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Effect of organic versus conventional agricultural systems on bioactive compounds of fruits and vegetables: an integrative review

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ABSTRACT

The production and consumption of organic food has increased significantly worldwide in recent decades, as organic food seems to be a healthy alternative to foods from conventional agricultural systems. Although scientific evidence is still scarce and divergent, there may be greater synthesis of bioactive organic compounds and nutrients in organic cultivation than in conventional cultivation. To gather quantitative evidence demonstrating how agricultural crop systems influence the profile of bioactive compounds, an integrative review was conducted to determine differences in the contents of these substances in vegetables. Of the 270 studies selected, 30 were eligible. Studies have shown that the cultivation system impacts the synthesis of bioactive compounds, with organic crops being those that had the highest concentrations of these substances, in addition to greater oxidative stability. The most significant results were in relation to the concentrations of carotenoids and phenolic acids, and antioxidant activity, which were, on average, 60.57%, 123.28% and 31.29% higher in foods grown in organic systems, respectively, which can be one argument to justify the greater functional potential and health benefits of organic foods. It is also worth noting the importance of encouraging the production and consumption of organic foods, as one of the pillars for building healthy and sustainable food practices as opposed to agriculture based on the agribusiness model and dependence on the use of pesticides.

Index terms: carotenoid, oxidative stability, pesticide, phenolic compound.

Efeito dos sistemas de cultivo orgânico versus convencional sobre os compostos bioativos de frutas e hortaliças: uma revisão integrativa

RESUMO

A produção e o consumo de alimentos orgânicos aumentaram significativamente em todo o mundo nas últimas décadas, pois os alimentos orgânicos parecem ser uma alternativa saudável em comparação aos alimentos dos sistemas agrícolas convencionais. Embora as evidências científicas ainda sejam escassas e divergentes, no cultivo orgânico pode haver maior síntese de compostos orgânicos bioativos e de nutrientes do que no cultivo tradicional. Buscando reunir evidências que demonstrem de forma quantitativa como os sistemas de cultivos agrícolas influenciam no perfil de compostos bioativos, uma revisão integrativa foi conduzida para determinar diferenças nos teores dessas substâncias em vegetais. Dos 270 estudos selecionados, 30 foram elegíveis. Os estudos demonstraram

Ideias centrais

- Os compostos bioativos desempenham numerosos efeitos fisiológicos benéficos para o organismo.
- Alimentos produzidos no sistema de cultivo orgânico apresentam maior conteúdo de compostos orgânicos bioativos e de nutrientes.
- Frutas e hortaliças produzidas em sistema de cultivo orgânico apresentam maiores concentrações de carotenoides, ácidos fenólicos e atividade antioxidante em comparação aos cultivos convencionais.
- Os alimentos orgânicos têm forte potencial funcional e saudabilidade.
- O estímulo à produção e ao consumo de alimentos orgânicos é fundamental para a construção de práticas alimentares saudáveis e sustentáveis.

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que o sistema de cultivo tem impacto na síntese de compostos bioativos, sendo cultivos orgânicos os que apresentaram maiores concentrações dessas substâncias, além de maior estabilidade oxidativa. Os resultados mais significativos foram em relação às concentrações de carotenoides, ácidos fenólicos, e atividade antioxidante, que foram, em média, 60,57%, 123,28% e 31,29% maiores nos alimentos cultivados em sistemas orgânicos, respectivamente, o que justifica o maior potencial funcional e grandes benefícios à saúde de alimentos orgânicos. Cabe destacar também a importância do estímulo à produção e consumo de alimentos orgânicos como um dos pilares para a construção de práticas alimentares saudáveis e sustentáveis em oposição à agricultura pautada no modelo do agronegócio e na dependência no uso de agrotóxicos.

Termos para indexação: carotenoide, agrotóxico, composto fenólico, estabilidade oxidativa.

INTRODUCTION

Organic food has gained increasing interest from consumers, which has promoted its trade and consumption. In part, the increase in this demand is justified by the fact that organic foods are perceived by consumers as healthier foods, given how they are produced.

In organic cultivation, synthetic chemical agents are not used as fertilizers or pesticides. Only compounds of natural origin are allowed, and their uses are strictly monitored, emphasizing sustainable technologies, crop rotation, and alternative methods for selecting resistant strains. Conventional agriculture, on the other hand, is based on monocultures grown in large areas and depends heavily on the use of synthetic pesticides and mineral fertilizers, as well as other agricultural inputs, to control the growth of vegetables (Zhao et al., 2006; Brantsæter et al., 2017).

Thus, the conventional agricultural model contrasts the four principles of organic agriculture, formulated by the International Federation of Organic Agriculture Movements (Ifoam, 2008): health, ecology, justice, and care. These aspects can put organic agriculture in a position to favour the biodiversity of cultures and environmental and human health, therefore, being seen as more sustainable and healthier by the population.

With these principles and guarantees, it can be concluded that organic foods are safer due to limited contamination with pesticides, among other chemical agents with negative health effects (Smith-Spangler et al., 2012; Barański et al., 2014; Brantsæter et al., 2017). However, in parallel with discussions on the beneficial potential of organic foods due to the lower risk of contamination with pesticide residues and other contaminants – besides the social, political, economic, and environmental impacts associated with conventional agriculture – the literature also notes that foods produced in organic farming systems can be healthier due to a more favourable nutritional and antioxidant profile.

Brandt et al. (2011), for example, mention that in addition to being subject to less contamination by pesticide residues, heavy metals, and mycotoxins than conventional foods, organic foods may have a lower nitrate content and higher vitamin C, tocopherols, and mineral (Fe, Mg, P, Zn) contents, in addition to a higher proportion of essential amino acids.

A review published by Hunter et al. (2011) with 66 studies published between 1980 and 2007 showed that organic plant foods have a 5.7% higher content of vitamins and minerals than their conventionally grown counterparts. The food groups that contributed to this difference in composition were vegetables, legumes and, to a lesser extent, fruit. Irrespective of cultivar, soil type, harvest conditions, and chemical analysis, organic plant foods contained significantly higher amounts of minerals, including phosphorus, compared to conventional foods.

Other references, however, concluded that there are no differences between organic and conventional forms of cultivation or even a reduction in nutritional composition and bioactive compounds in organic foods (Dangour et al., 2009; Smith-Spangler et al., 2012).

Thus, the studies published to date are insufficient to obtain consistent evidence on this hypothesis. Experimental studies and other narrative and systematic reviews, including meta-analyses, published to date cite, among the factors that justify the difficulty in obtaining conclusive evidence, the largest amount of nutrients and bioactive compounds in organic foods (Brandt et al., 2011; Barański et al., 2014; Reganold & Wachter, 2016; Brantsæter et al., 2017). Also, the divergences and limitations in many of these studies prevent the establishment of conclusive evidence on this issue.

On the other hand, the differences may be not clinically relevant to human health, a hypothesis that is made even more limiting by the lack of sufficient studies to elucidate this issue (Benbrook et al., 2009; Desjardins, 2016), besides the fact that preliminary results regarding effects of organic food on animal and human organisms indicate increased development and survival rates, improvement of reproductive system, improvement of immune system, and improvement of gut microbiota (Hurtado-Barroso et al., 2019).

Thus, by knowing the importance of bioactive compounds for health and aiming to contribute to updated discussions on this topic and to provide additional and consistent evidence about the influence that agricultural systems have on the content of bioactive compounds and antioxidant activity, this integrative review seeks to quantitatively investigate the experimental studies that compare how the different agricultural crop systems (organic and conventional) influence the profile of bioactive compounds in food.

METHODOLOGY

Search strategy

This is an integrative literature review study aimed to synthesize the results of studies on the influence that cultivation systems have on the content of bioactive compounds and antioxidant activity.

The search strategy in the scientific literature followed the protocol of Brandt et al. (2013), with adaptations in the keywords of the algorithm. The relevant records were identified in the ISI Web of Knowledge (2021), SciELO (2021) and PubMed (2021) by searching in English and using the following algorithm: (1) [organic * OR ecologic * OR biodynamic *]; AND (2) [conventional * OR integrated *]; AND (3) [bioactive compound * OR secondary metabolite *]; AND (4) [food * OR fruit * OR vegetable]. Manual searches on the reference lists of selected original reviews and publications were also conducted.

Records published in journals with peer-reviewed publications in any language that reported original data on the composition of bioactive compounds (secondary metabolites) comparing foods grown in organic and conventional agricultural systems were considered if there was an abstract in English. Records published at conferences or with unpublished results in full were excluded. The search was restricted to the period of January 2014 to October 2019. In all, 270 records were obtained. The flowchart of the search protocol used is shown in Figure 1.

The titles and abstracts of the selected records were analyzed to determine the adequacy of the inclusion criteria, which led to the selection of 40 records. Of these, 10 were excluded for not having sufficient quantitative data for analysis, for the absence of data on bioactive compounds of interest, or for the absence of comparison between organic and conventional cultivation systems.

The reported data were considered sufficient when there was an average concentration of at least one bioactive compound and/or secondary metabolite and/or measure of the antioxidant activity of foods grown in organic and conventional farming systems.

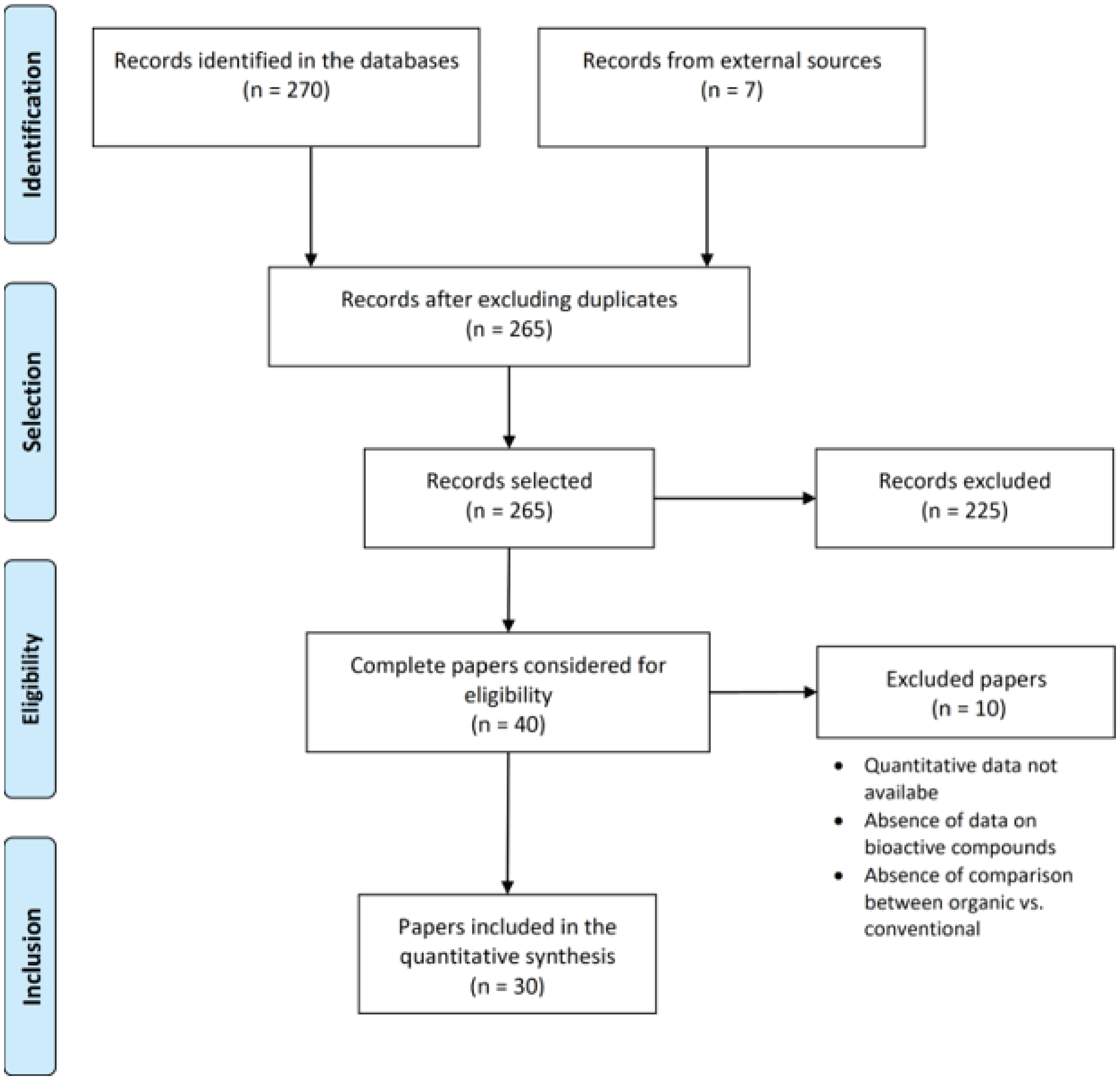

Figure 1. Summary of the search protocol in the scientific literature to identify studies included in the integrative review.

Data analysis

The data on the content of bioactive compounds in organic and conventional crops numerically reported in the publications were directly copied to a database and represented as organic and conventional concentrations. Data represented in the form of graphs were increased, printed, and measured using a ruler to determine the values more accurately by interpolation.

When multiple data points were reported for the same food, two approaches were used, depending on the situation. For mature vegetables with data from different periods/growing seasons or cultivars, the composition data were tabulated as a single value that represents the average of the values obtained in each sample, the number of comparisons being the expression of the number of samples gathered for calculation of that average. In cultures analyzed at different stages of maturation, only the averages of the mature stage were considered (Barański et al., 2014).

The reported bioactive compounds were grouped according to their biochemical similarities, as shown in Table 1.

Table 1. Bioactive compounds analyzed and biochemical classification used to group the data.

Class	Bioactive compound/measurements included
Antioxidant activity	ABTS, CUPRAC, DPPH, DMPD, FRAP, ORAC
Carotenoids	Carotenes (a-carotene, b-carotene, lycopene) Xanthophylls (a-cryptoxanthin, b-cryptoxanthin, capsorubin, lutein, zeaxanthin)
Total phenolic compounds	
Phenolic acids	Caffeic, chlorogenic, ellagic, ferulic, gallic, p-coumarin, protocatechuic, and vanillic acids
Flavonoids	Flavonoids Flavanones (naringin, naringenin, narirutin, neohesperidin) Flavones (apigenin, luteolin) Flavonoids (kaempferol, myricetin, quercetin, rutin) Anthocyanins (cyanidin, delphinidin, pelargonidin)
Minority phenolics	Tannins Phenylethanoids (hydroxytyrosol, oleuropein) Lignans

For the quantitative analysis of the effect that the culture system had on the contents of bioactive compounds, the relative effect was calculated using the following equation:

$$\text{Relative effect (\%)} = \frac{([\text{organic concentration}]-[\text{conventional concentration}])}{([\text{conventional concentration}])}\times 100$$

For numerical and graphical representation and, later, discussion of the results, data of the relative effect were separated between those whose calculated value was negative (indicating that the concentration of the compound in organic cultivation was lower compared to conventional cultivation) and those whose value calculated was positive (indicating that the concentration of the compound in organic cultivation was higher compared to conventional cultivation). The individual relative effects for each bioactive compound and antioxidant measure obtained for the organic and conventional cultivation systems were compared by the t-test of independent samples. Differences between means were considered significant when $p < 0.05$.

RESULTS

Of the 277 studies initially selected, 30 were eligible. Of these studies, 11 dealt with the difference in fruits and derivatives, 15 dealt with vegetables, 3 dealt with cereals and legumes (rye, wheat, and beans), and 1 dealt with herbs and spices. The quantified bioactive compounds were antioxidants, carotenoids, total phenolic compounds, phenolic acids, and flavonoids, in addition to minor phenolic compounds such as tannins; phenylethanoids such as hydroxytyrosol and oleuropein; and lignans (Table 2).

The studies used designs that involved cultivation in field experiments simulating conventional and organic conditions or obtaining commercial samples. In general, the positive relative effect (higher concentrations of bioactive compounds and antioxidant activity in organic crops compared to conventional ones) was significantly greater than the negative relative effect (higher concentrations of bioactive compounds and antioxidant activity in conventional crops). This was particularly evident in the data on antioxidant activity, carotenoids, and phenolic acids.

Table 2. Studies included in the integrative review, food and bioactive compounds analyzed.

Reference	Food analyzed	Compound					
		Antioxidants	Carotenoids	Total phenolics	Phenolic acids	Flavonoids	Minority phenolics
Abountiolas et al. (2018)	Strawberry		x	x		x	
Assumpção et al. (2016)	Grape seed oil		x	x			
Barbieri et al. (2015)	Strawberry	x		x	x		
Chebrolu et al. (2016)	Grapefruit					x	
Cuevas et al. (2015)	Plum	x	x	x			
Oliveira et al. (2017)	Passion fruit			x		x	
Frias-Moreno et al. (2019)	Raspberry	x		x	x	x	
Friedman et al. (2017)	Potatoes, dehydrated peel	x		x	x	x	
Grudizinska et al. (2016)	Potato	x		x			
Haas et al. (2016)	Grape, whole juice			x		x	x
Hallmann et al. (2017)	White cabbage			x	x	x	
Hallmann et al. (2019a)	Bell pepper		x		x	x	
Hallmann et al. (2019b)	Damascus		x	x	x	x	
Kazimierczak et al. (2015)	Mint, sage, rosemary, lemon balm		x				
Kazimierczak et al. (2016)	Beet, juice					x	
Ku et al. (2018a)	Asparagus	x	x	x		x	
Ku et al. (2018b)	Asparagus	x	x	x		x	x
Kurubas et al. (2019)	Lettuce	x		x			
Lima et al. (2017)	Green bean	x	x	x		x	
Lopez-Yerena et al. (2019)	Extra virgin olive oil			x	x	x	x
Martí et al. (2018)	Tomato				x	x	
Mishra et al. (2017)	Rye	x			x		
Nocente et al. (2019)	Durum wheat	x		x			
Pertuzatti et al. (2015)	Passion fruit		x				
Ponder et al. (2019)	Raspberry			x	x	x	
Ren et al. (2017)	Onion	x		x		x	
Renaud et al. (2014)	Broccoli		x				
Ribes-Moya et al. (2018)	Peppers, green and red		x	x			
Valverde et al. (2014)	Broccoli			x		x	
Wongsa et al. (2016)	Garlic	x		x			

For the bioactive compounds with a significant difference in content, organic cultivation showed a higher concentration in more than half of the comparisons and studies analyzed. For flavonoids, although the difference was not significant, the number of comparisons and studies that observed a positive relative effect was even more pronounced (Table 3 and Figure 2).

Table 3. Content of bioactive compounds in organic versus conventional crops: number of studies, number of comparisons, average relative effect and level of significance.

Data	Measure/Bioactive compound							
	Anti-oxidant activity	Carotenoids	Total phenolic compounds	Phenolic acids	Flavonoids	Minor phenolic compounds		
						Tannins	Phenylethanoids	Lignans
n total(1)	28	47	24	28	51	2	3	1
n comparisons(2)	146	122	145	81	161	3	3	1
Organic – higher								
n	15	22	13	16	35	0	2	0
(%)	(53.57)	(46.81)	(54.17)	(57.14)	(68.63)		(66.67)	
Mean relative effect (%)	+ 31.29	+ 60.57	+ 33.80	+ 123.28	+ 28.77		+ 11.85	
Standard deviation	37.25	90.93	59.09	221.42	72.33		15.01	
Min (%)	+ 0.97	+ 1.14	+ 1.25	+ 6.98	+ 1.70		+ 1.23	
Max (%)	+ 126.67	+ 386.09	+ 219.37	+ 678.79	+ 429.52		+ 22.47	
Organic – lower								
n	13	25	11	12	16	2	1	1
(%)	(46.43)	(53.19)	(45.83)	(42.86)	(31.37)	(100.00)	(33.33)	(100.00)
Mean relative effect (%)	- 8.66	- 30.80	- 15.35	- 26.00	- 24.68	- 13.59	- 99.03	- 40.51
Standard deviation	5.53	21.41	13.46	20.66	28.07	1.33		
Min (%)	- 0.14	0.00	- 3.27	0.00	- 1.92	- 12.65		
Max (%)	- 15.50	- 92.86	- 49.26	- 62.37	- 100.00	- 14.53		
p-Value(3)	0.016	0.004	0.090	0.005	0.571			

(1)Total number of data considered.

(2)Bioactive compound content in a single sample of organic food compared to the same sample of conventional food.

(3)Test for the average relative effect of organic versus conventional cultivation, obtained by the t-test of independent samples. The + and - signs refer to the average content of conventional cultivation (100%) as a reference. Significantly different means were considered when $p < 0.05$.

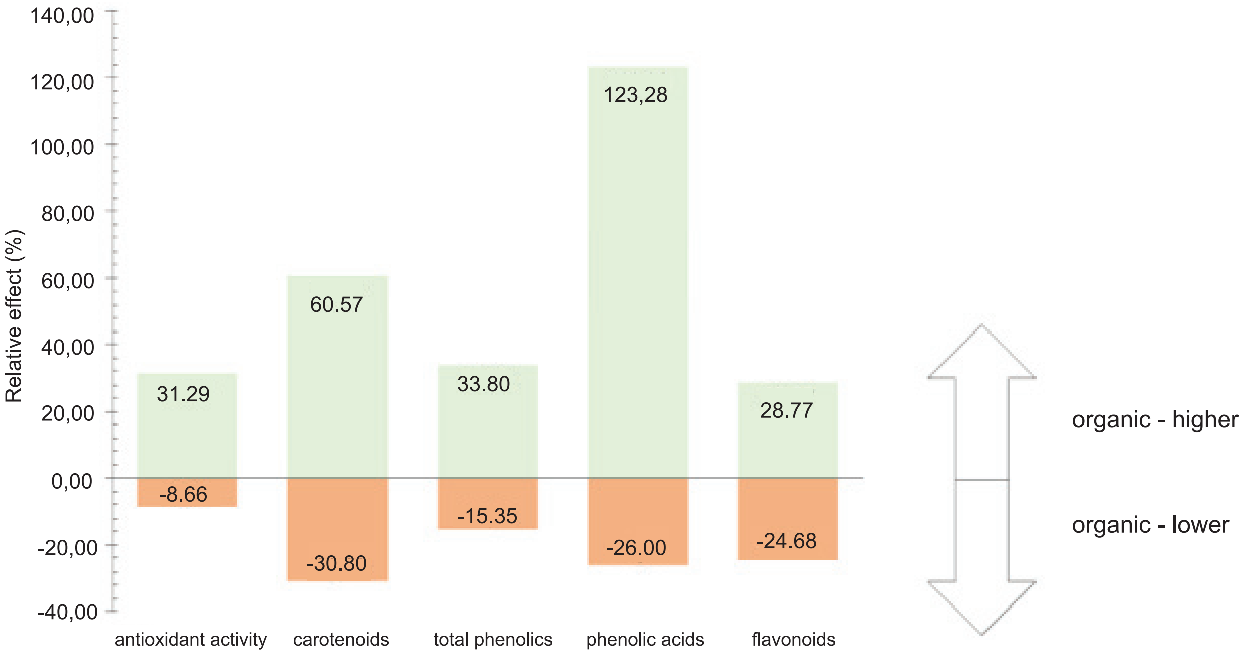

Figure 2. Mean relative effect of organic versus conventional cultivation on the content of bioactive compounds in food.

DISCUSSION

The results obtained in this integrative review provide evidence that the cultivation system has an impact on the concentration of bioactive compounds in plant foods, with organic crops being those that, on average, had higher concentrations of substances such as carotenoids and phenolic compounds, in addition to greater oxidative stability.

These results show that the most recent experimental studies corroborate previous studies, including systematic reviews and meta-analyses, which already provided evidence that organic crops have a higher content of secondary metabolites of functional interest (Brandt et al., 2011; Barański et al., 2014; Reganold & Wachter, 2016; Brantsæter et al., 2017), and contradict other divergent or inconclusive publications, which indicated the absence of significant differences between organic and conventional crops (Dangour et al., 2009; Smith-Spangler et al., 2012). The study by Dangour et al. (2009) even concluded that in organic products, the amount of some secondary metabolites was significantly lower. However, these results were questioned by Benbrook et al. (2009) and Desjardins (2016) afterwards due to controversies and methodological limitations, favouring the strengthening of results such as those presented in this study.

Oxidative stability

The antioxidant activity was measured in studies considered by different methodologies, capable of evaluating the oxidative stability of the food by different mechanisms. The hydrophilic antioxidant activity, which can serve as a measure to estimate the number of water-soluble antioxidants, such as phenolic compounds, was measured by the ability of antioxidant compounds to transfer hydrogen atoms to N,N-dimethyl-p-phenylenediamine (DMPD+), with consequent discoloration of the solution. This change was proportional to the amount of antioxidant present (Mehdi & Rizvi, 2013).

Other methods included quantifying the antioxidant activity of compounds of both hydrophilic and lipophilic nature, such as carotenoids. The methods included the following: the capture of the 2,2’-azinobis radical (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) (Barbieri et al., 2015; Cuevas et al., 2015; Grudzińska et al., 2016; Ku et al., 2018a) and 2,2-diphenyl-1-picryl-hydrazil (DPPH) (Wongsa et al., 2016; Friedman et al., 2017; Lima et al., 2017; Mishra et al., 2017; Ren et al., 2017; Ku et al., 2018b; Frias-Moreno et al., 2019; Kurubas et al., 2019) radicals in addition to methodologies involving metal ion reduction mechanisms such as Fe3+ and Cu3+ (FRAP and CUPRAC, respectively) (Friedman et al., 2017; Ren et al., 2017; Ku, 2018a, 2018b).

The greater antioxidant activity by these different mechanisms may be directly associated with the greater concentration of a wide range of compounds with antioxidant potentials, such as bioactive compounds of nutritional interest, mainly phenolic compounds, and carotenoids (Ku et al., 2018a). The higher antioxidant activity in organic food, therefore, may be indicative of the greater biosynthesis of secondary metabolites by the plant in the absence of conventional management.

In organic agriculture, the limited use of pesticides can contribute to increasing the pressure of pests, inducing the development of more robust defense mechanisms by the plant, which can result in the greater synthesis of organic compounds that provide the plant with means of mediating chemical interactions in its environment. These compounds are classified as secondary metabolites, which differ from the primary metabolites required for structure and function. While secondary metabolites are synthesized by plant metabolism in specific cells or tissues, tending to be more complex, primary metabolites predominantly participate in the basic metabolic processes for plant survival. The biosynthesis of secondary metabolites, however, is initiated from a primary metabolite or from a specific intermediate (Veberic, 2016).

Phenolic compounds

The shikimic acid pathway is responsible for the synthesis of most of the almost 8,000 plant phenolic compounds identified thus far (Latif et al., 2017), and its products are aromatic amino acids such as phenylalanine and tyrosine, and cinnamic acids and their derivatives (simple phenols, phenolic acids, coumarins, lignans and derivatives of phenylpropanoids). In this pathway, a sequence of seven enzymatic reactions occurs, which begins in plastids with the condensation of two phosphorylated metabolites: phosphoenolpyruvate – from glycolysis – and erythrose-4-phosphate – from the pentose pathway (Croft, 1998; Ryan et al., 2002; Quiñones et al., 2012).

The aromatic amino acids produced, mainly phenylalanine, are the precursors of most of the phenolic compounds produced later. Phenylalanine represents the starting substrate for a series of reactions known as "general phenylpropanoid metabolism" and refers to the production of cinnamic acid, coumaric acid, and its derivatives. These compounds are called phenylpropanoids because they contain a benzene ring (C6) and a side chain with three carbons (C3) (García & Carril, 2009). These products, combined with products obtained from the polyacetate pathway, form phenolic varieties known as lignans, lignins, suberins and cutins, stilbenes, chalcones, flavonoids, and tannins (Figure 2) (Parr & Bolwell, 2000).

The mechanisms by which these compounds exert plant protection are variable, and many of them are still unknown, but they may involve enzymatic and physiological reactions that impact hormonal activity, membrane permeability, photosynthesis and respiration, synthesis of organic compounds, autotoxicity, and suppression of weeds (Latif et al., 2017).

Carotenoids

Carotenoids, despite their great variability in structures, undergo sterol and isoprenoid biosynthesis as first steps for their biosynthesis reactions, giving rise to tetra-terpenoids. The first step consists of the condensation of two molecules of geranylgeranyl triphosphate (C20), generating phytoene (C40), which is catalyzed by the enzyme phytoene synthase. The conversion of colorless carotenoids to yellow-to-red-colored carotenoids follows a series of desaturation and/or cyclization reactions and/or the addition of functional groups (Águilla Ruiz-Sola & Rodríguez-Concepción, 2012; Von Lintig & Sies, 2013).

In addition to phenolics, carotenoids also participate in numerous protective functions in the plant, being able to act as defensive mechanisms or natural repellents, antioxidants, hormone precursors and volatile apocarotenoids, among other functions, thus being important mediators of tritrophic interactions (Heath et al., 2013).

Therefore, the synthesis of secondary metabolites, whether phenolic or carotenoid, can be understood as a standard response to any form of stress (biotic or abiotic), one of its functions being to help the plant overcome unfavorable conditions, especially in the development phase of the plant. These conditions seem to prevail in organic farming systems compared to systems using pesticides, which reinforces the hypothesis that organic foods have higher levels of secondary metabolites and, consequently, greater oxidative stability.

In addition, research on the effect of fertilization on the chemical composition of the plant shows that the increase in nitrogen availability, which is a common practice in conventional crops, reduces the accumulation of secondary metabolites involved in the defense system, in addition to vitamin C. However, the increase in certain metabolites that are not exclusively involved in the defense system against diseases and pests, such as carotenoids (Brandt et al., 2011), may explain the relative effect negative results found in the present review, even if those results are not significant.

On the other hand, some flavonoids, including anthocyanins, seem to be much more susceptible to the influence of the cultivar than the cultivation method (Abountiolas et al., 2018), which may explain the absence of a significant difference for this class of substances in this review. In addition, soil composition, in particular nitrogen availability, can also affect the biosynthesis pathways of these molecules (Mitchell et al., 2007), as previously discussed.

In postharvest and analytical methodologies, there may also be factors that interfere with the content of these compounds, which may not be related to the biosynthesis mechanisms themselves, but to the effect of operations and conditions that alter the food matrix. During storage, for example, the concentration of phenolics can occur due to the loss of moisture resulting from the exposure of food to the environment (Abountiolas et al., 2018).

For this reason, the literature is divergent in terms of providing consistent evidence about the chemical and nutritional composition of foods grown in different cultivation systems (Veberic, 2016).

Functional importance linked to human health

It is worth highlighting the relevance of the results obtained in this review from a nutritional point of view. Although phenolic and carotenoid compounds are not considered essential nutrients, an increasing number of studies have shown the beneficial potential of these substances in modulating biochemical and physiological reactions of the human organism, bringing positive impacts to health, contributing to the prevention of nonchronic diseases, and maintaining the quality of life of the subjects.

In this sense, a considerable amount of chemical, biochemical, epidemiological, and clinical evidence indicates the beneficial effects of phenolic and carotenoid compounds on human health. These effects are mainly related to the ability to react with reactive oxygen species (ROS) and reactive nitrogen species (RNS) and thus to act as antioxidants (Gürbüz et al., 2018; Alañón et al., 2019; Castaldo et al., 2019). However, they also exert several other specific biological effects through more complex mechanisms of action, thus being able to present chemopreventive efficacy (Zhou et al., 2019); modify the action of enzymes such as cyclooxygenases and lipoxygenases (Halliwell et al., 2005); interact in signal transduction pathways (Zhang et al., 2012) and interact with transcription factors involved in cell regulation mechanisms (Haneishi et al., 2012); act in the suppression and prevention of hyperplasia (Orozco-Sevilla et al., 2013); and inhibit platelet function (Murphy et al., 2003).

However, there is limited evidence to date on the direct relationship between organic food consumption and health. Some experimental studies in animals indicate that organic feed ingredients can improve animal physiology, such as immune parameters and hormonal balance. However, the scientific evidence from studies in humans is insufficient to conclude whether organic foods are generally more beneficial to health than conventional foods (Brantsæter et al., 2017).

It is unquestionable, however, that organic foods have residual levels of pesticides and heavy metals, such as Cd and Pb, which are present at lower levels than in conventional foods (Barański et al., 2014; Brantsæter et al., 2017). Smith-Spangler et al. (2012), for example, in a systematic review of the literature evaluating studies published between 1966 and 2011, demonstrated that organic foods are less likely to be contaminated with pesticides. Other studies also mention lower mycotoxin contamination, a lower nitrate content and higher vitamin C, tocopherol, and mineral (Fe, Mg, P, Zn) contents, in addition to a higher proportion of essential amino acids (Brandt et al., 2011).

Exposure to pesticide residues found in conventional foods can cause acute effects, which allows for determining the toxicological classification of its active ingredients, or chronic effects, which can be triggered in the medium and long term, manifesting in diseases such as cancer, congenital malformations, and endocrine, neurological and mental disorders. This situation is worrying since the remains of these toxic products in fruits and vegetables, even though they are within the tolerance provided by official agencies, may not be safe, especially for children (Santos et al., 2014).

This fact, added to the more favourable profile of bioactive compounds in organic foods than in conventional foods, determined in composition studies, promotes the statement that organic foods are healthier.

CONCLUSION

The cultivation system has an impact on the synthesis of bioactive compounds in plant foods, with organic crops being those that, on average, had higher concentrations of bioactive substances, in addition to greater oxidative stability, even in the face of environmental variations to which the plants are subjected regardless of the cultivation system. The most significant results were in relation to the concentrations of carotenoids, concentrations of phenolic acids and the antioxidant activity, which were, on average, 60.57%, 123.28% and 31.29% higher in foods grown in organic systems, respectively.

Therefore, knowing that it is proven that bioactive compounds demonstrate effects on the modulation of biochemical and physiological reactions in humans and that organic foods also have fewer chances of contamination by pesticide residues and contaminants such as heavy metals, it can be concluded that the potential functional and health benefits of organic foods are greater than those of foods produced in conventional farming systems.

It is also worth highlighting the importance of stimulating the production and consumption of organic food as one of the pillars for the construction of sustainable food practices, which can concomitantly have economic importance and benefit rural producers through the production of healthier and higher-quality foods.

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