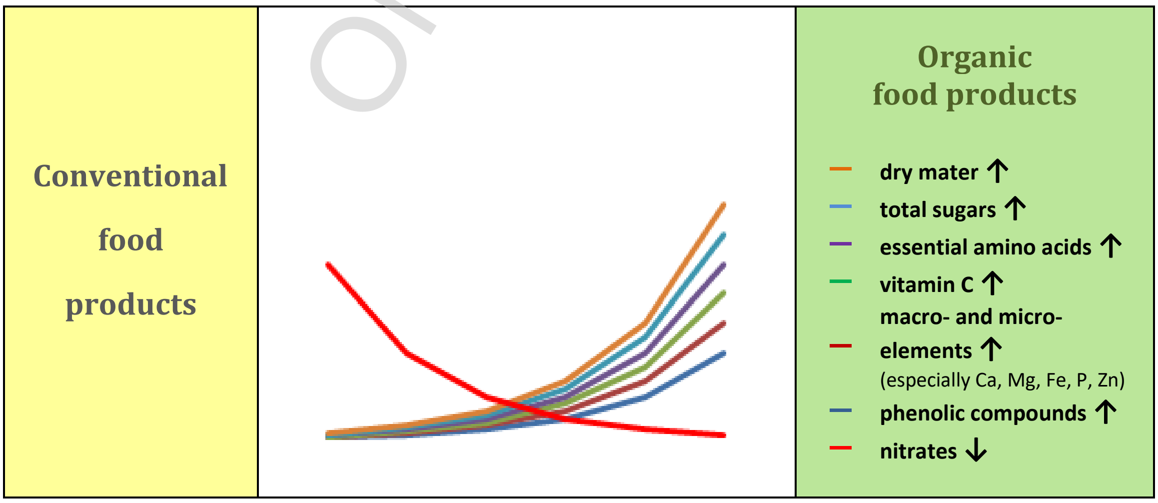

Figure 2. Effects of organic and conventional production methods on the chemical compositions of plants (data compiled from Woëse, Lange, Boess and Bogl, 1997; Worthington, 1998; Heaton, 2001; Worthington, 2001; Bourn and Prescott, 2002; Rembiałkowska, 2007; Baranski et al., 2014, and many others)

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 conventionnally grown crops (Finesilver, Johns & Hill, 1989; Hornick, 1992; Woëse et al., 1997; Worthington, 1998). According to some researches, 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 conventionnally 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; Gąstoł, Domagała-Świątkiewicz & Krośniak, 2011; Kalinova & Vrchotova, 2011; Aires, Carvalho, Rosa & Saavedra, 2012; Gorenjak, Koležnik & Cencič, 2012; Koh, Charoenprasert & Mitchell, 2012; Lombardo, Pandino & Mauromicale, 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 (Rembiałkowska, 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, Glover, Bohannan & Mooney (2006)	Apple orchard	N_2O, N_2, 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. N_2O emissions were not significantly different among treatments. N_2 emissions were highest in organic fields.
Liu, Tu, Hu, Gumpertz & Ristaino (2007)	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.
Hoogenboom et al. (2008)	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.
Lima, lopes, Rossetto & Vianello (2009)	Chinese cabbage, maize	Nitrate	Higher concentration of nitrate was found in organic production than conventional.
Dangour et al. (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.

Reference	**Samples**	**Compounds analysed**	**Major conclusions**
Gąstoł et al. (2011)	Apple, pear, blackcurrant,carrot, beetroot and celery	NH_{4-}, NO_{3-}	NH_4N content was lower in organic vegetable juices than in conventional ones. The conventional farming method favoured greater NO_3N accumulation for beetroot (846 mg NO_3N kg^{-1} f.w.) than for organic juice (229 mg $NO_{3-}N$ 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, Koukounaras, & 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.

Reference	Samples	Compounds analysed	Major conclusions
Golubkina et al. (2018)	Leek (*Allium porrum*)	Nitrate	Nitrate concentration was higher with conventional management.
Bender et al. (2020)	Carrot	Nitrogen, nitrate	Carrots managed organically had 14.1% lower nitrate than those managed conventionally. There were no convincing effects of cultivation system on the nitrogen or dry matter content of carrots.
Kwiatkowski & Harasim, (2020)	Crop rotations:potato-winter wheat-field bean-spring barley	Total nitrogen content, N-NO_3 and N-NH_4	Organic system contributed to an increased soil content of and total nitrogen, also a higher soil content of nitrogen in the form of N-NH_4 and its lower content in the form of N-NO_3.

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 (Dlouhy, 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 (Dlouhy, 1977; Chakhovskii, 1981; Starling & Richards, 1990; Starling & Richards, 1993; Bourn, 1994; Ragasits & 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 ($p \leq 0.05$) 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 nitrogen fertilisers 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 phenyllanine in organic maize. The content of crude proteins increased in the conventionally grown crop, while no differrence in the proportion of amino acids was detected (Lockeretz, Shearer & Kohl, 1981; Wolfson & Shearer, 1981).

SUGARS

The majority of previously conducted studies indicate that organically grown crops and their products have a higher content of total sugars. 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 saccharose, was found in organically grown vegetables (carrots, sugar beet, red beet, potato, spinach, Savoy cabbage) and fruits (apple, cherry, current) (Rembiałkowska, 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 (Bøhn 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 saccharose.

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, Caruso 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, Sciarappa, 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.
Gąstoł 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, & Kirhnere (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)	Kiwis	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.
Bøhn 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.
Brazinskiene 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.

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 su-gars) ranged from 67.85% in organic goji to 75.05% in conventional goji. Fructose was the most important soluble sugar identified in or-ganic 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 pro-duction 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 con-ditions unfavourable for the protein accumu-lation in grain.

Organic potato has higher con-tents of glucose and fructose, while the con-ventionally 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 sac-charose 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 beans, while the detected amount of starch was higher in organically grown soya beans. Seeds of orga-nically grown maize are characterised by a higher presence of non-reducing disaccharides. On the other hand, seeds of conventionally grown maize contained more monosaccha-rides. Moreover, Golijan et al. (2017a) esta-blished higher contents of soluble sugars in seeds of organically grown maize and buckwheat 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 carotenes 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 Alföldi (2000), a significantly higher P content (31.9%), higher technical and vital quality (14.7% and 65.7%, respectively), were established in apples in organic 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, nitrites 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; Lecerf, 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 & Rodríguez-Burruezo (2018) carried out studies on 37 accessions of Spanish landraces 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 alboglabra*, *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, Matterra, 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, Marszałek & Rembiałkowska (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 & Rembiałkowska (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 & Mirabrishami (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.
Martí 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.

Reference	Samples	Compounds analysed	Major conclusions
Kopczyńska et al. (2020)	Cougette	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 & Sabała (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.

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 andFe 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 Cierpiala (2012) the production method has no effect on the contents of microelements in barley, while seeds of organic wheat contained significantly 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, Gawęda, 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 characterise 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% respecttively) 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 (Rembiałkowska, 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 (Rembiałkowska, Załęcka, Badowski & Ploeger, 2012). Golijan (2020a), studying the contents of macro-and microelements in organically and conventionnally 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, presservation 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 (2001)	Many organic and conventional crops	Ca, Mg, K, Na, P, Fe, Cu	Organically grown cereals contained significantly higher contents of Fe, Mn and P compared to conventional cereals.
Kumpulainen (2001)	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 et al. (2004)	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. (2009)	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, hulled 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.
Bøhn 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 high 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.

Reference	Samples	Compounds analysed	Major conclusions
Golijan et al. (2019a)	Buckwheat	B, Cu, Fe, Mn, Mo, Zn	In conventional buckwheat grains, higher quantity of B, Cu and Zn was determined, while organic buckwheat seed contained higher content of Fe and Mn compared to conventionally grown sample.
Golijan et al. (2019b)	Maize	Cd, Cr, Ni, Pb	Conventional maize contained higher amount of Cr and Pb, while content of Ni and Cd was higher in the organic seed.
Kwiatkowski &Harasim (2020)	Crop rotations:potato-winter wheat-field bean-spring barley	P, K, Mg, B, Cu, Mn, Zn	Organic system contributed to an increased soil content of magnesium, boron, copper, manganese, zinc, organic carbon, and total nitrogen.
Wang et al. (2020)	*Triticum aestivum* vs *T. spelta*, flour type (wholegrain vs white)	P, K, Mg, Mn, Zn, Cu, Al, Na, Ca, S, Mo	Organic flour had higher levels minerals (Al (12%) and Ni (81%)) content than conventional flour. Spelt wheat had higher mineral levels than common wheat, as well as 28% higher Cd content.

SECONDARY METABOLITES

Plants contain a large number of organic compounds, traditionally classified as primary and secondary metabolites. The latter are compounds that have no direct role in fundamental metabolic processes but have an important ecological significance for the survival of plants, as well as a protective role in the adaptation of plants to conditions of abiotic and biotic stress. A variety, plant maturity, light, temperature and a number of factors affect the number of secondary metabolites in the plant (Lairon, 2010).

Phenolic compounds represent the largest group of secondary metabolites and encompass simple compounds such as phenolic acids, as well as polymers of high molecular weight, such as condensed tannins (Šarčević-Todosijević et al., 2019). Polyphenols are found in plants in two forms - free and bound polyphenols. In fruits and vegetables, the bound polyphenols make up to 24% of total polyphenol content, while the majority of polyphenols in cereals are found in the bound form (Acosta-Estrada, Gutiérrez-Uribe & Serna-Saldívar, 2014).

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 *Perilla* leaves, Kapoulas et al. (2017) for lettuce and onion, Dutra et al. (2018) for grape juices and wines.

According to Benbrook, Zhao, Yáñez, 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 Rembialkowska (2007), organically produced foods have twice the amount of polyphenols compared to conventional ones. According to

Benbrook (2005), organic products have an antioxidant 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 micro-nutrients and have reported that organically grown plants contained signifycantly 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 phenolics 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 phenolics 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 5-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.
Gąstoł 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, quercetin3-O-glucoside, 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.
Brazinskiene 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 conventional oranges compared to organic production. Total phenol content was significantly higher in organic strawberries than the 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
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 juice, 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.
Ribes-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, Kazimierczak& 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 myrycetin, quercetin, luteolin and quercetin-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 quercitin-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.
Kopczyńska et al. (2020)	Cougette	Polyphenols	Organic courgette fruits were characterised by their significantly higher content of phenolic acids and flavonoids when compared to the conventionally grown.
Hallmann & Sabała (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. spelta* 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 (Veberic et al., 2005), polyphenols, antho-cyanins and total antioxidant activity in oran-ges

(Tarozzi 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 polyphe-nols 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 conven-tionally 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 ten-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 correspond-ding value of kaempferol amounted to 63.3 mg/g d.m. which was higher by 97%. Further-more, levels of flavonoids improved over time in samples organically grown. This improve-ment 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 signi-ficant 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 (Pandey, 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 Genovese, 2013) showed that the distribution of isoflavones 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.

Rembiałkowska (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 re searchers 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 BILJNI PROIZVODI IMAJU BOLJI HEMIJSKI SASTAV OD KONVENCIONALNIH PROIZVODA

Jelena M. Golijan*[1], Mile D. Sečanski[2]

[1]Univerzitet u Beogradu, Poljoprivredni fakultet, 11080 Beograd, Nemanjina 6, Srbija
[2]Institut za kukuruz Zemun Polje, 11185 Beograd, Slobodana Bajića 1, Srbija

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 hutritvnog 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, nitriti*

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