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Physicochemical composition of fruits and vegetables under organic and conventional growing systems: A systematic review

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Abstract
Food production in organic and conventional systems requires different managements and practices, especially regarding the use of agrochemicals, which affects growing conditions and can influence food composition. Thus, studies comparing the physical-chemical composition of fruits and vegetables under the two production systems were carried out according to the Preferred Reporting Items for Systematic Reviews method, and the differences found were compared using the Chi-square test. There was a higher percentage of organic fruits with higher levels of vitamin C (62.50%) and Total Phenolic Compounds (92.31%), and a higher percentage of organic vegetables with higher contents of Dry Matter (76.47 %), vitamin C (85.71%) and Total Phenolic Compounds (82.35%). Therefore, it is essential that more studies occur in the area, in addition to the elaboration of an organic food composition table, or one, addressing nutrients that do not generate further discussions about their changes between systems, such as vitamin C.

Keywords: bioactives; health; nutrition; pesticides

Introduction

Brazilian agricultural production is composed mostly of conventional food, where, in the 70s, the government adopted the Green Revolution, an agriculture model based on the intensive use of chemical inputs, thus having an exponential increase in agricultural production and livestock in the country, however, with great incentive to use of pesticides (herbicides, fungicides and insecticides), chemical fertilizers (Rossi and Lemos 2013; Mariani and Henkes 2015) [50, 37]. This is due to the fact that in this type of production system, the need for durability and resistance of the product is recommended, prioritizing quantities produced and not human, animal or environmental health issues (Rossi and Lemos 2013; Mariani and Henkes 2015) [50, 37].

As an alternative to conventional foods, the organic production system is observed, whose methods used during food cultivation are alternative, and must meet the organic standards described by the Ministry of Agriculture, Livestock and Supply (MAPA) in Brazil, which prohibits or limits the use of pesticides and chemical inputs (Brazil 2021; FAO 2021) [11]. Furthermore, organic foods are not processed with irradiation, industrial solvents or synthetic food additives, which improves the health of the agroecosystem and the environment (Brazil 2021; FAO 2021) [11].

The main risks in relation to the use of pesticides are water pollution (rivers, seas, river basins and even rain); contamination of soils and air; toxicity to fish, amphibians, insects, bees and microorganisms; the emergence of pesticide-resistant weeds and pests causing ecological instability; and toxicity to humans and other organisms (Silva and Silva 2016; Lopes and Albuquerque 2018; Majeed 2018) [54, 32, 35]. Pesticides when in direct contact with humans can cause toxicity, neurotoxicity, genotoxicity and hormonal dysfunction (Forman et al. 2012) [22]. In addition to direct contact, humans can be affected through ingestion of contaminated food and water, leading to chronic exposure, which can be associated with numerous health problems, affecting the eyes, gastrointestinal tract, liver, kidneys and cardiovascular, nervous, reproductive and endocrine systems, also causing memory disorders, kidney diseases, rheumatoid arthritis, respiratory and dermatological problems, depression, neurological deficits such as Parkinson's disease, miscarriages, fetal malformation and different types of cancers (Forman et al. 2012; Silva and Silva 2016; Majeed 2018) [22, 54, 32].

Johann et al. (2019) [27] point out that in addition to conventional foods having greater toxicity than organic foods due to the large amounts of chemicals used, they may also have a lower nutritional quality. This is because organic agriculture uses soil conservation techniques, such as crop rotation and intercropping (which prevents nutrient depletion), green manures (planting special crops that enrich the soil), mulching (protects the soil against erosion), plant and animal compost (organic matter for the soil), minimal cultivation, resistant varieties and alternative and integrated pest control; which preserves the structure of the soil, providing food for its microorganisms, preventing the emergence of pests, reducing the soil loss, displacement of nutrients and contamination, and causing the slow release of nutrients to the plants; unlike conventional agriculture (Worthington 2001; Silva and Polli 2020) [61, 55].

Thus, as organic foods can have higher nutrient contents than conventional foods (Worthington 2001) [61] and nutritional aspects characterize an important aspect of Food and Nutrition Security (FAO 2013) [18], and there are few studies carried out in this area, mainly when considering the adequate control of variables that can influence the composition of a food, such as soil type, environmental conditions (light, temperature and humidity), processing, storage and genetic variability (Williams 2002; Lima and Vianello 2010; Forman et al. 2012) [22, 60, 31], it is extremely important to carry out this research on the subject, providing more information and comparisons between the physical-chemical composition of organic and conventional foods.
Therefore, the present research sought to identify possible nutritional differences between fruits and vegetables grown under organic and conventional systems.

Materials and Methods
The study was based on bibliographic research and carried out using the Preferred Reporting Items for Systematic Reviews method (PRISMA 2020) [45], described by Galvão, Pansani and Harrad (2015) [23]. It was guided by the following questions: “Do fruits and vegetables from organic and conventional farming systems present nutritional differences? If so, what are they?” Using the following descriptors: “physicochemical characteristics of organic and conventional foods”; “organic and conventional fruits and vegetables”; “organic and conventional foods”; “organic food nutrients”, thus having a qualitative-quantitative, descriptive and exploratory character. The following databases were used: Academia, ACS publications, Elsevier, Lilacs, Portal Capes, Portal Domínio Público, Portal Embrapa, PubMed, Repositories, Research Gate, Scielo and Symposia. Initially, 425 studies were collected, from 2002 to 2021, of which 237 were excluded after reading the title, noting the lack of establishment of a relationship with the nutritional quality of organic foods, or because they were review articles, theses, dissertations, Course Conclusion Papers (CCP's), papers from symposia or other events, and duplications. Of the 188 remaining articles, 101 were discarded after reading the abstract, noting that it was not a nutritional comparison between organic and conventional fruits and vegetables; of the remaining 87 studies, 53 were eliminated because they did not present the following characteristics: analysis of variance, adequacy in the construction of methodology and results, as they were not published in journals classified by the latest Cite Score Ranking (Scopus Preview 2022) [53] or by the Impact Factor - FI (Web of Science database) (Clarivate 2022) [16] in percentiles that fit into the eight strata of Qualis-Periódicos (2019) [46] (A or B journals), and for not having a good control of variables that influence the nutritional composition of foods, such as: climate, soil, cultivar and management; thus leaving 34 articles that were included in the review. A flowchart detailing the identification, selection and inclusion of studies can be seen in Figure 1.

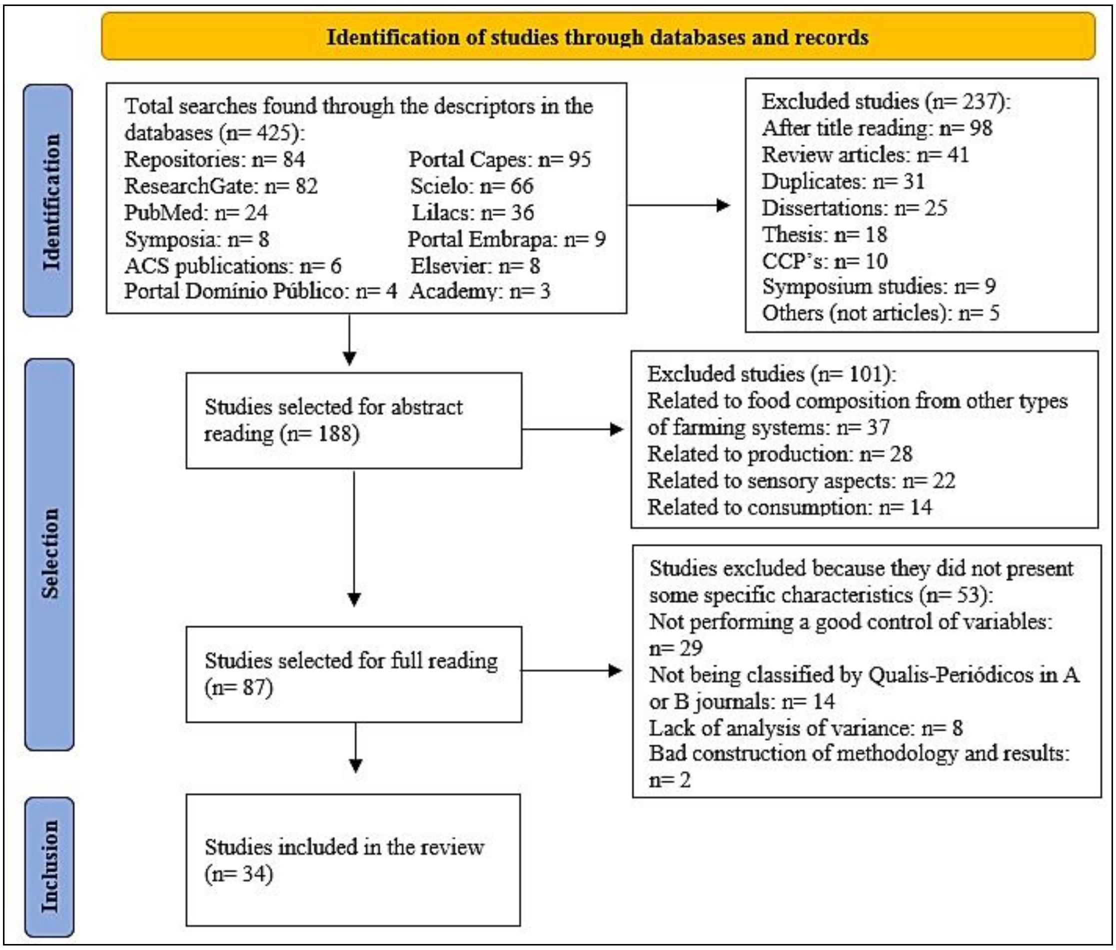

Fig 1: Flowchart of the methodology steps according to their phases: identification, selection and inclusion.

The foods collected through the 34 selected articles were then divided into two groups: the fruit group and the vegetables group, following the description of the food groups in the Food Guide for the Brazilian Population (Brazil 2014) [10] and FAO (2014) [19]. There are 17 articles for each group, which are arranged in chronological order in Tables 1 and 2, where you can also find the country where each one was carried out and the foods analyzed by them.

Table 1: Articles that compared the physicochemical composition of fruits.

Article	Country	Food/s analyzed
Carbonaro *et al*. (2002)	Italy	1- Regina Bianca Peach; and
		2- Williams Pear.
Amodio *et al*. (2007)	United States of America	1- Hayward Kiwi.
Fischer *et al*. (2007)	Brazil	1- Yellow Passion Fruit.
Roussos and Gasparatos (2009)	Greece	1- Starking Delicious Apple.
Raganold *et al*. (2010)	United States of America	1- Diamante Strawberry;
		2- Lanai Strawberry; and
		3- San Juan Strawberry.
Cardoso *et al*. (2011)	Brazil	1- Rama Forte Persimmon;
		2- Oliver Acerola; and
		3- Oso Grande Strawberry.
Maciel *et al*. (2011)	Brazil	1- Tommy Atkins Mango.
Ribeiro *et al*. (2012)	Brazil	1- Caipira Banana;
		2- Pacovan Ken Banana;
		3- Maravilha Banana;
		4- Prata-Anã Banana;
		5- Thap maeo Banana; and
		6- Tropical Banana.
Petry *et al*. (2012)	Brazil	1- Valência Orange.
Amarante *et al*. (2015)	Brazil	1- Royal Gala Apple.
Kazimierczak *et al*. (2015)	United States of America	1- Polka Raspberry; and
		2- Polona Raspberry.
Kohn *et al*. (2015)	Brazil	1- Valenciano Melon.
Pertuzatti *et al*. (2015)	Brazil	1- Yellow Passion Fruit.
Frias-Moreno *et al*. (2019)	Mexico	1- Heritage Raspberry.
Zahedipour *et al*. (2019)	Iran	1- Thompson Grape.
Srinil *et al*. (2020)	Thailand	1- Paen Srithong Guava; and
		2- Kim Ju Guava.
Sangiorgio *et al*. (2021)	Italy	1- Enrosadira Raspberry.

Table 2: Articles that compared the physicochemical composition of vegetables.

Article	Country	Food/s analyzed
Moreira *et al*. (2003)	Argentina	1- Bressane Chard.
Caris-Veyrat *et al*. (2004)	France	1- Félicia Tomato;
		2- Izabella Tomato; and
		3- Paola Tomato.
Bender *et al*. (2009)	Estonia	1- Jõgeva Nantes Carrot.
Arbos *et al*. (2010)	Brazil	1- Verônica Lettuce;
		2- Arugula; and
		3- Chicory.
Citak and Sonnez (2010)	Turkey	1- Espinach.
Resende *et al*. (2010)	Brazil	1- Red Creole Onion;
		2- Montana Onion;
		3- Baia Periforme Onion;
		4- Crioula do Mercosul Onion;
		5- Bola Precoce Onion; and
		6- Baia Periforme Onion.
Silva *et al*. (2011)	Brazil	1- Curly Lettuce.
Hallmann and Rembialkowska (2012)	Poland	1- Roberta Bell Pepper;
		2- Spartacus Bell Pepper; and
		3- Berceo Bell Pepper.
Luthria *et al*. (2012)	United States of America	1- Blackbell Eggplant; and
		2- Millionaire Eggplant.

Kazimierczak *et al*. (2014)	Poland	1- Libero Beet.
Vinha *et al*. (2014)	Portugal	1- Redondo Tomato.
Martins *et al*. (2017)	Brazil	1- Rubra Lettuce; and
		2- Crystal Lettuce.
Bender *et al*. (2020)	Estonia	1- Jõgeva Nantes Carrot.
Guilherme *et al*. (2020)	Portugal	1- Green Sweet Pepper; and
		2- Red Sweet Pepper.
Basay *et al*. (2021)	Turkey	1- Pala-49 Eggplant;
		2- Topan374 Eggplant;
		3- Rio Grande Tomato;
		4- Pink Tomato; and
		5- Kandil Dolma Pepper.
Mian *et al*. (2021)	Brazil	1- Grazianni Tomato.
Najman *et al*. (2021)	Poland	1- White Harna Garlic; and
		2- Black Harna Garlic.

After gathering all the physicochemical analyzes carried out on foods by the 34 articles, it was observed that there were some of them that were explored by few articles and in few foods. This situation can be considered an obstacle to assertive conclusions about the differences found. Therefore, in order to provide a reliable result, the present research excluded from each food group all variables that were analyzed in three or less foods. Thus, the present research included only the variables analyzed in four or more foods.

In the fruit group, the variables analyzed in four or more foods were: 1- Moisture; 2- Total Soluble Solids (TSS); 3- Total Titratable Acidity (TTA); 4- TSS/TTA ratio (Ratio); 5- Hydrogenonic Potential (pH); 6- Total Sugars; 7- Reducing Sugars; 8- Non-reducing sugars; 9- Vitamin C; 10- β-carotene; 11- Lycopene; 12- Total Phenolic Compounds (TPC); 13- Flavonoids; 14- Anthocyanins; and 15- Antioxidant Activity.

In the vegetables group, the variables analyzed in four or more foods were: 1- Moisture; 2- Dry Matter (DM); 3- Total Soluble Solids (TSS); 4- Total Titratable Acidity (TTA); 5- Hydrogenonic Potential (pH); 6- Vitamin C; 7- β-carotene; 8- Lycopene; 9- Total Phenolic Compounds (TPC); 10- Flavonoids; 11- Chlorogenic Acid; 12- Gallic Acid; 13- Antioxidant Activity; and 14- Nitrates.

Taking into account all these selections, the amount and percentage of organic fruits and vegetables was clearly defined, which showed, or not, differences in physicochemical composition when compared to their conventional versions. These differences were tabulated with the aid of electronic spreadsheets, and were divided into three groups (ORG: organic with higher contents than their conventional versions, NDS: organic and conventional that did not differ significantly, and CONV: conventional with higher contents than their organic versions). To compare the percentage of foods from these three groups, the chi-square test was applied. Percentage differences were considered significant when the probability value for the test was 5% or less. Data analyzes were conducted using the FREQ procedure of the Statistical Analysis System software (SAS Inst. Inc., Cary, NC, USA; version 9.4). The results were then discussed, through the exploration of all necessary information on the subject.

Results

Regarding the moisture content, both organic and conventional fruits and vegetables did not show significant differences between any of their groups (Tables 3 and 4). As for the dry matter content, only vegetables were analyzed in four or more foods, where the ORG group (76.47%) was significantly higher than the NDS (11.76%) and CONV (11.76%) groups, while the latter two did not show statistical differences between them (Table 4).

Table 3: Comparison of the percentages of fruits in the three groups (ORG: organic fruits with higher contents than their conventional versions, NDS: organic and conventional fruits that did not show significant differences between them; and CONV: conventional fruits with higher contents than their organic versions) for each variable analyzed by the studies surveyed.

Variables	Articles (n_1)	Fruits (n_2)	ORG % (n)	NDS % (n)	CONV % (n)	*P* value
Moisture	1	6	33,33 (2)	66,67 (4)	×	0,4142
TSS	12	20	30,00 (6)^{ab}	60,00 (12)^{a}	10,00 (2)^{b}	0,0224
TTA	10	17	5,88 (1)^{b}	76,47 (13)^{a}	17,65 (3)^{b}	0,0007
Ratio	6	11	18,18 (2)^{b}	81,82 (9)^{a}	×	0,0348
pH	5	11	×	100,00 (11)	×	×
TS	3	8	25,00 (2)	62,50 (5)	12,50 (1)	0,1969
RS	2	7	14,29 (1)	71,43 (5)	14,29 (1)	0,1017
NRS	1	6	16,67 (1)	66,67 (4)	16,67 (1)	0,2231
Vitamin C	9	16	62,50 (10)^{a}	25,00 (4)^{ab}	12,50 (2)^{b}	0,0388
β-carotene	2	4	×	50,00 (2)	50,00 (2)	1,0000

Lycopene	2	4	×	75,00 (3)	25,00 (1)	0,3173
TPC	9	13	92,31 (12)^{a}	7,69 (1)^{b}	×	0,0023
Flavonoids	4	5	80,00 (4)	×	20,00 (1)	0,1797
Anthocyanins	4	7	57,14 (4)	42,86 (3)	×	0,7055
AA	6	8	100,00 (8)	×	×	×

n_1: total number of articles; n_2: total number of fruits; % (n): percentage (number of fruits); TSS: Total Soluble Solids; TTA: Total Titratable Acidity; Ratio: TSS/TTA ratio; TS: Total Sugars; RS: Reducing Sugars; NRS: Non-Reducing Sugars; TPC: Total Phenolic Compounds; AA: Antioxidant Activity. ^{a,b}Percentages followed by the same letter in each variable do not differ from each other at the level of 5% by the chi-square test. ×: no fruit in a given group and when there is no fruit in two of the three groups, statistical comparison cannot be performed.

Table 4: Comparison of the percentages of vegetables in the three groups (ORG: organic vegetables with higher contents than their conventional versions, NDS: organic and conventional vegetables that did not show significant differences between them; and CONV: conventional vegetables with higher contents than their organic versions) for each variable analyzed by the studies surveyed.

Variables	**Articles (n_1)**	**Fruits (n_2)**	**ORG % (n)**	**NDS % (n)**	**CONV % (n)**	***P* value**
Moisture	4	6	16,67 (1)	83,33 (5)	×	0,1025
DM	7	17	76,47 (13)^{a}	11,76 (2)^{b}	11,76 (2)^{b}	0,0008
TSS	8	16	43,75 (7)	43,75 (7)	12,50 (2)	0,2096
TTA	6	13	×	76,92 (10)	23,08 (3)	0,0522
pH	6	14	14,29 (2)^{b}	64,29 (9)^{a}	21,43 (3)^{ab}	0,0464
Vitamin C	10	14	85,71 (12)^{a}	×	14,29 (2)^{b}	0,0075
β-carotene	4	8	75,00 (6)	×	25,00 (2)	0,1573
Lycopene	3	5	80,00 (4)	20,00 (1)	×	0,1797
TPC	7	17	82,35 (14)^{a}	11,76 (2)^{b}	5,88 (1)^{b}	<0,0001
Flavonoids	5	12	50,00 (6)	41,67 (5)	8,33 (1)	0,1738
CA	4	12	41,67 (5)	25,00 (3)	33,33 (4)	0,7788
GA	2	4	75,00 (3)	×	25,00 (1)	0,3173
AA	6	13	69,23 (9)	30,77 (4)	×	0,1655
Nitrates	4	4	×	×	100,00 (4)	×

n_1: total number of articles; n_2: total number of vegetables; % (n): percentage (number of vegetables); DM: Dry Matter; TSS: Total Soluble Solids; TTA: Total Titratable Acidity; TPC: Total Phenolic Compounds; CA: Chlorogenic Acid; GA: Gallic Acid; AA: Antioxidant Activity. ^{a,b}Percentages followed by the same letter in each variable do not differ from each other at the level of 5% by the chi-square test. ×: no vegetables in a given group and when there are no vegetables and vegetables in two of the three groups, it is not possible to perform the statistical comparison.

As for the Total Soluble Solids content, the NDS group (60%) of fruits showed no significant differences in relation to the ORG group (30%), but was significantly higher than the CONV group (10%); the ORG and CONV groups did not present significant differences between them (Table 3). And the vegetable groups did not show significant differences regarding the content of Total Soluble Solids (Table 4).

According to the variable Total Titratable Acidity, the NDS group (76.47%) of fruits was significantly superior to the ORG (5.88%) and CONV (17.65%) groups, and these did not show significant differences between them; it is also observed that 100% of the fruits are in the NDS group for pH, however, as there are no fruits in two of the three groups surveyed, it was not possible to perform a statistical comparison (Table 3). Meanwhile, vegetables did not present significant differences in relation to Total Titratable Acidity for any of their groups; and regarding pH, the NDS group (64.29%) was significantly superior to the ORG group (14.29%), whereas the CONV group (21.43%) did not show significant differences compared to the other two groups (Table 4).

Only in the fruit group there were four or more foods analyzed in terms of Ratio, Total Sugars, Reducing and Non-Reducing Sugars. The Ratio variable showed significant superiority in the NDS group (81.82%) compared to the ORG (18.18%), while in the CONV group no food was observed, whereas the variables Total, Reducing and Non-Reducing Sugars did not present significant differences between none of their groups (Table 3).

As for the vitamin C content, the ORG group (62.5%) of fruits was significantly superior to the CONV group (12.50%), whereas the NDS group (25.00%) did not differ significantly from any of the groups (Table 3). And the ORG group (85.72%) of vegetables showed significant superiority to the CONV group (14.29%), while in the NDS group no food was observed (Tables 4). Regarding the β-carotene and lycopene content, there were no significant differences for either the fruit or vegetable groups (Tables 3 and 4).

Regarding the content of Total Phenolic Compounds, the ORG group (92.31%) of fruits was significantly higher than the NDS group (7.69%), while in the CONV group no food was observed (Table 3); and the ORG group (82.35%) of vegetables was significantly superior to the NDS (11.76%) and CONV (5.88%) groups, and the latter two do not show statistical differences between them (Table 4).

As for the flavonoid content, it is observed that both fruits and vegetables did not show significant differences for any of their groups (Tables 3 and 4). As for the anthocyanin content, only the fruit group had four or more foods analyzed, where there were no significant differences between the groups (Table 3). Meanwhile, for Chlorogenic and Gallic Acids, only the vegetables group presented four or more foods analyzed, and also did not present significant differences in any of the groups (Table 4).

Regarding antioxidant activity, 100% of the fruits are in the ORG group. However, as there are no fruits in two of the three groups surveyed, it was not possible to perform a statistical comparison (Table 3); for vegetables, however, there were no significant differences in any of the groups (Table 4). For the nitrate content, four or more foods were analyzed only in the vegetables group, where 100% of them are in the CONV group, and as there are no vegetables in two of the three groups surveyed, it was not possible to carry out the statistical comparison (Table 4).

Analyzing all 34 studies surveyed (Tables 1 and 2), it is noted that 20 of them stated that, in general, the organic foods analyzed by them were better and/or superior to the conventional ones; and no study classified organic foods as inferior to conventional foods.

Discussion

The higher content of Dry Matter in organic vegetables may be related to the inputs used in organic cultivation and production systems, where nitrogen is absorbed by the plant after mineralization, not "forcing" plant growth, thus concentrating a higher content. of Dry Matter (Caris-Veyrat et al. 2004) [14]. Due to the higher content of Dry Matter presented by organic foods, nutrients can be concentrated, especially if the analyzes are carried out in dry weight, since the nutritional value of foods is proportional to the content of Dry Matter (Bourn and Prescott 2002; Martins et al. 2017) [9, 38].

Observing the nutritional elements of foods, the content of Total Soluble Solids is noted, which in theory would be lower in organic foods due to the reduction of these compounds caused by nitrogen fertilization in conventional agriculture (Guilherme et al. 2020) [25]. However, the present research did not observe this fact, since both fruits and vegetables were similar in terms of Total Soluble Solids contents. The opposite could be seen in the acidity content of a food, where nitrogen fertilizers from conventional agriculture could increase it (Guilherme et al. 2020) [25]. However, the present research also did not observe this result, since organic and conventional fruits and vegetables were similar both in Total Titratable Acidity and in pH. Organic and conventional fruits were similar in relation to Ratio. The Ratio is the ratio of Total Soluble Solids to Total Titratable Acidity. This relationship is essential so that there is a balance between the sweetness of a food and its acidity (Zahedipour et al. 2019) [63].

As for Total, Reducing and Non-Reducing Sugars, organic foods could have higher levels than conventional ones, which would give them a better organoleptic characteristic (Borguini 2006) [8]. However, according to Ribeiro et al. (2012) [49] there is no proof of this statement, and in agreement, the present research also found results that show that most organic and conventional fruits have similar contents of Total, Reducing and Non-Reducing Sugars.

Before addressing the next variables raised by the present research, it is essential that there is an unfolding regarding the deleterious effect of free radicals, whose presence affects many physiological functions, and its formation occurs during cellular metabolism and exposures to external factors such as gamma and ultraviolet radiation, smoking, medications and diet, such as the consumption of a lot of fried food and refined foods (Bianchi and Antunes 1999; Vasconcelos et al. 2014) [7, 58]. The production of too many free radicals (oxidizing molecules) in relation to the amount of antioxidants, cause cell damage, and is called oxidative stress and can be associated with more than 50 diseases related to DNA damage and degenerative diseases, such as: heart disease, lung problems, atherosclerosis, cancers, Parkinson's, Alzheimer's, arthritis, brain dysfunction, diabetes mellitus, cataracts, aging, multiple sclerosis, chronic inflammation, and immune system diseases (Bianchi and Antunes 1999; Borguni 2006; Brazil 2014; Vasconcelos et al. 2014) [7, 10, 58].

Thus, the prevalence of defense mechanisms that inhibit and reduce cell damage caused by free radicals is very important to prevent such damage; these defense mechanisms are formed by antioxidant compounds, such as those raised by the present research: vitamin C, β-carotene, lycopene and Total and specific Phenolic Compounds: flavonoids, anthocyanins, chlorogenic and gallic acids (Bianchi and Antunes 1999; Borguini 2006; Maciel et al. 2011) [7, 34]. Fruits and vegetables have large amounts of these compounds and are linked to reducing the development of diseases caused by free radicals (Bianchi and Antunes 1999) [7].

Vitamin C, in addition to its antioxidant function, is very important for healing, defense against organic infections, collagen synthesis (existing in practically all body tissues), acting as a cofactor of enzymes, increasing photo protection and preventing scurvy, and in nature is found only in fruits and vegetables (Manela-Azulay et al. 2003; Yu et al. 2018) [36, 62]. Both fruits and vegetables, surveyed by the present research, had higher levels of vitamin C in their organic versions compared to conventional ones. One theory to explain this fact is that this result may be associated with nitrogen fertilizers from conventional agriculture and their high doses used, increasing protein production and decreasing carbohydrate production, and consequently, ascorbic acid (vitamin C) production, which depends on the carbohydrate to be formed (Petry et al. 2012; Silva et al. 2011) [44, 56].

On the other hand, Kazimierczak et al. (2014) [29], Guilherme et al. (2020) [25] and Mian et al. (2021) [29] state that the vitamin C content is higher in organic foods, due to the C/N ratio, where high fertilization with nitrogen (N) inhibits the formation of secondary metabolites that do not have nitrogen in their molecule, such as vitamin C, phenolic acids and flavonoids. Meanwhile, Moreira et al. (2003) [40] also point out that pesticides can affect the lability of vitamin C during food storage.

Other compounds that bring benefits to the human body in addition to antioxidants are bioactive compounds, which promote organic health and prevent diseases. Some examples of bioactive compounds can be observed in the present study, such as carotenoids and Total and specific Phenolic Compounds (flavonoids and anthocyanins) (Figueiredo and Carvalho, 2015) [20].

Bioactive compounds, in addition to having an antioxidant function, are also associated with helping to reduce weight, block the activity of viral or bacterial toxins, activate enzymes, inhibit cholesterol absorption, destroy harmful bacteria in the gastrointestinal tract and atherosclerosis reduction. The consumption of these components is important and there is a need to encourage greater dietary intake of them (Figueiredo and Carvalho, 2015) [20].

Addressing carotenoids, Yu et al. (2018) [62] observed higher levels of these compounds in organic foods compared to conventional foods. However, in relation to the levels of β-carotene and lycopene, the present research demonstrates similarity between organic and conventional fruits and vegetables.

Phenolic Compounds or Polyphenols are secondary metabolites produced by plants during their development or as a response to stress, and can be divided into flavonoids (anthocyanins, flavonols and isoflavones) and non-flavonoids (phenolic acids, such as chlorogenic and gallic acids). more than 8,000 phenolic compounds have already been identified (Pereira and Angelis-Pereira 2014) [42].

Phenolic Compounds are abundant in plant foods and are probably the richest antioxidants in the human diet. In addition to their antioxidant and bioactive function, they may also have antiallergic, antimicrobial, antithrombotic, anti-inflammatory and antiproliferative actions (Maciel et al. 2011; Basay et al. 2021) [24, 4]. Due to the benefits of phenolic compounds, it is important to search for foods with higher levels of them, which can be observed in organic foods (Hallmann and Rembialkowska 2012; Kazimierczak et al. 2015) [26, 28]. This is because the content of phenolic compounds in a food can be influenced by the cultivar, environment, soil type, growth and storage conditions, but also by the cultivation methods, organic or conventional (Luthria et al. 2012). The present research confirms this statement, since both the fruits and the organic vegetables surveyed had higher levels of Total Phenolic Compounds than the conventional ones. In relation to specific phenolic compounds, organic and conventional fruits and vegetables were similar.

There are many hypotheses to explain the higher levels of antioxidant and bioactive substances in organic foods. One of them is associated with the nitrogen sources used in the conventional model of production, which are not used in the organic model. According to this hypothesis, the type of nitrogen fertilizer used in conventional agriculture, due to its high solubility in water, makes this nutrient quickly and abundantly available to plants, which would direct the use of nitrogen and other substances in the plant metabolism, for plant growth, and not for the generation of other compounds (which do not have nitrogen in their composition), such as simple and complex sugars, and secondary metabolites such as organic acids, phenolic compounds, pigments and vitamins (Caris-Veyrat et al. al. 2004; Amodio et al. 2007; Hallmann and Rembialkowska 2012; Kazimierczak et al. 2015; Zahedipour et al. 2019; Basay et al. 2021) [14, 2, 26, 63, 4].

Another hypothesis is in relation to the stress that the organic plant undergoes, since due to the absence of pesticides, they need to defend themselves against insects, diseases and spontaneous plants, which would induce a greater production of defense substances, such as phenolics, which are present in plants associated with defense mechanisms and in scars, and their production can increase when they undergo stress (Carbonaro et al. 2002; Caris-Veyrat et al. 2004; Vinha et al. 2014; Farinazzo et al. 2018; Frias-Moreno et al. 2019; Zahedipour et al. 2019; Basay et al. 2021) [12, 14, 59, 63, 4]. Amodio et al. (2007) [2] and Zahedipour et al. (2019) [63], also emphasize that the application of insecticides, fungicides and herbicides affect the specific biosynthetic steps of these secondary metabolites, interrupting their production. Thus, as conventional plants are managed using synthetic nutrients and pesticides, over time, their natural defense mechanisms are expected to weaken, which contributes to lower plant resistance (Basay et al. 2021) [4].

In addition to nutrients, bioactive compounds and antioxidants, foods can have elements in their composition that can have harmful effects on human health, such as nitrates. When ingested, they can react with amines to form nitrosamines, carcinogens and mutagens that cause cancers of the digestive tract and leukemia. In addition, nitrates converted to nitrites can oxidize hemoglobin and cause methemoglobinemia, acute poisoning, and cancers (Silva et al. 2011; Yu et al. 2018; Golijan and Sečanski 2021) [56, 62, 24].

Worthington (2001) [61], Bourn and Prescott (2002) [9], Williams (2002) [60] and Yu et al. (2018) [62] observed that organic foods have lower levels of nitrates compared to conventional foods. The present research also observed that all the vegetables surveyed had lower levels of nitrates in their organic versions, however, as there were no foods in the other two groups, it was not possible to perform a statistical comparison of them. It is observed, then, that a higher percentage of fruits presented higher levels of vitamin C and Total Phenolic Compounds when grown organically; and a higher percentage of greens and vegetables had higher contents of Dry Matter, vitamin C and Total Phenolic Compounds also in their organic versions. All fruits presented similar pH levels and higher levels of Antioxidant Activity when submitted to the organic cultivation system; and all vegetables had lower levels of Nitrates in their organic versions compared to the conventional ones.

Thus, as no study found a nutritional inferiority of organic foods, it can be said that either organic food is nutritionally better compared to conventional food, as observed in the present study, or similar; either of the two options are characterized as extremely important findings, since food produced in a more sustainable way, with the absence of pesticides, in harmony with the environment and which respects social, cultural and human and animal health factors, is capable of generate products with nutritional quality at least similar to conventional foods. It is also important to emphasize that nutrition, and any diet, goes beyond the consumption and availability of food, it also goes beyond nutritional issues, encompassing healthier and more sustainable food production systems, since only the nutritional issue in isolation cannot provide all the necessary benefits for human, animal and environmental health (Lima and Vianello 2011; Ribeiro et al. 2017) [31, 48].

Conclusions

Organic foods showed higher levels of Dry Matter, antioxidant and bioactive compounds compared to conventional ones, demonstrating the very important need for further studies in the area, in addition to the elaboration of a complete table of the nutritional composition of organic foods, or a table addressing the nutrients that no longer generate more discussions about their changes in organic foods, as is the case with vitamin C.

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Disclosure statement

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Declaration of data availability

Data supporting the findings of this study are available from the corresponding author [C.M.] upon reasonable request.

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