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Research article

Are organics more nutritious than conventional foods? A comprehensive systematic review

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A R T I C L E I N F O

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Vegetables

A B S T R A C T

The growing consumer interest fueled by the belief in the superiority of organic foods raises questions about their actual nutritional superiority over conventional ones. This assumption remains a controversial issue. The present study addresses scientific evidence to clarify this controversy and provide relevant insights for informed decision-making regarding dietary choices. We collected 147 scientific articles containing 656 comparative analyses based on 1779 samples of 68 vegetable, fruit, and other (cereals, pulses, etc.) foods, 22 nutritional properties, and nine residues. Results show that in 191 (29.1%) comparisons, there were significant differences between organic and conventional foods. In a similar quantity of cases (190; 29.0%), there were divergences in the results since some studies reported significant differences while others did not. Finally, most of the comparative analyses (275; 41.9%) showed no significant difference between organic and conventional foods. Therefore, the results herein show no generalizable superiority of organic over conventional foods. Claims for nutritious advantages would eventually be applied to specific comparisons, depending on the food type and nutritional parameter.

1. Introduction

Eating habits have changed in recent decades in pursuit of a lifestyle considered healthier. Reasons for this change are diverse, including the impetus driven by concern over the increase in diseases resulting from inadequate nutrition and diets based on processed foods, which are high in fats, sugars, and sodium [1,2]. Health professionals and the food industry have proposed alternative dietary styles, such as vegan, vegetarian, and ketogenic diets [3–7]. Such diets, recognized as healthy, sensitize many consumers due to their

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role in digestive and immune health [8,9].

The scientific literature points to different definitions related to healthy foods and diets. However, there is a consensus that healthy foods should have, or be close to, high nutritional value, ideal levels of essential macro and micronutrients, low-fat content, and absence of preservative and additive residuals [10–12]. Furthermore, some trendy foods, fruits, and vegetables are related to healthy foods and a healthier lifestyle [13]. In this frame, organic foods have a special place [14], a reason why the production and consumption of organic foods have been growing in recent decades [14–19]. Furthermore, some evidence indicates that foods produced without agrochemicals and chemical or synthetic fertilizers might improve the nutritional quality of foods [20–23]. However, analyzing these data and conclusions in more depth is of general and scientific interest.

In this respect, some published evidence derives from subjective parameters, such as consumer perception regarding organic food consumption [24–27]. In such a situation, the main determinants of organic consumption identified by consumers are related to i) their understanding of the environmental impacts related to food production [28,29]; ii) perceived nutritional attributes [30,31]; and iii) the absence of agrochemical residues [32,33]. The consumers' perception regarding those determinants is grounded in the individual values and beliefs [34]. Beliefs and subjective object-related perceptions may directly influence food choice [35,36].

Fear and concerns are among the factors influencing the beliefs construction [37]. Therefore, these factors are also related to food choice. For example, worries about the possible undesirable health effects caused by agrochemical residues may lead consumers to prefer organic because they believe those foods are safer and, consequently, healthier [14,31,38–41]. However, some published studies have shown no evidence that organic foods are nutritionally superior to conventional foods [42,43].

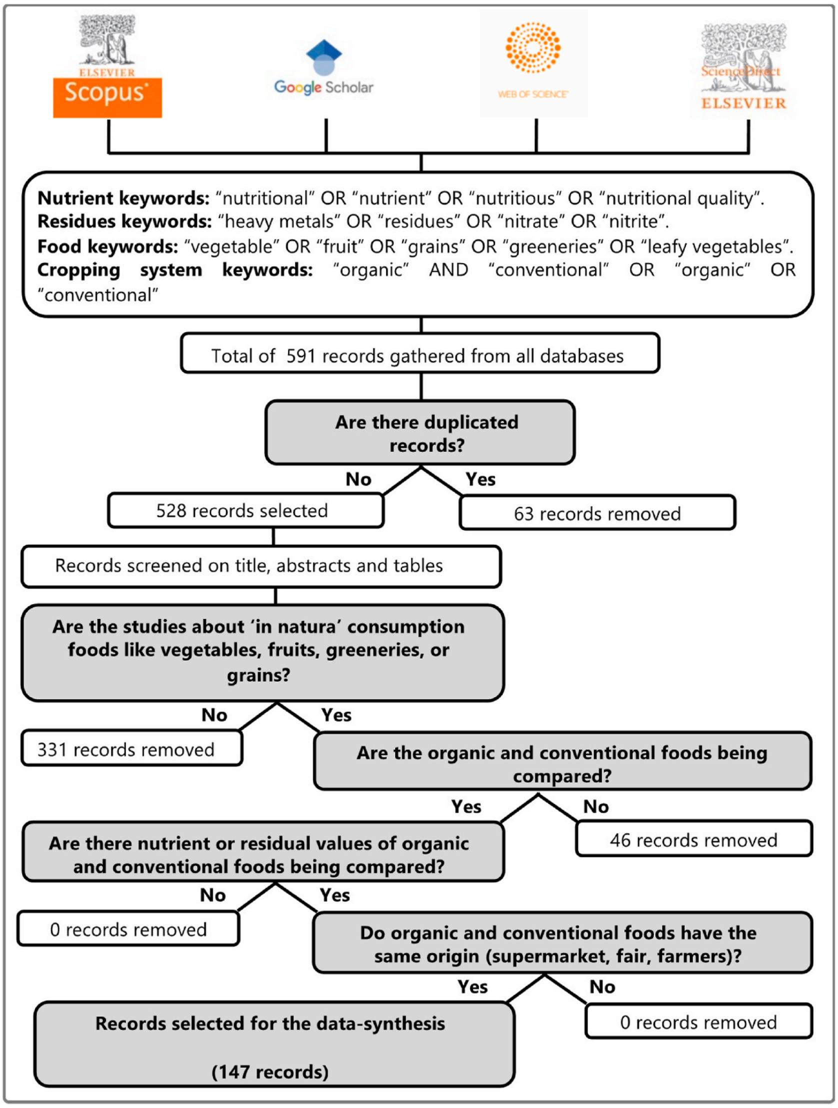

Fig. 1. Scientific literature search and screening process procedures.
Source: elaborated by the authors.

Given this backdrop, information about the nutritional superiority of organic or conventional foods remains controversial. Despite this, putative results and conclusions support advertising campaigns that inform or misinform consumers and induce them to think about the superiority of one kind of food – or the other [44,45]. Skewed practices lead to motivations based on in-vogue sense and subjective knowledge rather than supported by scientific evidence.

It is of scientific and public interest to align the consumer's perception of the nutritional superiority of organic or conventional foods with objective information produced by science. Several studies evaluate and compare organic and conventional foods using different nutritional and residual parameters [17,46–56]. While these studies provide relevant findings, to the best of our knowledge, there is no updated review on this topic, i.e., on organic and conventional foods, seeking to synthesize the scientific results regarding the nutritional values of these two types of food. The reviews close to this proposal refer to specific foods and nutritional parameters [36,40,41,55]. For example, the study carried out by Ref. [44] compares only the nutrients of organic and conventional tomatoes, while the analysis by Ref. [57] is restricted to 11 nutritional parameters of organic and conventional foods.

Therefore, it is relevant to gather scientific articles comparing organic and conventional foods' nutritional and residual parameters and synthesize the accumulated knowledge. In the present data synthesis, we address the answer to the following research questions: i) are there significant differences in nutritional and residual parameters between organic and conventional foods? ii) are organics nutritionally superior to conventional foods? Answering these questions is relevant for many reasons. First, by providing relevant information for consumers regarding the nutritional attributes of organic and conventional foods. Second, by presenting an updated set of results that can support new research avenues. Third, our findings help clarify the controversial debates about organic and conventional foods and their respective nutrients and residues. Therefore, the present study aims to synthesize scientific evidence confirming or refuting the nutritional superiority of organic foods over conventional foods.

2. Materials and methods

2.1. Search and data collection criteria

The scientific literature on measuring and comparing the nutritional properties of organic and conventional foods is abundant. However, this body of studies has generally compared specific nutritional or residual parameters and was restricted to some foods. Therefore, results from a limited set of studies do not allow for a general and consistent conclusion regarding a possible nutritional superiority and the absence of residues between organic and conventional foods. Then, an analysis broad in scope and restricted in terms of evidence and how to present the results is needed, addressing as many studies as possible comparing organic and conventional foods under various nutritional and residual parameters.

We performed a comprehensive search on the topic from February to July 2020. We used widely referenced scientific databases, including Google Scholar, Science Direct, Scopus, and Web of Science. In addition, the following keywords were combined in the query.

a) Nutritional parameter keywords: 'nutritional' OR 'nutrient' OR 'nutritious' OR 'nutritional quality.'
b) Residual parameter keywords: 'heavy metals' OR 'residues' OR 'nitrate' OR 'nitrite.'
c) Food keywords: 'vegetable' OR 'fruit' OR 'grains' OR 'greeneries' OR "leafy vegetables." and,
d) Cropping system keywords: "organic and conventional."

We consider studies published in the last three decades, from January 1990 to March 2020.

Fig. 1 shows the complete procedures used to identify and screen the literature and the criteria for deciding on the final inclusion or exclusion for the analysis.

The initial search retrieved 591 studies. After removing the duplicate studies, 528 remained for screening by analyzing the titles, abstracts, and results presented in tables. The following inclusion criteria were considered during the screening procedures: (i) studies concerning foods of vegetal origin and for fresh consumption; (ii) studies that quantitatively analyzed and compared the nutritional and residual parameters of foods grown in organic and conventional cropping systems based on laboratory analysis; (iii) studies based on controlled experiments in which foods were produced under organic and conventional cultivation standards and protocols, and studies in which samples of foods were obtained in supermarkets, fairs or directly from the farmers. None of the selected articles compared agrochemical residues, probably because using agrochemicals in organic farming is not allowed [22,23]. Thus, the residual parameters synthesized in the present study refer to heavy metals, nitrate, and nitrite.

Based on the criteria, we discarded 331 studies not following the scope of our analysis, such as studies on processed or ultra-processed foods, animal products, and duplicate comparisons that already appeared in another study. Therefore, 193 studies were shortlisted, of which 46 were removed based on the criteria set for screening. Finally, we reached the number of 147 studies that met the requirements. The list of selected studies used for data synthesis is available in Appendix A.

2.2. Data extraction and data synthesis

From the 147 selected articles, the following data and information were extracted and recorded: i) food: fruits (acerola, apple, banana, etc.), vegetables (arugula, broccoli, lettuce, etc.), and others (barley, bean, pea, etc.); ii) sample origin (experiment or market shelf); iii) nutritional or residual parameter; iv) mean value of the nutritional or residual parameter analyzed in each organic and conventional food sample; v) unit of measure of the analyzed nutritional and residual parameter (g/g, mg/g, etc.); and, vi) statistical significance of the difference between organic and conventional food for the nutritional or residual parameter under analysis (Fig. 2).

Statistical significance was used as a decision criterion for the presence or absence of nutritional and residual differences between organic and conventional foods for each nutrient and residue analyzed (See Appendix B). After extracting the information from the set of studies, 68 foods, 23 nutritional parameters, and nine residual parameters were identified. Some studies compared just one organic and conventional food, while others compared two or more. The same fact occurred for nutritional and residual properties.

Data were systematized and divided into food groups and parameters (Fig. 3). The foods were grouped according to the classification of the Food and Agriculture Organization of the United Nations [58] and the Brazilian Table of Food Composition [59], in which Group 1 relates to Fruits and derivatives; Group 2: Vegetables, root, tubers and derivatives, and Group 3: Cereals, pulses, seeds, nuts, and derivatives. Nutritional and residual parameters were divided into Macronutrients: carbohydrates, lipids, protein, total sugar, and fibers [59,60]; Micronutrients: vitamin C, Calcium (Ca), Copper (Cu), Iron (Fe), Magnesium (Mg), Manganese (Mn), Phosphor (P), Potassium (K), Sodium (Na), Sulfur (S) and Zinc (Zn) [59,60]; residuals (nitrate and nitrite) and the heavy metals Aluminum (Al), Arsenic (As), Cadmium (Cd), Chrome (Cr), Lead (Pb), Mercury (Hg) and Nickel (Ni); and d) Others: lycopene, β-carotene, total flavonoids, total phenolic acids, total polyphenols, and yield [59,60].

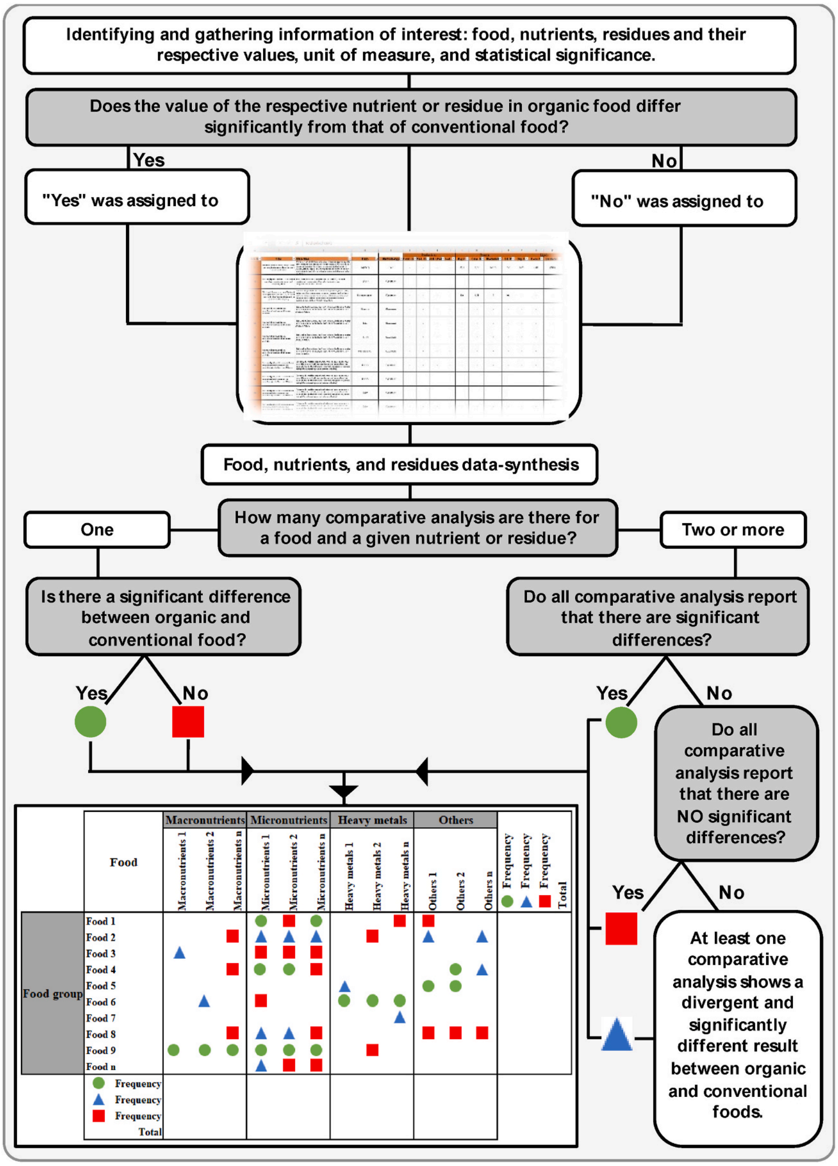

Fig. 2. Process of systematization of information extracted from the analyzed studies.
Source: elaborated by the authors.

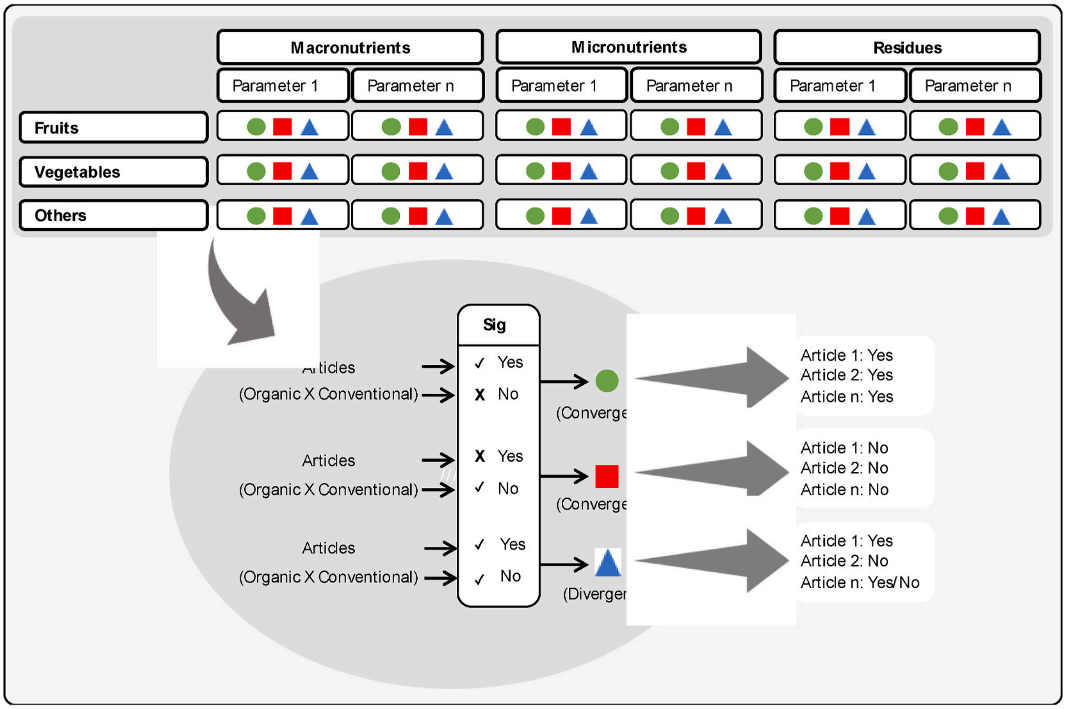

Fig. 3. Meaning of each symbol used in synthesizing the data. Note: Convergences: (fx1), all analyses showed significant differences; and (fx2), all analyses showed no significant differences. Divergence: (fx3), some results showed significant differences, while others did not.

2.2.1. Data synthesis

In systematic reviews that lack data amenable to meta-analysis, alternative synthesis methods are commonly used [61]. First, we intended to perform a meta-analysis using the data reported in the selected articles. However, particularities in the procedures and presentation of the data would make it impossible to include all selected articles. Alternatively, we resorted to data synthesis to ensure that we could use the information with the necessary accuracy to use all the comparisons between organic and conventional foods reported in the selected articles. Data synthesis has been widely used in many scientific areas, like environmental [62] and health sciences [63].

The variables belonging to the parameters were analyzed according to the statistical significance between organic and conventional foods, classified as 'Yes' when there was a significant difference and 'No' when there was no significant difference. We tabulated and analyzed all variables (more details in Appendix B and C).

In order to facilitate the visualization of the results, the categorization of the variables of each parameter and for each food was represented by the following symbols: a) green circle (fx1), when all the collected articles converge in showing a significant difference for a particular parameter of a specific food; b) red square (fx2), when all collected articles converge in showing no significant difference for a particular parameter of a specific food; and c) blue triangle (fx3), when all the collected articles showed divergence in the significant difference for a particular parameter of a specific food. For instance, some studies showed a significant difference, while others showed no significant difference for the same variable and food (Fig. 3).

The 'fx1' and 'fx2' symbols indicate convergence between the results, showing a consensus among the studies. The agreement may be related to the presence ('yes') or absence ('no') of nutritional or residual superiority between organic and conventional foods.

Table 1
Absolute frequency of individual food samples regarding the convergent and divergent results.

Food Group	Food Samples (n)	Convergence/Divergence			Total
		fx1	fx2	fx3	
Fruits	421	74	115	40	229
Vegetables	1020	93	104	116	313
Others	338	24	56	34	114
Total	**1779**	**191**	**275**	**190**	**656**

Note: fx1 = all articles converge in showing a significant difference for a particular parameter of a specific food; fx2 = all articles converge in showing no significant difference for a certain parameter of a specific food; and fx3 = all articles showed divergence in the significant difference for a certain parameter of a specific food.
Source: research data.

Conversely, the 'fx3' symbol indicates divergence between the results, meaning that not all studies reached the same conclusion regarding the presence or absence of superiority between organic and conventional foods - for a specific variable belonging to one of the parameters.

3. Results

From the 147 reviewed articles, 1779 laboratory samples of organic and conventional foods were identified regarding their respective nutritional and residue parameters. This figure corresponds to 432 fruit samples, 1020 vegetable samples, and 338 from other categories. These data, when synthesized, yielded 656 comparative analyses between organic and conventional foods. Not all analyses featured the same number of samples, owing to treatment variations and repetitions within the reviewed articles. Table 1 provides a detailed breakdown of sample quantities and comparisons among the food groups.

3.1. Convergence and divergence into food groups

The 'vegetables' group corresponds to 57.33% of the individual food samples, followed by the 'fruits' group (23.67%) and 'others' (19.00%). Regarding the synthesized data on convergence or divergence, the 'vegetables' group shares 47.71% of the total synthesized results, followed by 'fruits' (34.91%) and 'others' (17.38%) groups. On average, each 3.26, 2.96, and 1.84 individual food samples correspond to one synthesized data for the groups 'vegetables,' 'other,' and 'fruits,' respectively, illustrating the average comparisons reported in the articles examined.

In most synthesized situations (71.03%), there was convergence (fx1+fx2) among the reported findings. In 41.92% of the cases, there was no significant difference (fx2) for a certain nutritional or residual parameter when comparing a specific organic and conventional food. A significant difference (fx1) was found in only 29.11% of the cases. On the other hand, in 28.96% of the synthesized situations, there was a divergence (fx3) between the results. In this case, some studies reported a significant difference and others found no significant difference for a certain nutritional or residual parameter when comparing a specific organic and conventional

Table 2
Absolute and relative frequency of individual food samples by nutritional and residual parameters under a convergent or divergent situation.

Parameter	Variable	Absolute Frequency				Relative Frequency (%)			
		fx1	fx2	fx3	Total	fx1	fx2	fx3	Total
Macronutrients	Carbohydrates	11	16	0	27	40.74	59.26	0.00	100.0
	Lipids	5	5	13	23	21.74	21.74	56.52	100.0
	Protein	14	11	56	81	17.28	13.58	69.14	100.0
	Total Sugar	4	16	26	46	8.70	34.78	56.52	100.0
	Total Fibers	7	4	6	17	41.18	23.53	35.29	100.0
	Total	**41**	**52**	**101**	**194**	**21.10**	**26.80**	**52.10**	**100.0**
Micronutrients	Vitamin C	21	6	36	63	33.33	9.52	57.14	100.0
	Calcium (Ca)	11	30	71	112	9.82	26.79	63.39	100.0
	Copper (Cu)	7	30	66	103	6.80	29.13	64.08	100.0
	Iron (Fe)	5	34	63	102	4.90	33.33	61.76	100.0
	Magnesium (Mg)	13	11	91	115	11.30	9.57	79.13	100.0
	Manganese (Mn)	16	25	40	81	19.75	30.86	49.38	100.0
	Phosphorus (P)	12	20	62	94	12.77	21.28	65.96	100.0
	Potassium (K)	12	16	93	121	9.92	13.22	76.86	100.0
	Sodium (Na)	9	18	37	64	14.06	28.13	57.81	100.0
	Sulfur (S)	6	21	2	29	20.69	72.41	6.90	100.0
	Zinc (Zn)	9	28	79	116	7.76	24.14	68.10	100.0
	Total	**121**	**239**	**640**	**1000**	**12.10**	**23.90**	**64.00**	**100.0**
Heavy metals, nitrite, and nitrate	Aluminum (Al)	4	3	0	7	57.14	42.86	0.00	100.0
	Arsenic (Ar)	2	1	0	3	66.67	33.33	0.00	100.0
	Cadmium (Cd)	5	18	38	61	8.20	29.50	62.30	100.0
	Chrome (Cr)	7	15	8	30	23.33	50.00	26.67	100.0
	Lead (Pb)	3	22	21	46	6.52	47.83	45.65	100.0
	Mercury (Hg)	1	2	0	3	33.33	66.67	0.00	100.0
	Nickel (Ni)	5	26	12	43	11.63	60.47	27.91	100.0
	Nitrate	27	12	44	83	32.53	14.46	53.01	100.0
	Nitrite	8	5	0	13	61.54	38.46	0.00	100.0
	Total	**62**	**104**	**123**	**289**	**21.45**	**35.99**	**42.56**	**100.0**
Others	Lycopene	4	2	33	39	10.26	5.13	84.62	100.0
	β-carotene	12	7	45	64	18.75	10.94	70.31	100.0
	Flavonoids	13	13	17	43	30.23	30.23	39.53	100.0
	Phenolic Acids	24	13	50	87	27.58	14.94	57.48	100.0
	Polyphenols	9	5	32	46	19.57	10.87	69.57	100.0
	Yield	5	2	10	17	29.41	11.76	58.82	100.0
	Total	**67**	**42**	**187**	**296**	**22.63**	**14.19**	**63.18**	**100.0**
Total		**291**	**437**	**1051**	**1779**	**16.36**	**24.56**	**59.08**	**100.0**

Source: research data.

food. Most of the food samples from the ‘fruits’ and ‘others’ groups were synthesized under a convergent (fx2) situation with 50.21% and 49.12%, respectively. As for the ‘vegetables’ group, most of the samples (37.06%) were synthesized under the divergent (fx3) category.

The situations of convergence and divergence among the studies were synthesized based on the characteristics of the samples and laboratory analyses whose results were extracted from the reviewed articles. Table 2 shows the absolute and relative frequency with which the samples occurred, considering the nutritional or residual parameters and the convergence/divergence situation associated with them. The first column lists the macronutrients, micronutrients, heavy metal residues, nitrite and nitrate, and others as a group of parameters. The second column lists the nutrients compared within each parameter. The other columns show the absolute and relative frequency of convergence/divergence according to data extracted from the systematic literature review.

The absolute frequency corresponds to the number of comparisons that did or did not show significant differences (convergence/divergence). For example, in the ‘macronutrients’ parameter, the protein variable showed 14 significant differences (fx1) in the protein value between organic and conventional foods; in 11 comparisons, the protein value showed no differences (fx2), and in 56 comparisons, there was at least one sample showing a significant difference in the protein value of organic and conventional foods (fx3). The relative frequency shows that in 64.19% of the comparisons, there was a difference in the protein value of organic and conventional foods; in only 17.28% of the comparisons, there were significant differences.

The results show substantial differences in the frequency of individual samples between the groups of nutritional parameters. ‘Micronutrients’ comprised most of the nutritional parameters analyzed in food samples (56.21%), followed by ‘others’ (16.64%), ‘heavy metals, nitrite, and nitrate’ (16.25%), and ‘macronutrients’ (10.90%) parameters.

Carbohydrates is the only macronutrient for which there was convergence in all the pairs of samples analyzed. Most comparisons (59.26%) showed no significant differences in the amount of carbohydrates in organic and conventional foods, compared to 40.74% that found statistically significant differences. However, for all parameters, the highest frequency was for divergence (fx3); some studies have reported results favoring organic foods, while others found better outcomes for conventional foods when comparing the same parameter in the same food item.

Among the ’micronutrients,’ magnesium showed divergence in 79.13% of the comparisons of pairs of samples, followed by potassium (76.86%), calcium (63.39%), and iron (61.76%). The findings suggest that these micronutrients seem more sensitive to variables other than the cultivation system (organic or conventional).

However, parameters belonging to ‘Heavy Metals, nitrate, and nitrite,’ although the second most frequent in variety, have been scarcely considered and need further comparative studies, especially for Hg (3), Ar (3), and Al (7). Except for carbohydrates, Al, Ar, Hg, and nitrite, which only presented convergence (fx1 or fx2) for a given organic and conventional food, all other parameters were convergent (fx1 and fx2) and divergent (fx3), depending on the studies. So far, there is a scientific consensus regarding carbohydrates, Al, Ar, Hg, and nitrite for some specific foods when comparing organic and conventional ones.

Higher frequencies of divergent situations between pairs of samples can also be observed in the ’other’ parameters. The three most prominent nutritional variables are lycopene, β-carotene and polyphenols, where 84.62%, 70.31%, and 69.57% of the pairs of samples did not reach a consensus on the nutritional superiority of organic or conventional foods, respectively.

The debate on whether organic or conventional foods are superior in nutrition is ongoing. In fact, out of the pairs of samples analyzed, 59.08% showed a divergence in nutritional parameters, meaning there was disagreement on which type of food was better. On the other hand, 24.56% of the pairs showed convergence, suggesting no significant differences were found between organic and

FRUITS	Macronutrients					Micronutrients											Heavy Metals									Others													
	Carbohydrates	Lipids	Protein	Total Sugar	Total Fibers	Vitamin C	Calcium	Copper	Iron	Magnesium	Manganese	Phosphorus	Potassium	Sodium	Sulfur	Zinc	Aluminum	Arsenic	Cadmium	Chrome	Lead	Mercury	Nickel	Nitrate	Nitrite	Lycopene	ß-carotene	Flavonoids	Phenolic Acids	Polyphenols	Yield	Frequency ●	Frequency ▲	Frequency ■	Total	Frequency ●	Frequency ▲	Frequency ■	**Total**
Acerola							●1	■1	●1	■1	●1	■1	■1	■1		■1				■1							●1					4	0	7	11				
Apple			■1	●1			▲12	▲4	▲4	▲12	▲4	▲12	▲12	▲4	●1	▲6			■2		■1		●1	■2				▲4	■3	■2	●2	4	10	6	20				
Banana							■3	■1	■1	■3	■1	▲2	■3	■1		■1												■1				0	1	9	10				
Blackcurrant			■1	■1			●1	●1	■1	●1	■1	●1	■1	●1	■1	●1			●1		■1		●1	■2						■1		8	0	9	17				
Blueberry																												■4	●1			1	0	1	2				
Courgette						■1																					▲3	▲4	■1	■1		0	2	3	5				
Cranberry																												■1	■1	■1		0	0	3	3				
Eggplant																													▲2			0	1	0	1				
Goji Berry	●1	●1	●1	●1	●1		●1	●1	●1	●1	●1	●1	●1	●1		●1			■1		●1	●1										16	0	1	17				
Grape				▲3			▲3	■3	■3	▲3	▲3	■3	▲4	■3		■3										●3	▲10	■1	■1	▲9		1	7	7	15				
Jujube			●1				■1	■1	■1	■1	■1		■1			■1												■1	■1			1	0	9	10				
Kiwifruit	●1	■1	■1			■2	▲3	■1	■1	▲3	■1	▲3	▲3	■1	●2	■1													●2			3	4	8	15	74	40	115	**229**
Mandarin Juice						▲2	●2	▲2	▲2	●2	●2		●2	●2		●2																6	3	0	9	(32.3)	(17.5)	(50.2)	**(100.0)**
Mango							■1	■1	■1	●1	■1	■1	●1	■1		■1				●1												3	0	7	10				
Olive																											●2	■1	▲5			1	1	1	3				
Orange						●3	▲3			●2		■2	▲3																			2	2	1	5				
Passion fruit																										●1	●1					2	0	0	2				
Peach																													●1	●1		2	0	0	2				
Pear			■2	■2			■1	■1	■1	●1	■1	■1	■1	■1	■1	■1			■1		■1		■1	■2					●1	●3		3	0	15	18				
Persimmon							■1	●1	■1	●1	■1	●1	●1	●1		●1				■1						■1	■1					6	0	6	12				
Plum		■1	■1	■1	■1		■1	●1	■1	●1	■1	■1	●1	●1		●1											■1					5	0	9	14				
Prunes																												●1	●1	●1		3	0	0	3				
Strawberrie	●2	▲2	▲2	■1		■2	■4	▲3	▲3	▲4	■1	▲2	▲4	■2		■4				■1			■1	●1			▲2	■1	▲5	■1		2	9	10	21				
Zucchini			■1									■1	●1											■1								1	0	3	4				
● Frequency	3	1	2	2	1	1	4	4	2	8	3	3	6	5	2	5	0	0	1	1	1	1	2	1	0	2	3	1	5	3	1	**74**							
▲ Frequency	0	1	1	1	0	1	4	3	3	4	2	4	5	1	0	1	0	0	0	0	0	0	0	0	0	0	3	2	3	1	0		**40**						
■ Frequency	0	2	6	4	1	3	7	7	9	3	9	7	5	7	2	8	0	0	3	3	3	0	2	4	0	1	2	7	5	5	0			**115**					
Total	3	4	9	7	2	5	15	14	14	15	14	14	16	13	4	14	0	0	4	4	4	1	4	5	0	3	8	10	13	9	1				**229**	**(32.3)**			
● Frequency	9 (36.0)					43 31.2)											6 (35.3)							1 (25.5)		15 (34.0)									**(32.3)**	**74**	**(17.5)**		
▲ Frequency	3 (12.0)					28 (20.3)											0 (0.0)							0 (0.0)		9 (20.5)										**(17.5)**	**40**	**(50.2)**	
■ Frequency	13 (52.0)					67 (48.5)											11 (64.7)							4 (50.0)		20 (45.5)											**(50.2)**	**115**	**(100.0)**
Total	**25 (100.0)**					**138 (100.0)**											**17 (100.0)**							**5 (100.0)**		**44 (100.0)**												**(100.0)**	**229**

Fig. 4. Frequency of individual samples (numbers) and synthesized convergence/divergence situations (graphical elements) comparing nutritional and residual parameters of organic and conventional **fruits**.
Source: elaborated by the authors based on research data.

conventional. It was found that higher nutritional values were present in only 16.36% of the pairs of samples analyzed, whether organic or conventional.

3.1.1. *Fruits*

The fruit group comprises 24 foods, 421 individual samples, and 229 synthesized convergence/divergence situations. In most synthesized situations (50.22%), studies were convergent to say no significant difference exists between organic and conventional foods for a parameter evaluated (fx2). The convergence in the opposite direction was found in 32.31% of synthesized situations; depending on the type of fruit and the nutritional parameter being compared, studies converge there is a significant difference (fx1) between organic and conventional foods. In a smaller set of synthesized situations (17.47%), the scientific evidence is divergent (fx3) regarding the existence or not of a significant difference between organic and conventional foods; for a given fruit and specific nutritional parameter, for instance, some studies reported ‘yes’ and other ‘no’ differences.

The most compared fruits were apple, grape, and strawberry, with 90, 55, and 48 individual samples and 20, 15, and 21 synthesized convergence/divergence situations, respectively (see Fig. 4). Conversely, fruits like pear, blackcurrant, and goji berry were less frequently compared with 23, 18, and 17 individual samples and 18, 17, and 17 synthesized situations, respectively. These fruits presented a higher rate of synthesized situation per number of unique food samples compared to grapes, for instance, meaning that in grape-related studies, there are more samples involved in a synthesized situation.

Except for flavonoids and phenolic acids, for which only one study (one individual sample) compared organic and conventional grapes, all other variables in the literature presented three studies or more. For example, the opposite situation happened with the pear, in which some convergence/divergence was synthesized based only on one study (e.g., results for Ca, P, and K parameters). The most analyzed parameters are micronutrients, namely potassium, calcium, magnesium, and phosphorus, with 40, 38, 37, and 32 individual samples and 16, 15, 15, and 14 synthesized samples, respectively.

3.1.2. *Vegetables*

The vegetable group comprises 33 foods, 1020 individual samples, and 313 convergence/divergency syntheses. The number of synthesized situations in vegetables varied less among the convergent and divergent situations (fx1 29.71%; fx2 33.22%, and fx3 37.06%) than in fruits. Most of the individual food samples (62.93%) are convergent regarding significant differences in nutritional or residual parameters when comparing organic and conventional vegetables (fx1 = ‘yes’ + fx2 = ‘no’).

Tomato, potato, lettuce, carrot, and pepper with 275, 160, 94, 93, and 65 individual samples and 28, 24, 25, 29, and 19 convergence/divergence synthesized situations, respectively, were the most analyzed vegetables (see Fig. 5). On the other hand, endive, bell pepper, buckwheat, chickpea, and jambu plant were the less compared vegetables, with only one to three individual samples and convergence or divergence situation synthesized.

Micronutrients were most frequently parameters in comparing organic and conventional vegetables, mainly K, Mg, and Cu, with 59, 57, and 55 individual food samples and 16, 12, and 15 synthesized convergence/divergence situations, respectively. However,

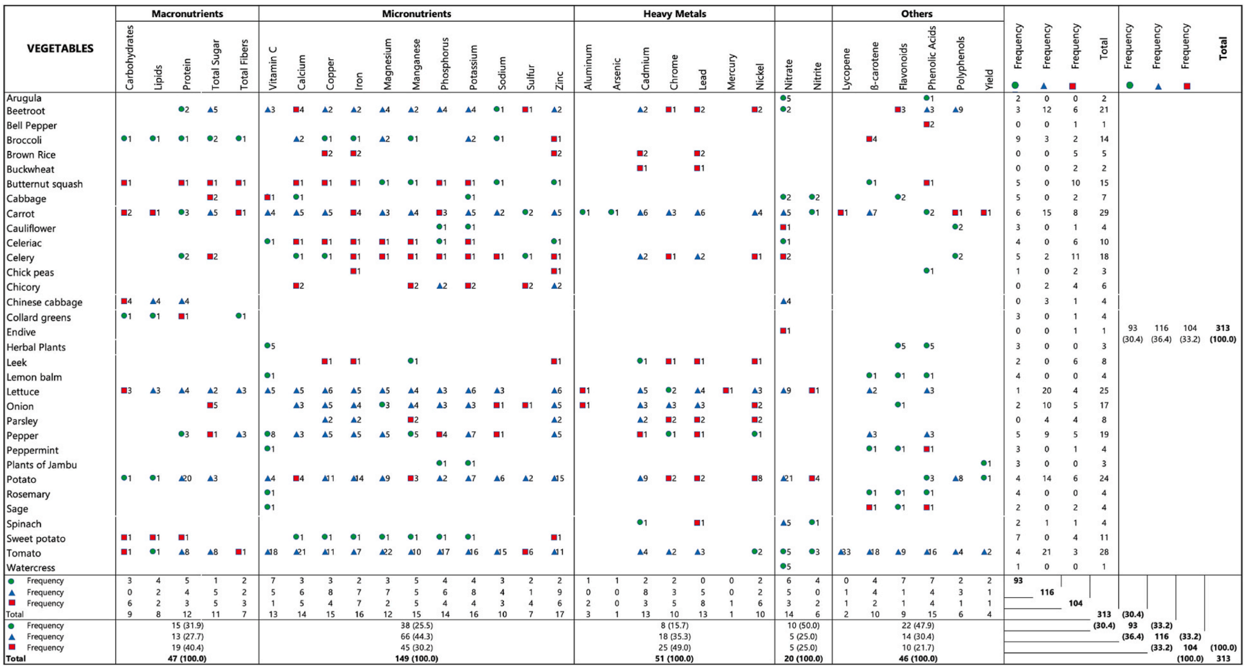

Fig. 5. Frequency of individual samples (numbers) and synthesized convergence/divergence situations (graphical elements) comparing nutritional and residual parameters of organic and conventional vegetables. Source: elaborated by the authors based on research data.

protein, belonging to the 'macronutrients' parameters, with 50 individual samples and 12 synthesized situations, and nitrate, with 68 individual samples and 14 synthesized situations, also presented an expressive number of comparisons.

3.1.3. Others

The 'others' group comprises cereals, legumes, seeds/grains, and other non-fruit and non-vegetable foods. The 'others' group shall include 11 foods, 338 individual samples, and 114 convergence/divergence syntheses. Most syntheses (49.12%) showed no significant difference between organic and conventional foods (fx2) regarding the evaluated nutritional or residual parameters. Divergent situations (fx3) with 29.82% ranked second, followed by situations converging to a significant difference (fx1; 21.05%) between organic and conventional foods.

'Others' most frequently analyzed foods were wheat, rice, cashew nuts, and beans, with 133, 42, 36, and 31 individual samples and 20, 19, 9, and 16 synthesized convergence/divergence situations, respectively (see Fig. 6). However, in the specific case of peas, the number of synthesized situations (10) was greater than that of cashew nuts and with fewer individual samples (10). Therefore, for instance, in the case of cashew nuts, a convergence or divergence situation was synthesized based on a larger number of samples. Unlike peas, where each synthesized situation had only one sample, all parameters reported in the literature for cashew nuts had four samples.

Micronutrients were the most frequently analyzed nutritional parameters in the 'others' foods. Zinc, iron, copper, and potassium with 29, 28, 26, and 22 individual samples and 9, 9, 8, and 6 synthesized situations were the most compared in other organic and conventional foods.

3.2. Nutritional and residual superiority

The syntheses denoted by 'fx1' indicate convergence among scientific studies in reporting a significant difference in the values of nutritional or residual parameters of a specific food, agreeing on the superior performance of organic against conventional or vice versa. We found more convergent situations in the 'vegetables' group, with 151 individual samples, followed by the 'fruit' groups, with 92 individual samples, and the 'others' with 48 individual samples. However, the pattern changes among the groups. While superior values in the macronutrient parameters were found in 80% of the individual samples of conventional 'fruits,' 68.2% of the individual samples converged to show superior macronutrient values for organic 'vegetables' (see Fig. 7).

The articles examined pairs of fruit and vegetable samples, focusing on micronutrient analysis. Out of 53 pairs of fruit, 75.47% showed organic products to be nutritionally superior in some micronutrients, while 24.53% showed conventional products to be superior. A similar trend was observed in vegetables, where 73.21% of 56 analyses indicated organic food's nutritional superiority compared to 26.79% for conventional food. However, in the 'other' category, 53.85% of the 13 pairs of samples showed the nutritional superiority of organic food over conventional food, while 38.46% showed the superiority of conventional food over organic food.

Among the micronutrients analyzed in fruit and vegetables grown in organic and conventional systems, higher levels of vitamin C, magnesium, and potassium were found in organic products. On the other hand, a significant difference was found in the manganese content, favoring the vegetables grown in the conventional system.

Heavy metals, nitrite, and nitrate residual parameters were higher in 71.4% and 67.56% of the individual samples of conventional fruits and vegetables, respectively. On the other hand, the values associated with the other parameters, such as lycopene, flavonoids, etc., were higher in 55.6% of the individual organic food samples.

Our findings indicate that the nutritional superiority of organic foods over conventional foods, or vice versa, depends on the type of food and the nutritional/residual parameter being compared. For example, there is a convergence among studies that carbohydrate levels are higher in goji berries and strawberries produced in conventional systems versus those produced in organic systems. On the other hand, when the levels of carbohydrates present in kiwifruit are analyzed, the analyzed articles report that the values found in organic kiwifruit are higher than those grown in conventional systems. Similar behavior was seen for the other parameters of macro and micronutrients, heavy metals, nitrite, nitrate, and others (See Appendix D for details).

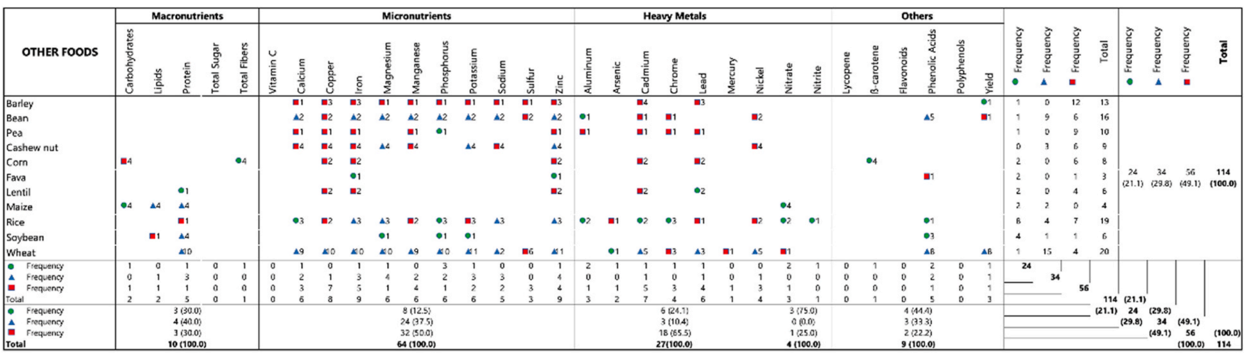

Fig. 6. Frequency of individual samples (numbers) and synthesized convergence/divergence situations (graphical elements) comparing nutritional and residual parameters in 'others' organic and conventional foods. Source: elaborated by the authors based on research data.

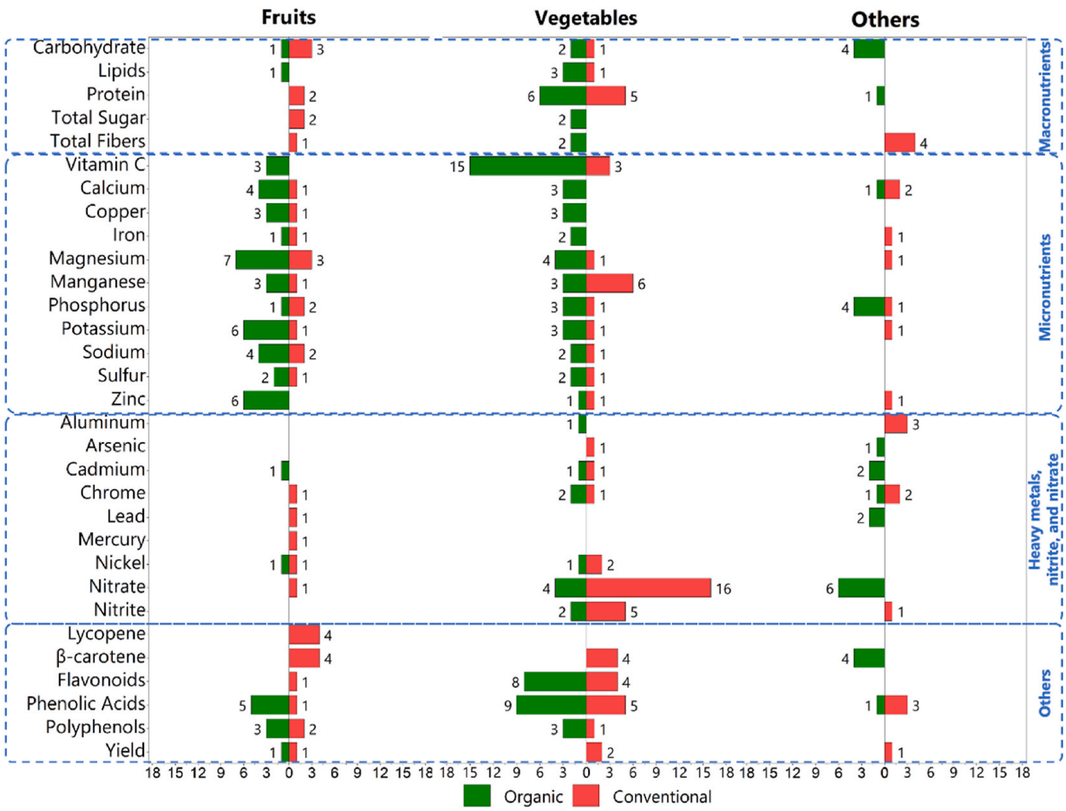

Fig. 7. Comparing the nutritional and residual superiority between groups of organic and conventional fruits, vegetables, and others. Source: elaborated by the authors based on research data presented in Figs. 4–6.

3.3. *Association between syntheses (fx2, fx1, andfx3) and food groups*

A Chi-square test was performed to statistically substantiate the synthesized results. The Chi-square parameters show an association between ratings (fx2, fx1, andfx3) and food groups (fruits, vegetables, and others) [$\chi^2(4) = 31.91$, $p < 0.001$] (Table 3). This association is due to i) studies that diverged in their results between organic and conventional 'fruits' and 'vegetables,' ii) studies that converged in reporting a significant difference between 'other' organic and conventional foods, and iii) studies that converged in

Table 3
Chi-square test comparing convergence/divergence syntheses among food groups.

Group	Description	fx2	fx1	fx3	fx2+fx1+fx3
Fruits	Observed frequency	115.00	74.00	40.00	229
	Expected frequency	95.93	66.04	66.04	229
	Adjusted Residue	3.17	1.26	−4.71	
Vegetables	Observed frequency	104.00	93.00	116.00	313
	Expected frequency	131.69	90.66	90.66	313
	Adjusted Residue	−4.38	0.40	4.37	
Others	Observed frequency	56.00	24.00	34.00	114
	Expected frequency	48.38	33.31	33.31	114
	Adjusted Residue	1.79	−2.11	0.16	

Test	Value	df	Sig*
Qui-square	31.91	4	0.000
Phi	0.221		0.000
N of valid cases	656		

Note: *Chi-square test at the significance level of $p < 0.001$.
We can assess the significance between the observed values comprising the data extracted from scientific studies and the expected values for each category. Residual values between −1.96 and 1.96 (−1.96 ≤ Adjusted residuals ≤1.96) do not indicate a significant difference between the expected and observed frequency. Thus, we observed a significant difference in the 'fruits' and 'vegetables' group for the fx3 and fx2 syntheses and in the 'others' group for the fx1 syntheses. For example, the group of vegetables has a lower tendency to show divergence (fx3) than convergence (fx2) in the value of the nutritional and residual parameters when comparing organic and conventional foods.

reporting a significant difference between organic and conventional 'fruits' and 'vegetables.'

4. Discussion

The organic food production system avoids using synthetic fertilizers, pesticides, and genetically modified organisms [26]. Instead, organic agriculture relies primarily on crop rotation, nitrogen-fixing plants, and organic fertilizers to maintain soil crop yields and pest control. Like conventional foods, organic foods must meet food safety requirements, and, in order to maintain an organic label, organic farmers must produce under organic norms and regulations [64]. Organic regulations may vary between countries, and no universal reference standard exists in Ref. [65]. It is important to note that the organic labels only indicate that a specific product was produced or prepared according to some guidelines; it is not related to the final and intrinsic attributes of the product. This remark is important as organic foods are routinely promoted for their ultimate characteristics, using the organic label as supposed proof of nutritional superiority and free of residues.

It is important to highlight that studies have been significantly focused on comparing micronutrients between organic and conventional foods, reflecting the growing interest in nutritional quality. Micronutrients, such as vitamins and minerals, are essential for the proper functioning of the body and directly impact health [66]. Among the micronutrients frequently studied in fruits and vegetables, vitamin C stands out as an antioxidant found in citrus fruits and leafy greens [67]. Conversely, magnesium in leafy green vegetables, nuts, and seeds plays a crucial role in muscle function and bone health [68]. Meanwhile, manganese in fruits like pineapple and leafy green vegetables is essential for metabolism and bone formation [69].

Regular intake of fruits and vegetables has been associated with a reduced risk of various chronic diseases, including, among others, cardiovascular disease, diabetes, and certain types of cancer [8,70–74]. This benefit is attributed to the abundance of bioactive compounds present in these foods, such as polyphenols, vitamin C, and carotenoids. These bioactive compounds are crucial in neutralizing free radicals and protecting the body against oxidative damage [8,9]. The results of our research highlight vitamin C as one of the main components under analysis, revealing a notable difference in concentration between organic and conventional foods. The analysis of 21 comparisons indicated a predominance of 85.71% higher vitamin C content in organic compared to 14.3% in conventional (Fig. 7). On the other hand, lycopene and β-carotene were 100% higher in fruits and vegetables grown in the conventional system (Fig. 7). The nutritional content of food can be affected by various variables such as soil type, cultivation method, soil cover, and organic production system maturity, and even season, farmer to farmer or year to year [71–73]. These findings highlight that both types of food have potential health benefits for consumers.

Therefore, it is essential to emphasize that food quality plays a pivotal role in microbiota health and promoting a conducive intestinal environment for probiotics [75,76]. Both organic and conventional foods can contribute to diet quality, provided they are adequately produced, processed, and prepared. Fresh foods, abundant in fiber, nutrients, and low chemical additives, are critical for maintaining intestinal microbiota balance [77,78]. A diet rich in fruits and vegetables supplies substrates for the growth of beneficial bacteria in the gut, whereas processed and ultra-processed foods, high in saturated fats, sugars, and additives, can hinder microbiota diversity and inhibit probiotic growth [76].

Food quality extends beyond the choice between organic and conventional, encompassing the entire production process from cultivation to the consumer's table. Organic farming, grounded in sustainable practices and the reduction of synthetic pesticides, can offer foods with lower residue levels [79,80]. However, conventional production can also adhere to stringent food safety regulations. Hence, diet quality hinges on consumer awareness, the selection of minimally processed foods, and a preference for trustworthy, healthy products, irrespective of organic or conventional labels. Maintaining a balanced and diversified diet, focusing on food quality, is paramount for the health of intestinal microbiota and support for probiotics in the digestive system.

Currently, consumers are concerned about the food they consume [81,82]. Food scandals and the widely publicized controversy over genetically modified organisms may have contributed to a growing search for alternative foods considered safer than conventional ones. Food crises such as Bovine Spongiform Encephalopathy (mad cow disease), H5N1 (bird flu), and H1N1 (swine flu) have sensitized consumers about food quality and safety [83,84]. These scandals aided the ever-increasing demand for organic foods, arising from the perception that organic foods are safer than conventional ones [11,85].

The pro-organic movement is grounded in the belief that organic food is free of agrochemicals, nitrates, or other residual contaminants, creating the acceptance that organics are superior and practically free of dangers [85]. However, some studies have indicated higher nitrate levels in organic foods compared to conventional foods, mainly in vegetables [50,86–90] (Fig. 7). The consumers' belief that organic food is a safer alternative is not supported by science due to the lack of consistent scientific evidence for generalizing such superiority [91].

In the present study, such a statement can be corroborated by i) the divergences reported in scientific studies comparing nutritional and residual parameters of organic and conventional foods (fx3); ii) the convergences between scientists reporting results that indicate the absence of significant differences between organic and conventional foods regarding specific foods and parameters (fx2); and iii) the convergence of scientific findings pointing to a significant difference between organic and conventional foods regarding specific foods and parameters (fx1). Therefore, science does not support the claim for nutritional and residual superiority on the part of organic foods. Sometimes, a particular organic food is nutritionally superior in a specific parameter, in others, the same food grown in a conventional system is superior in another parameter (Figs. 4–6).

Thus, some specific claims can be made. For example, conventional potatoes have a higher carbohydrate (macronutrient) content than organic potatoes [92]. On the other hand, organic broccoli has a higher carbohydrate (macronutrient) content than conventional broccoli [93]. Organic carrots have a higher aluminum content (heavy metals) than conventional carrots [17]. Meanwhile, conventional rice has a higher aluminum content (heavy metals) than organic rice [94]. So, it is necessary to be specific and not generalist when comparing organic and conventional foods' nutritional and residual values. The results vary depending on foods and parameters (nutrients or residues), as statistically evidenced in Table 3. Therefore, the alleged superiority is not generalizable and will depend on the food and the parameter being compared, evidence that aligns with the conclusion of other studies, such as in Refs. [93–95].

5. Conclusions

The prevalence of subjectivity of personal convictions, based on emotions and beliefs, compared to objective knowledge (derived from verifiable scientific evidence), can produce contradictory information regarding the nutritional and residual content in organic and conventional foods. Contradicting information can cause confusion and misunderstandings for consumers. However, our findings show that the generalizations are debatable, and strong statements linking organic foods to a synonym for superior foods need to be considered more.

Based on the findings of our data synthesis, we can conclude that.

a. It was not possible to identify a generalized superiority of organic foods over conventional ones, nor of conventional foods over organics.
b. Superiority claims can only be made for specific comparisons, depending on the food and the nutritional or residual parameter.
c. A particular organic food may be superior in a given nutrient or residue and inferior in another compared to its conventional equivalent.
d. Specific organic foods may also have a higher content of certain heavy metals than their conventional counterpart.

Therefore, if a belief in the nutritional superiority of organic foods over conventional foods is established among consumers, such a belief can only be grounded in subjective knowledge.

Limitations of the study and future research

The present study has some limitations that can be addressed in future research. First is the difficulty in gathering homogeneous data to apply more sophisticated statistical analysis that could support the analyses and conclusions. Future research may employ a meta-analysis to review, improving the understanding of differences between organic and conventional foods. Second, our analysis compared the nutritional values of foods produced under organic and conventional systems. Future research may consider other types of production systems, for example, the hydroponic system. Our research aimed to determine whether there is a nutritional and residual difference between organic and conventional food systems. Future studies could examine the environmental impact associated with the nutritional content of both farming methods. Another area for improvement is the keywords used in the query; although comprehensive, some scientific articles may have been excluded from the data synthesis.

Data availability statement

Data are included or referenced in the article or available in the supplementary material.

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CRediT authorship contribution statement

Daiane Thaise de Oliveira Faoro: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Felipe Dalzotto Artuzo:** Writing – review & editing, Validation, Methodology, Formal analysis, Conceptualization. **João Augusto Rossi Borges:** Writing – review & editing, Supervision, Formal analysis, Conceptualization. **Cristian Rogério Foguesatto:** Writing – review & editing, Formal analysis. **Homero Dewes:** Writing – review & editing, Formal analysis. **Edson Talamini:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Methodology, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e28288.

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