Journal of Food Composition and Analysis 100 (2021) 103922

Contents lists available at ScienceDirect

Journal of Food Composition and Analysis

journal homepage: www.elsevier.com/locate/jfca

Critical Review

Comparison of major nutrients and minerals between organic and conventional tomatoes. A review

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ARTICLE INFO

Keywords:
Ascorbic acid
β-carotene
Lycopene
Minerals
Nutritional quality
Lycopersicon esculentum Mill.

ABSTRACT

Consumers have considered organic crops more beneficial to health and the environment as opposed to conventional crops. The following review aims to compare the major nutrients and mineral content in organic and conventional tomatoes. As such, articles related to the comparison of organic and conventional tomato crops were selected, as well as articles in which nutrient and/or mineral content were determined. Four research groups were formed based on their hypotheses. The quality of each study was evaluated considering the statistical tools used to determine the results' significance. Result ranges were compared to analyze the variation in the individual nutrient and mineral content in each study. No objective evidence was found that organic crops are nutritionally better than conventional crops; in both cases, results were within similar ranges. For conventional and organic tomatoes (fresh weight), the respective concentration ranges were 1.00–63.8 mg/100 g and 10.7–40.0 mg/100 g for ascorbic acid, 0.02–337.0 mg/100 g and 0.44–422 mg/100 g for lycopene, and 0.0058–4.44 mg/100 g and 0.0061–3.90 mg/100 g for β-carotene. For polyphenol and mineral content, the results varied depending on farming technique. Finally, aspects related to environmental protection help organic products achieve better market positioning.

1. Introduction

The tomato (*Lycopersicon esculentum Mill.*) is considered native to Latin America; although its exact origin is unknown, its early production occurred in Peru and Mexico, from where it was exported to Europe starting in the 16th century (Gould, 1992; El Mashad et al., 2019; Klee and Resende, 2020). Tomatoes are currently grown and distributed on all continents, which is why it is considered one of the crops with the greatest economic impact worldwide. The tomato has considerable nutritional benefits due to its high content of nutrients such as lycopene, β-carotene, ascorbic acid (vitamin C), and polyphenols, among others. Moreover, its consumption and marketing has not been restricted only to the fresh product. The industry has expanded into soups, tomato paste, juices, sauces, concentrates, and other products derived from this plant (Bergougnoux, 2014).

According to the Food and Agriculture Organization of the United Nations (FAO), in 2019, global tomato production was about 1808 mln. tons. The three countries with the highest production in the same year were China (628 mln. tons), India (190 mln. tons), and Turkey (128 mln. tons) (FAO, 2020a). Additionally, in 2019, organic agriculture in general grew 2.9 % compared to the previous year, and a considerable increase in organic trade is projected for subsequent years (IFOAM-Organics International, 2020a), with tomato being one of the most relevant and characteristic products of this type of non-conventional farming.

Organic farming rescues traditional practices without abandoning new clean technologies, adapting them to each situation. The terms "ecological," "biological," and "organic" are considered synonyms according to several authors (Soto, 2003; García and Santiago, 2012; Agencia Ecuatoriana de Aseguramiento de la Calidad del Agro, 2013). The FAO defines organic agriculture as a production system based on the maximum use of available resources, protection of soil fertility and biological activity, minimal use of non-renewable resources, and restricted use of synthetic substances harmful to the ecosystem and

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Abbreviations: ANOVA, analysis of variance; CONVE, conventional; FAO, Food and Agriculture Organization of the United Nations; FW, fresh weight; IFOAM, International Federation of Organic Agriculture Movements; ORG, organic; USDA, United States Department of Agriculture.

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https://doi.org/10.1016/j.jfca.2021.103922
Received 11 December 2020; Received in revised form 30 March 2021; Accepted 30 March 2021

living beings (FAO, 2020b). Nevertheless, in some countries (e.g., Australia), non-conventional products need to meet specific standards regarding different types of agricultural techniques to be considered biological, sustainable, and organic (Wynen and Affairs, 2002).

Various authors agree that organic foods have advantages regarding promoting human health, protecting the environment, and preserving biodiversity, which is why these products have been widely accepted by consumers, especially in developed countries (Robinson-O'Brien et al., 2009; Vinha et al., 2014; Yu et al., 2018). In countries such as the United States and China, the market for organic products has reached values two to three times higher than that for conventional products, which has generated mistrust for fake and low-quality organic products as an unexpected consequence (Yu et al., 2018). As Smith-Spangler et al. (2012) mention, sales of organic products have increased in recent years, despite consumers having to pay approximately double the price of the same conventionally produced product that is not guaranteed to be free of pesticide residue or grown using environmentally friendly methods (Vinha et al., 2014).

One of the main characteristics of organic farming practices according to the FAO is their focus on production processes rather than on the product itself. For example, organic farming practices should not include the use of synthetic fertilizers, pesticides, stimulants, growth hormones, preservatives, or radiation in post-harvest handling, and the use of materials or products from genetically modified organisms is prohibited. Additionally, their production techniques must be eco-friendly, and producers are paid fairly, unlike the producer-intermediary-trader inequality that exists in conventional production (FAO, 2003). The International Federation of Organic Agriculture Movements (IFOAM-Organics International) is a non-governmental organization that has determined the four fundamental principles of organic agriculture: health, ecology, fairness, and care of the environment and living beings (IFOAM-Organics International, 2020b).

The Codex Alimentarius Commission created the "Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Foods" to help ensure that requirements for organic products are consistent worldwide (FAO/OMS, 2007). With these emerging regulations, control and certification bodies have implemented guides based on the codex guidelines, as in the European Union, where Regulation (EU) 2018/848 of the European Parliament and of the Council of the European Union (2018) defines the objectives, principles, and purposes of organic agriculture and production. The same is true in the United States, where the U.S. Department of Agriculture (USDA) works with the organic sector, either in implementation for accreditations or in programs, services, and education for this type of crop (U.S. Department of Agriculture, 2021). Another example is Ecuador, where the government has implemented the "Manual of General Regulations to Promote and Regulate Organic-Ecological-Biological Production" (Agencia Ecuatoriana de Aseguramiento de la Calidad del Agro, 2013).

Compliance with natural laws and ecological principles such as land use (i.e., a two-year conservation period before planting) is included among the requirements for organic production systems, which are adopted by each country's control organizations for their certification. This compliance is regulated through inspection systems. Other requirements are progressive, plot-by-plot farming conversion and regular evaluation of soil fertility and biological activity. The codex guidelines also mention several options to combat diseases, weeds, and pests, including mechanical cultivation, diversified ecosystems, weed removal with fire, covering with a layer of organic matter, and mowing, among others. Regarding the use of synthetic materials, options are limited, and lists of approved materials are available such as those found in Table 3 ("Ingredients of non-agricultural origin") in Annex 2 of the Codex Alimentarius: Organically Produced Foods, which should strictly be used in emergencies (FAO/OMS, 2007; Smith-Spangler et al., 2012; Yu et al., 2018). The implementation of quality-related techniques and labels has generated controversy in many cases, as there is a lack of consistent scientific evidence that would allow the true nutritional content and the presence of certain minerals in the different types of crops to be determined.

Contrary to organic production, conventional agriculture has no restrictions on the use of chemical substances (Muscănescu, 2013) as long as they are applied according to the regulations or specific instructions of each product. Further, pest control, fertilizer use, application of genetically modified organisms, and environmental protection protocols also do not have major restrictions (FAO, 2003; Ortega, 2009; Seufert et al., 2012). Considering the disadvantages of both farming techniques, for conventional crops, the permitted use of chemical substances to achieve higher yields at lower costs has been strongly linked to the increase of human diseases such as cancer (Kim et al., 2017). On the other hand, according to several authors, organic production disadvantages, including vulnerability to pests and diseases, a lower self-live period, more land needed to produce the same amount of food as conventional farms, and high production costs, make organic food more expensive for consumers (Lammerts van Bueren et al., 2011; Forman and Silverstein, 2012; Muscănescu, 2013). There are also risks that apply to both agricultural techniques, for example, other reported diseases such as methemoglobinemia, which occurs mainly in young people and is a consequence of the intake of high concentrations of nitrates from contaminated water as a byproduct of irrigation of fertilized soils (Biernat et al., 2020; McCasland et al., 2020).

Therefore, as described above, the purpose of this review is to collect relevant published information to identify and compare the content of select nutrients and minerals present in organically and conventionally grown tomato fruit and thus determine the food quality, production costs, and ecological benefits of each type of crop.

2. Methods

2.1. Data sources and searching

Zotero software (https://www.zotero.org) was used to manage the bibliography and its references. Searching was carried out in seven of the main databases —Directory of Open Access Journals, Science Direct, Web of Science, Food Chem, Latindex, ResearchGate, and Google Scholar—with terms such as "tomato," "organic crop," "conventional crop," and "nutritional quality."

2.2. Study selection

Potentially relevant peer-reviewed studies (in English and Spanish) related to nutrient and mineral levels in tomatoes, as well as comparative studies between organic and conventional tomatoes, were evaluated. In studies that did not specify "organic crops," the crops were considered conventional. For all studies, nutrient and mineral values in ripe tomatoes were included. Studies on processed tomatoes and their derivatives were excluded.

2.3. Data collection and quality assessment

This review included information from 49 studies conducted specifically on tomatoes, which were classified into four groups described as follows.

All included studies were selected based on their use of statistical analyses to establish the significance of the values obtained in each one. Among the most common statistical methods were analysis of variance (ANOVA), Duncan's test, Tukey's test, Pearson correlation coefficient, the Student's t-test, Fisher's exact test, Levene's test, and the R^2 correlation. Many of the studies applied multiple statistical tools. Only studies with confidence intervals greater than 95.45 % (significance level $p \leq 0.05$ %) were selected.

With the data of the referenced articles, a comparison was performed with the available information, considering the statistical methods applied in each study to evaluate the reliability of the results. For all studies, ranges of nutrient and mineral levels were compared, while the variety of tomato, harvest season, crop location, and specific modifications in farming techniques applied to the crops were not considered. Since these differences may directly affect the nutrient and/or mineral content, only the control values were used for the comparison.

2.4. Data synthesis

The articles were divided into four groups based on their focus. The first group included studies that directly compared organic agriculture to conventional agriculture. The second group consisted of studies in which analyses were conducted on the use of different fertilizers in both organic and conventional crops. The third group comprised studies that analyzed organic crops and the use of organic bio stimulators or green fertilizers specifically used in organic farming. Finally, the fourth group incorporated studies related to the mineral and nutrient content in the tomato fruit and its relationship to other factors.

The inclusion criteria were quite limiting when searching exclusively for studies of tomato fruit and their major nutrients—ascorbic acid, β-carotene, lycopene, and polyphenols (Table 1)—and mineral content, such as calcium, copper, chromium, iron, magnesium, nickel, potassium, and zinc. Included in the latter are toxicologically significant metals such as arsenic, cadmium, and lead (Table 2) (Ferrer, 2003) found in ripe tomatoes, whether organic or conventional.

3. Results and discussion

Studies in the first group had as a common objective to compare the effect of organic and conventional cultivation on nutrients and minerals in tomato fruit. In most of the studies, the authors concluded that tomatoes from organic farming showed a higher amount of nutrients than those from conventional farming (Borguini et al., 2013; Bressy et al., 2013; Oliveira et al., 2013; Vinha et al., 2014). Hattab et al. (2019); Bressy et al. (2013), and Hadayat et al. (2018) determined that the concentration of toxic metals in the conventional fruit was slightly higher than in the organic fruit, while Romero-Estévez et al. (2020) found a higher concentration of trace metals in organic tomatoes. In Ulrichs et al. (2008), no significant differences for the analyzed nutritional parameters were found between organic and conventional farming techniques; only tomatoes grown organically had slightly lower total phenolic content. Even though farming technique and crop location (to a lesser extent) affect the presence and composition of volatile organic compounds and, in turn, certain organoleptic characteristics of the fruit, this does not translate to a relationship with the major nutritional components and mineral content (Muilwijk et al., 2015). However, Knap et al. (2015) concluded that higher mineral content could not be confirmed in either the organic or conventional crops because mineral absorption is related to other factors, primarily crop location, bio-availability in the soil, adjuvants, and the presence of favorable absorption conditions.

Studies in the second group evaluated differences when using different fertilizers depending on the farming technique. In Amiri et al.

Table 1
Summary of studies related to nutrients in tomato fruit from organic and conventionally grown crops.

Nutrient	Number of studies	Number of comparisons in the studies		Studies with sample size descriptions		References for each comparison group*			
		In favor of organic cultivation	In favor of conventional cultivation	Organic	Conventional	Group I	Group II	Group III	Group IV
Ascorbic acid	27	8	–	4	13	(Caris-Veyrat et al., 2004; Lumpkin, 2005; Hernández Suárez et al., 2008; Pieper and Barrett, 2009; Ordoñez-Santos et al., 2011; Oliveira et al., 2013; Borguini et al., 2013; Vinha et al., 2014)	(Polat et al., 2010; Amiri et al., 2008; Martí et al., 2018; Hossain Sani et al., 2020; Owagboriaye et al., 2020; Sharpe et al., 2020)	–	(Majkowska-Gadomska et al., 2012; Aguiló-Aguayo et al., 2013; Erba et al., 2013; Raiola et al., 2016; Riga et al., 2016; Ramos et al., 2017; Melfi et al., 2018; Asensio et al., 2019; Caruso et al., 2019; Li et al., 2019; Wang et al., 2019; Londoño-Giraldo et al., 2020; Shu et al., 2020)
Lycopene	30	5	1	4	10	(Caris-Veyrat et al., 2004; Lumpkin, 2005; Ulrichs et al., 2008; Pieper and Barrett, 2009; Riahi et al., 2009b; Ordoñez-Santos et al., 2011; Borguini et al., 2013; Vinha et al., 2014)	(Amiri et al., 2008; Bilalis et al., 2018; Hossain Sani et al., 2020; Sharpe et al., 2020)	(Riahi et al., 2009a; Riahi and Hdider, 2013; Sidhu et al., 2017; Zörb et al., 2020)	(Erba et al., 2013; Aguiló-Aguayo et al., 2013; Raiola et al., 2016; Riga et al., 2016; Ramos et al., 2017; Coyago-Cruz et al., 2017; Schweiggert et al., 2017; Melfi et al., 2018; Coyago-Cruz et al., 2018; Li et al., 2019; Asensio et al., 2019; Wang et al., 2019; Caruso et al., 2019; Londoño-Giraldo et al., 2020)
β-carotene	18	2	–	1	11	(Caris-Veyrat et al., 2004; Lumpkin, 2005; Ulrichs et al., 2008; Ordoñez-Santos et al., 2011; Borguini et al., 2013)	(Hossain Sani et al., 2020; Owagboriaye et al., 2020)	(Sidhu et al., 2017)	(Erba et al., 2013; Aguiló-Aguayo et al., 2013; Raiola et al., 2016; Riga et al., 2016; Schweiggert et al., 2017; Coyago-Cruz et al., 2018; Li et al., 2019; Asensio et al., 2019; Londoño-Giraldo et al., 2020; Coyago-Cruz et al., 2017)

[*] Groups created according to scope: **Group I:** Direct comparison between organic and conventional products; **Group II:** Use of different fertilizers in both organic and conventional crops; **Group III:** Use of organic bio stimulators or green fertilizers; **Group IV:** Other factors.

Table 2
Summary of studies related to minerals in tomato fruit from organic and conventionally grown crops.

Mineral	Number of studies	Number of comparisons in the studies		Studies with sample size descriptions		References for each comparison group*			
		In favor of organic cultivation	In favor of conventional cultivation	Organic	Conventional	Group I	Group II	Group III	Group IV
As	1	1	–	1	1	(Hadayat et al., 2018)	–	–	–
Ca	11	1	1	–	3	(Hernández Suárez et al., 2007; Pieper and Barrett, 2009; Kelly and Bateman, 2010; Ordoñez-Santos et al., 2011; Knap et al., 2015)	(Polat et al., 2010)	(Ambrosano et al., 2018)	(Erba et al., 2013; Riga et al., 2016; Li et al., 2019; Caruso et al., 2019)
Cd	5	–	–	3	4	(Bressy et al., 2013; De Souza Araújo et al., 2014; Hadayat et al., 2018; Romero-Estévez et al., 2020)	–	–	(Trebolazabala et al., 2017)
Cu	13	3	–	2	7	(Hernández Suárez et al., 2007; Kelly and Bateman, 2010; Ordoñez-Santos et al., 2011; De Souza Araújo et al., 2014; Hattab et al., 2019)	(Polat et al., 2010)	(Ambrosano et al., 2018; Zörb et al., 2020)	(Erba et al., 2013; Riga et al., 2016; Trebolazabala et al., 2017; Afshari et al., 2016; Li et al., 2019)
Cr	5	–	–	2	4	(Bressy et al., 2013; De Souza Araújo et al., 2014; Hadayat et al., 2018)	–	–	(Afshari et al., 2016; Trebolazabala et al., 2017)
Fe	13	2	–	2	7	(Hernández Suárez et al., 2007; Kelly and Bateman, 2010; Ordoñez-Santos et al., 2011; Bressy et al., 2013; De Souza Araújo et al., 2014; Hattab et al., 2019)	(Polat et al., 2010; Hossain Sani et al., 2020)	(Ambrosano et al., 2018)	(Erba et al., 2013; Riga et al., 2016; Trebolazabala et al., 2017; Li et al., 2019)
K	14	2	1	1	5	(Hernández Suárez et al., 2007; Pieper and Barrett, 2009; Kelly and Bateman, 2010; Ordoñez-Santos et al., 2011; De Souza Araújo et al., 2014; Knap et al., 2015; Hattab et al., 2019)	(Polat et al., 2010; Hossain Sani et al., 2020)	(Ambrosano et al., 2018)	(Erba et al., 2013; Riga et al., 2016; Caruso et al., 2019; Li et al., 2019)
Mg	12	2	–	1	4	(Hernández Suárez et al., 2007; Pieper and Barrett, 2009; Kelly and Bateman, 2010; Ordoñez-Santos et al., 2011; De Souza Araújo et al., 2014; Hattab et al., 2019)	(Polat et al., 2010)	(Ambrosano et al., 2018)	(Erba et al., 2013; Riga et al., 2016; Caruso et al., 2019; Li et al., 2019)
Ni	6	1	–	2	5	(Bressy et al., 2013; De Souza Araújo et al., 2014; Hattab et al., 2019)	–	–	(Christou et al., 2014; Afshari et al., 2016; Trebolazabala et al., 2017)
Pb	5	–	–	2	4	(De Souza Araújo et al., 2014; Hadayat et al., 2018; Romero-Estévez et al., 2020)	–	–	(Afshari et al., 2016; Trebolazabala et al., 2017)
Zn	15	3	–	2	9	(Hernández Suárez et al., 2007; Kelly and Bateman, 2010; Ordoñez-Santos et al., 2011; Bressy et al., 2013; De Souza Araújo et al., 2014; Hattab et al., 2019)	(Polat et al., 2010; Hossain Sani et al., 2020)	(Ambrosano et al., 2018)	(Erba et al., 2013; Christou et al., 2014; Afshari et al., 2016; Riga et al., 2016; Trebolazabala et al., 2017; Li et al., 2019)

* Groups created according to scope: **Group I:** Direct comparison between organic and conventional products; **Group II:** Use of different fertilizers in both organic and conventional crops; **Group III:** Use of organic bio stimulators or green fertilizers; **Group IV:** Other factors.

(2008), the possibility of replacing artificial (chemical) fertilizers with organic fertilizers, like poultry manure, or biofertilizers, such as soluble biophosphorus, was examined. No significant differences were observed regarding lycopene content between these two types of fertilizers; however, in most of the examined parameters, an improvement in product quality was observed, such as taste properties. On the other hand, some studies have found a higher content of lycopene and ascorbic acid in tomato fruits that were treated with organic fertilizers compared to those treated with synthetic fertilizers (Murmu et al., 2013; Polat et al., 2010; Bilalis et al., 2018; Owagboriaye et al., 2020). The use of organic fertilizers and biofertilizers has also been shown to activate photo inhibition processes and the transport and nitrogen uptake genes, which directly affect the accumulation of nutrients in the fruit (Sharpe et al., 2020). Hossain Sani et al. (2020) indicated the effectiveness of the combined use of organic and synthetic fertilizers, resulting in a technique for sustainable tomato production with a higher yield and quality of antioxidants and minerals in the product (Riahi et al., 2009a). Even in studies carried out in short periods (one year), a difference in the content of lycopene and other antioxidant compounds can be seen with different types of fertilizer (Riahi et al., 2009b; Riahi and Hdider, 2013). Additionally, as Zuba et al. (2011) affirmed, “the use of mineral and organic fertilizers significantly reduced the incidence of soft rot and pests in comparison to the use of chemical fertilizers.” In Pradeepkumar et al. (2017) study, despite favorable results with organic fertilizer, the long-term sustainability of its application depended on many aspects that were beyond producers’ control. However, at the field level, the specific fertilizers’ quantity and quality were the key factors that determined the nutritional content in a particular crop. When using

Table 3
Summary of nutrient concentrations reported in the different studies.

Study	Ascorbic acid (mg/100 g)		Lycopene (mg/100 g)		β-carotene (mg/100 g)	
	Conventional cultivation	Organic cultivation	Conventional cultivation	Organic cultivation	Conventional cultivation	Organic cultivation
(Caris-Veyrat et al., 2004)	9.6–13.7	12.5–17.5	3.2–3.8	3.6–4.2	0.83–0.92	1.03–1.35
(Lumpkin, 2005)	25.0	24.0	8.34	7.69	0.51	0.53
(Ulrichs et al., 2008)	–	–	0.987[a] 1.055[b]	0.937[a] 1.1[b]	0.0058[a] 0.0083[b]	0.0061[a] 0.009[b]
(Hernández Suárez et al., 2008)	12.3–19.9	11.2–19.5	–	–	–	–
(Riahi et al., 2009a)	–	–	–	7.69–11.94	–	–
(Riahi et al., 2009b)	–	–	110–150*	90–140*	–	–
(Polat et al., 2010)	298.6**, [c]	282.2–306.0**,[c]	–	–	–	–
(Ordoñez-Santos et al., 2011)	5.99–10.60	11.16–12.68	1.41–6.38	1.46–5.51	1.30–4.44	2.02–3.90
(Majkowska-Gadomska et al., 2012)	31.0	–	–	–	–	–
(Borguini et al., 2013)	22.6	29.3	1.81	1.71	–	–
(Oliveira et al., 2013)	17.1	26.5	–	–	–	–
(Aguiló-Aguayo et al., 2013)	18.0–21.0	–	6.70–9.10	–	–	–
(Erba et al., 2013)	26.9–33.3	–	3.95–6.58	–	0.43–0.71	–
(Riahi and Hdider, 2013)	–	–	–	4.47–8.76	–	–
(Vinha et al., 2014)	27.9	40.0	1.76	2.19	–	–
(Amiri et al., 2008)	10.4	10.7	1.53	1.84	–	–
(Raiola et al., 2016)	54.1–63.8	–	–	–	–	0.53–0.68
(Riga et al., 2016)	5.11–6.20	–	6.96–10.3	–	–	–
(Ramos et al., 2017)	11.5–21.2	–	2.30–3.84	–	–	–
(Sidhu et al., 2017)	–	–	–	0.52–0.70	–	0.17–0.20
(Schweiggert et al., 2017)	–	–	0.02–4.74	–	0.27–1.12	–
(Coyago-Cruz et al., 2017)	–	–	10.5–19.8*	–	1.50–4.20*	–
(Bilalis et al., 2018)	–	–	8.05	8.85	–	–
(Melfi et al., 2018)	25.9	–	33.0	–	–	–
(Coyago-Cruz et al., 2018)	–	–	3.10–259*	–	1.80–37.9*	–
(Martí et al., 2018)	12.321	12.367	–	–	–	–
(Li et al., 2019)	20.0–30.0	–	–	–	–	–
(Asensio et al., 2019)	1.56–7.75	–	2.90–6.50	–	0.14–0.64	–
(Wang et al., 2019)	20.0–25.0	–	9.00–10.0	–	–	–
(Caruso et al., 2019)	18.5	23.9	188.2	171.0	–	–
(Owagboriaye et al., 2020)	13.9	–	–	–	0.02	–
(Hossain Sani et al., 2020)	11.1	–	0.07	–	0.07	–
(Londoño-Giraldo et al., 2020)	1.00–5.00	–	0.012–12.0**	–	0.0007–0.008**	–
(Shu et al., 2020)	5.17–16.7	–	–	–	–	–
(Zörb et al., 2020)	–	–	–	0.44–1.77	–	–
(Sharpe et al., 2020)	15,700[d]	17,500[d]	377	422	–	–

* Dry weight value.

** Value reported in μg/mL.

[a] Nutrition content without mycorrhiza treatment.

[b] Nutrition content with mycorrhiza treatment.

[c] Ascorbic acid content of tomato fruits as an average of two years of study.

[d] Reduced ascorbic acid.

organic fertilizers, the supply of nutrients also depended on microbial degradation of organic compounds, and this biochemical process was directly affected by temperature, soil water content, and pH. For organic farming processes, nitrogen was a limiting factor for plant growth (Farneselli et al., 2013; Bergstrand et al., 2020). Finally, synthetic fertilizers in conventional farming systems can result in high concentrations of nutrients as the fertilizers are directly available for root uptake in a shorter time, which leads to a greater number of fruit per plant and higher average fruit weight and cultivation yield (Bilalis et al., 2018).

Studies in the third group concluded that the use of green fertilizers and bio stimulators promote higher quality and nutrient content in the tomato fruit in both conventional and organic farming (Sidhu et al., 2017; Ambrosano et al., 2018; Caruso et al., 2019). Finally, in the fourth group, researchers such as Riga et al. (2016); Asensio et al. (2019), and Londoño-Giraldo et al. (2020) concluded that the concentrations of ascorbic acid and antioxidants varied depending on tomato genotype. Furthermore, tomato variety and fruit harvest ripeness were some of the main factors that affected the tomatoes' nutritional value (Erba et al., 2013; Coyago-Cruz et al., 2017; Ramos et al., 2017). Regarding genotype, Martí et al. (2018) found that in some tomato varieties, ascorbic acid can increase with organic farming, and Caris-Veyrat et al. (2004) concluded that variety significantly affects lycopene content, while for β-carotene, no genotype effect was found. In addition, a significant correlation between lycopene concentration and fruit weight was ruled out after genotype identification (Zörb et al., 2020). However, the increase or decrease of nutrients in tomatoes may be influenced by genotype selection, growing environment, and farming system. Other studies analyzed the effects of different irrigation systems—using freshwater, saltwater, or a mixture, as well as the form of distribution (drip or controlled, among others)—both on the soil and on the tomato plants and fruit, concerning their quality in terms of nutrient and mineral content, as well as the relationship between bioaccumulation and translocation of heavy metals (Christou et al., 2014; Afshari et al., 2016; Schweiggert et al., 2017; Trebolazabala et al., 2017; Coyago-Cruz et al., 2018; Li et al., 2019; Shu et al., 2020). Finally, some studies analyzed different tomato cultivation, preservation, and conservation techniques, such as the use of chlorine dioxide, pulsed light, and thermal processing; only the latter was found to influence nutrients in the tomato fruit (Majkowska-Gadomska et al., 2012; Aguiló-Aguayo et al., 2013; Raiola et al., 2016; Wang et al., 2019).

The present study considered the values corresponding to the ripe fruits used as controls to compare conventional and organic cultivation systems. In the case of articles that did not report a value, the proximal value of the graphic scale where the results were reported was considered. In the case of studies with different types of tomatoes, a standard range of the ripe fruits used as controls and that were not subjected to variations was taken.

Table 2 presents a summary of the number of studies conducted regarding different minerals; the most studied elements were Zn, Fe, and Cu, and studies that focused on minerals considered toxic, such as Pb, Cd, and As, were done with similar frequency.

The reported ascorbic acid concentrations in the different studies (Table 3) have similar values in fresh weight (FW), with concentrations ranging from 1.00 mg/100 g to 63.8 mg/100 g FW in conventionally grown tomatoes. Connecting these results to the studies of organic crops, where reported values ranged from 10.7–40.0 mg/100 g FW, it is not possible to take a firm position regarding which farming technique had a higher concentration of ascorbic acid since in both cases, results were within similar ranges. These results showed there is no relationship between farming technique and ascorbic acid content since several factors, including soil pH, soluble solids, and glucose, were shown to have a positive correlation, while fruit density and titratable acidity had a negative correlation (Rosales Laguna and Arias Arroyo, 2015). Moreover, variation in ascorbic acid content is mainly influenced by genetic and maturation factors (Oliva et al., 2018). Soil quality and water for irrigation directly influence tomatoes' ascorbic acid concentration (Hernández Suárez et al., 2008), as does the cultivation site and its intrinsic characteristics (Martí et al., 2018).

For lycopene, concentrations in conventional tomatoes corresponded to a wide range (0.02–337.0 mg/100 g FW), while the range for organic tomatoes was narrower, from 0.44 to 422 mg/100 g FW. From the information collected from studies that reported values in both farming techniques, tomatoes from conventional crops had a considerably lower concentration than organic products. Like ascorbic acid, lycopene content is related to genetics, ripening state, and total carotenoid content in the fruit (García B, 2011; Luna-Guevara and Delgado-Alvarado, 2014), as well as sunlight availability, planting and harvesting dates, drainage conditions, irrigation, and soil fertility management practices (Lumpkin, 2005; Ordoñez-Santos et al., 2011). One of the principal determinants of lycopene is temperature: the most favorable rate of lycopene production occurs between 22–25 °C, which is affected by sunlight (Lumpkin, 2005).

For β-carotene, Caris-Veyrat et al. (2004) showed that organic cultivation led to tomatoes with a higher content of this antioxidant. Studies that only analyzed conventional tomatoes reported values ranging from 0.0058 to 4.44 mg/100 g FW. In the case of organic crops, β-carotene content was between 0.0061 and 3.90 mg/100 g FW. Despite having similar ranges, in some cases, the β-carotene content in the fruits of conventional crops was significantly higher than that of organic products.

Considering the information from the studies, conventional crops had a higher lycopene and β-carotene content, meaning their nutritional quality was higher than that of organic crops. This finding contradicts those of several studies (Borguini et al., 2013; Bressy et al., 2013; Oliveira et al., 2013; Vinha et al., 2014) that observed a greater amount of nutrients in organically grown fruit. It is important to note that stress management is the most effective strategy for increasing antioxidants, vitamins, and other phytonutrients in both organic and conventional farming (Mukherjee et al., 2020). For all nutrients, the factors described act simultaneously; thus, it is difficult to ascertain which farming technique most improved nutrient uptake (Hernández Suárez et al., 2007).

Phenolic compounds, including flavonoids, are one of the main nutritional compounds found in tomatoes. Thirteen selected articles determined the concentrations of the different phenolic compounds; however, not all cases found a correlation between either of the two cultivation systems and fruit antioxidant content. Oliveira et al. (2013) determined that anthocyanin content (0.36 mg/100 g) in organic tomato was lower than that in conventional tomatoes (0.99 mg/100 mg), whereas the concentration of yellow flavonoids in organic tomatoes (4.37 mg/100 g) was higher than that in conventional tomatoes (2.57 mg/100 g). Martí et al. (2018) reported no correlation between different phenolic compounds considering both cultivation systems. Higher values of chlorogenic acid, caffeic acid, p-Coumaric acid, and rutin were found in organic samples, while ferulic acid, myricetin, quercetin, and naringenin had higher concentrations in conventional samples. Thus, a correlation between farming technique and phenolic compound concentration could not be established. In addition, regarding studies in which total phenol concentration was determined to be equivalent to that of gallic acid, Vinha et al. (2014) and Sharpe et al. (2020) found a higher concentration of total phenols in organically grown tomatoes, whereas Ulrichs et al. (2008) reported higher concentrations in conventional culture samples. The concentrations of these compounds depend on both intrinsic and extrinsic factors, including variety (genotype), cultivation conditions (use of fertilizers and nutrients), soil conditions (Ramos et al., 2017), and, in some cases, thermal and mechanical treatments (Domínguez et al., 2020), maturation stage (Anton et al., 2017), type of soil treatment, and fertilizer use (Riahi and Hdider, 2013). Genotype affects antioxidant accumulation more than farming technique, and organic farming has a limited effect on polyphenol accumulation, which is highly dependent on cultivation site (Martí et al., 2018).

Tomato fruit has different antioxidant components, which makes measuring the antioxidant activity of each component separately relatively difficult (Borguini et al., 2013); however, antioxidant activity is mainly affected by fruit ripening, not type of farming (Anton et al., 2017). Some authors like Vinha et al. (2014) reported a higher concentration of phytochemicals and antioxidant activity in organically grown rather than conventionally grown fruit. Nevertheless, as with the other nutritional components, there was no relation between polyphenols and farming technique (Riahi and Hdider, 2013; Ramos et al., 2017; Martí et al., 2018; Domínguez et al., 2020). Antioxidant activity depends on several factors, including presence of phytochemicals, oxygen reactions (atmosphere exposure), light exposure, and oxidative mineral content (Erba et al., 2013), and it is also affected by fertilizer use (Riahi and Hdider, 2013).

Regarding mineral concentrations (Table 4), studies focused on organic tomatoes; however, one comparative study (Hadayat et al., 2018) found higher concentrations of As, Ca, Cd, Cr, Ni, and Pb in tomatoes from conventional crops, while Fe, K, and Mg were higher in organic crops. In the case of Cu and Zn, some studies (Hernández Suárez et al., 2007; Kelly and Bateman, 2010; Polat et al., 2010; Bressy et al., 2013; De Souza Araújo et al., 2014) showed higher values for organic crops and others (Ordoñez-Santos et al., 2011; Hadayat et al., 2018; Hattab et al., 2019) for conventional crops. Meanwhile, Bressy et al. (2013) indicated the presence of these minerals was an identifier of organic crops owing to arbuscular mycorrhizal fungi, which are characteristic of soils of organic crops because they release and solubilize soil nutrients that are relatively immobile, as is the case with these particular nutrients (Restrepo Giraldo et al., 2019). This variation in mineral concentration between the two farming techniques is consistent with what is described by Knap et al. (2015), who found that there was no hard rule regarding mineral content between the different agricultural systems. Ordoñez-Santos et al. (2011) agreed that the principal factor in tomatoes' micronutrient content was the variety, and when soil fertility is maintained, there was no nutritional difference between organically and conventionally grown tomatoes. In addition, the mineral concentrations in the tomato samples varied according to the species and ripening stage; between the 21 st and 105th day of cultivation, an increase in mineral absorption was expected. Further, when using synthetic fertilizers, metals such as cadmium and thallium reached higher levels than in the organic products (Liñero et al., 2015). Other elements such as manganese, calcium, copper, and zinc achieved higher concentrations in both organic and conventional farming because of the presence of elevated levels of arbuscular mycorrhizal fungi in organic substrates (Kelly and Bateman, 2010). Other cultivation characteristics also affect mineral content in tomato samples; absorption depends on

Table 4
Reported mineral concentrations (mg/kg) in the different studies.

Study	As		Ca		Cd		Cr		Cu		Fe		K		Mg		Ni		Pb		Zn	
	CONVE	ORG	CONVE	ORG	CONVE	ORG	CONVE	ORG	CONVE	ORG	CONVE	ORG	CONVE	ORG	CONVE	ORG	CONVE	ORG	CONVE	ORG	CONVE	ORG
(Hernández Suárez et al., 2007)	–	–	56.2–76.2	53.1–78.7	–	–	–	–	0.101–0.308	0.181–0.403	1.58–2.66	1.65–2.74	2227–2923	2124–3233	100–144	107–134	–	–	–	–	0.578–0.894	0.519–0.957
(Pieper and Barrett, 2009)	–	–	1200–1800*	1200–1600*	–	–	–	–	–	–	–	–	32,200–37,400*	37,400–45,700*	1800–2600*	1600–2200*	–	–	–	–	–	–
(Polat et al., 2010)	–	–	105.86*,[a]	102.91–109.95*,[a]	–	–	–	–	1.14* [a]	1.30–1.58 * [a]	2.33* [a]	2.03–3.05* [a]	1558* [a]	1461–1580 * [a]	88.69* [a]	88.58–92.08 * [a]	–	–	–	–	1.32*	1.26–1.68*
(Kelly and Bateman, 2010)	–	–	1027*	2126*	–	–	–	–	6*	8*	40*	50*	35,000*	31,000*	1900*	2100*	–	–	–	–	26*	31*
(Ordoñez-Santos et al., 2011)	–	–	159.7–178.9	162.9–231.3	–	–	–	–	0.5–1.1	0.5–0.9	7.6–13.7	5.4–11.4	1914.2–2365.4	2099.5–2285.0	103.0–111.8	112.0–118.8	–	–	–	–	1.6–2.2	1.4–3.3
(Bressy et al., 2013)	–	–	–	–	0.21*	0.061*	0.395*	0.15 *	5.13*	5.25*	43.1*	43.7*	–	–		–	0.77*	<0.049 *	–	–	29.5*	12.1*
(Erba et al., 2013)	–	–	52.6–65.9	–	–	–	–	–	1.03–1.49	–	4.09–5.94	–	1838–2423	–	100.8–120.1	–	–	–	–	–	1.14–1.57	–
(De Souza Araújo et al., 2014)	–	–	–	–	0.61	0.59	6.09	5.41	0.38	0.39	37.89	37.78	4708.75	5025.6	81.55	110.44	0.65	0.77	2.2	2.15	20.86	18.78
(Christou et al., 2014)	–	–	–	–	–	–	–	–	21.11*	–	–	–	–	–	–	–	1.36*	–	–	–	47.77*	–
(Knap et al., 2015)	–	–	2.12*	1.39*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
(Riga et al., 2016)	–	–	40	–	–	–	–	–	–	–	0.15	–	2900	–	110	–	–	–	–	–	0.07	–
(Afshari et al., 2016)	–	–	–	–	–	–	1.48	–	15.87	–	–	–	–	–	–	–	4.06	–	19.39	–	73	–
(Hadayat et al., 2018)	0.003	0.002	–	–	0.0043	0.001	–	–	0.642	0.325	–	–	–	–	–	–	0.055	0.015	0.0077	0.005	1.63	2.281
(Ambrosano et al., 2018)	–	–	–	1380	–	–	–	–	–	7	–	54.36	–	33,280	–	1950	–	–	–	–	–	27.71
(Caruso et al., 2019)	–	–	6020*	5510*	–	–	–	–	–	–	–	–	35,010*	36,430*	1520*	1440*	–	–	–	–	–	–
(Hattab et al., 2019)	–	–	–	–	–	–	–	–	0.32*	0.21*	198.1*	248.3 *	48.3*	56.4*	2192*	2832*	38.5*	25.4*	–	–	2.33*	1.28*
(Romero-Estévez et al., 2020)	–	–	–	–	0.009–0.035	0.0033–0.058	–	–	–	–	–	–	–	–	–	–	–	–	0.041–0.209	0.053–0.110	–	–
(Hossain Sani et al., 2020)	–	–	–	–	–	–	–	–	–	–	146.6	–	41,200	–	–	–	–	–	–	–	55.1	–

Abbreviations: CONVE: conventional; ORG: organic.

* Dry weight values.

[a] Micronutrition element content of tomato fruits as an average of two years of study.

biotic and abiotic factors, air and soil temperatures, humidity, light, genotype, and nutrient concentrations in the soil, among others (Bressy et al., 2013; De Souza Araújo et al., 2014). In Erika et al. (2020) study, mineral concentrations differed significantly by cultivar and year, and they were directly related to genotype-per-year effects; several cultivars exhibited high genotype stability over the years for the individual traits studied, meaning medium-to-high heritability.

According to the FAO document titled "Relevant Characteristics of Organic Agriculture," the reasons consumers prefer organic products cannot be generalized; many believe they are healthier or have better organoleptic qualities. Even now, it is difficult to verify these statements, given that for other consumers, food safety and/or environmental awareness are the most important factors in the decision to consume organic products (FAO, 2003).

Evidence has not shown any significant nutritional benefits or deficits from consuming organic foods instead of conventional products. No well-founded human studies have directly demonstrated organic foods' health benefits or protection against disease, nor have they confirmed any harmful or disease-promoting effects produced by an entirely organic diet (Hoefkens et al., 2010; Forman and Silverstein, 2012). Caris-Veyrat et al. (2004) demonstrated that even though organic products had higher ascorbic acid content, no significant difference was observed in plasma ascorbic acid.

Nevertheless, competition between organic and conventional products regarding nutritional and safety guarantees has resulted in advertising campaigns that misinform consumers, leading them to think certain organic products are superior and triggering an increase in their price that is clearly related to the high investment necessary for non-conventional production.

Outside of the controversy related to conventional and organic products' nutritional quality, one of the greatest benefits of organic farming is its consideration for the medium- and long-term effects on the environment from agricultural operations (Caradonia et al., 2020). Current studies have demonstrated that when land previously used in conventional farming is later used for organic farming, this conversion may improve important soil functions, including nutrient cycling and storage, biodiversity, and habitat provisioning (Massaccesi et al., 2020). Further, organic farming proposes food production that takes into account ecological balance, which ensures soil fertility and pest prevention. In this type of agriculture, an active approach is maintained to avoid dealing with problems only as they arise (FAO, 2020c). In turn, the demand for organic tomatoes has been growing; however, their supply remains limited in comparison with the demand for conventionally grown tomatoes. Additionally, organic food production requires more labor per unit, more post-harvest handling of small quantities of products, and a marketing and distribution chain for relatively smaller volumes than conventional products, which increases the price of organic products (FAO, 2020d). Considering the lower productivity of organic agriculture, the next target must be reducing the yield gap compared to conventional agriculture and limiting the possible environmental impact that it may generate (Ronga et al., 2019).

4. Conclusions

As described above, there is no evidence that organic crops are nutritionally better than conventional crops, and there is no need for organic tomatoes to cost more than conventional tomatoes, even when the former adhere to specific FAO-established standards and organic production processes. However, their eco-friendly and environmental protection aspects give them better market positioning. Regarding toxicity, many studies lean in favor of organic crops; however, limitations in the number of comparative studies make it impossible to choose between the two types. Organic agriculture under the established guidelines, as opposed to conventional agriculture, guarantees a sustainable crop.

Funding

This research did not receive any specific grants from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Pamela Y. Vélez-Terreros: Conceptualization, Methodology, Data curation, Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing - original draft, Writing - review & editing. **David Romero-Estévez:** Conceptualization, Methodology, Validation, Formal analysis, Data curation, Writing - review & editing, Supervision, Visualization. **Gabriela S. Yánez-Jácome:** Validation, Writing - review & editing. **Karina Simbaña-Farinango:** Writing - review & editing. **Hugo Navarrete:** Project administration, Funding acquisition, Resources.

Declaration of Competing Interest

The authors declare no conflict of interest.

Acknowledgments

The authors thank the Pontificia Universidad Católica del Ecuador for the financial support in the publication of this article.

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