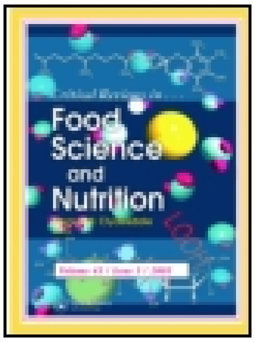

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REVIEW

Bioactive compounds and nutritional composition of Swiss chard (*Beta vulgaris* L. var. *cicla* and *flavescens*): a systematic review

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ABSTRACT
Swiss chard (*Beta vulgaris* L. var. *cicla* or *flavescens*) is a green leafy vegetable whose bioactive compounds have been studied due to its effects on health. We systematically reviewed the nutritional profile and bioactive composition of Swiss chard and reported their concentrations. Four main databases were searched for studies analyzing the chemical composition of Swiss chard. Screening, selection of articles, and data extraction were carried out by two independent reviewers. Twenty-eight articles of 1102 records identified by bibliographic search met our inclusion criteria for final analysis. We found a total of 192 chemical compounds categorized into 23 groups. The *cicla* variety was the most studied, and nutrients and phytochemicals were reported mainly on leaves. Betalains with 20% of the reported data, fats (16%), flavonoids (11%), non-flavonoid phenolics (11%), terpenes and derivatives (8%), carbohydrates (7%), and minerals (6%) were among the most reported categories. Swiss chard leaves have the highest content of fiber, sodium, magnesium, flavonoids, and vitamin C, while stems are high in potassium. Swiss chard should be considered a source of nutrients and phytochemicals, and further research is needed on identifying and quantifying other bioactive compounds and understanding their impact on health.

KEYWORDS
Beta vulgaris; bioactive compounds; minerals; nutritional profile; phytochemicals; Swiss chard

Introduction

Green leafy vegetables (GLVs) have been recently recommended for consumption in the everyday diet; they are low in energy but relatively high in micronutrients. Experimental studies show that increased consumption of green vegetables can prevent coronary heart disease by inhibiting the development of atherosclerosis (Sener et al. 2002; Adams et al. 2006). Indeed, a meta-analysis of observational studies reported a 15.8% decreased risk of developing cardiovascular disease associated with high consumptions of GLVs (Pollock 2016). Other epidemiological studies have shown a potential benefit of GLVs in diabetes, cognitive decline and overall mortality (Chen et al. 2018; Morris et al. 2018; Mori et al. 2019).

Swiss chard (*Beta vulgaris cicla*, BVc and *Beta vulgaris flavescens*, BVf), an edible plant of the Chenopodiaceae family, is considered one of the GLVs. The plant has a thick, crunchy stalk that can be white or colorful and wide fanlike green leaves (Rana 2016). Leaves can be consumed raw as part of a salad or cooked alone or along with the stems in a similar way as spinach (Dietitians of Canada 2020). It is commonly found in the Western diet and is rich in bioactive chemicals such as phytopigments, flavonoids and minerals with antioxidant and immunomodulating properties (Ivanovic et al. 2019). Swiss chard is also rich in dietary fibers, proteins and antioxidants such as alpha-lipoic acid, which is linked to lower glucose levels and increased insulin sensitivity (Ivanovic et al. 2019; Yang et al. 2014). Therefore, Swiss chard has potential preventive and therapeutic effects in diabetes, as seen in animal studies (Sener et al. 2002). Among GLVs, Swiss chard has considerable levels of nitrate, involved in the pathophysiology of atherosclerosis (Freeman et al. 2017). The available evidence suggests a possible health benefit of GLVs, yet epidemiological studies are lacking on the association of Swiss chard consumption with cardiometabolic diseases and other health outcomes. Thus, it is important to understand better the nutrient and phytochemical content of Swiss chard since it may provide more clues on its health effects. Therefore, a comprehensive quantitative review is required, also given the global micronutrient deficiency, increased incidence of chronic diseases and Swiss chard being an easy to grow and inexpensive vegetable crop available throughout the year (Ivanovic et al. 2019; Ninfali and Angelino 2013). We conducted a systematic review of studies evaluating the presence and levels of nutrients and bioactive components in Swiss chard.

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Methods

Literature search

This review was conducted and reported following the PRISMA 10 (eAppendix 1), as well as based on the systematic review approach designed by Muka et al. (2020). Published studies examining the nutrient and bioactive composition of Swiss chard were identified from inception until January 22, 2020 (date last searched) using four bibliographic databases (PubMed, Embase, Web of Science, and Cochrane trials). Search terms were related to nutrient and bioactive compounds (e.g., nutrients, metabolism, phytochemical, carbohydrate, fatty acids) and the plant (Swiss chard) (eAppendix 2). We did not apply any restrictions concerning language and publication date. Conference abstracts, cost-effectiveness studies, letters to the editor, conference proceedings, literature reviews, systematic reviews, or meta-analyses and, studies conducted in animals were excluded. To retrieve further relevant publications, we checked the reference lists of studies included in the current review.

Study selection criteria

Studies were included if they met the following criteria: (1) used samples of any part of Swiss chard or its seeds; and (2) evaluated nutrient and bioactive compounds. We excluded studies in which Swiss chard was genetically manipulated and if the analysis included Swiss chard-based dietary supplements or meals. Two reviewers independently evaluated the titles and abstracts according to the inclusion criteria. For each potentially eligible study, two reviewers assessed the full-text for relevance. In cases of disagreement, a decision was made by consensus or, if necessary, a third reviewer was consulted.

Data extraction

Two reviewers using a predesigned form including first author and publication year, variety, cultivar (cv.), analyzed part of the plant, compounds name, their concentrations, and biological activity reported in the articles did data extraction independently.

Classification and report of compounds

All compounds were classified into categories according to their chemical structure. This cataloging was established using the PubChem Database of the U.S. National Library of Medicine (Kim et al. 2019), which provides several types of chemical structure classifications. In our case, we used the "KEGG Phytochemical Compounds" classification, if available. Otherwise, we categorized the compounds using the "MeSH tree" classification. The compounds not identified or not included in the PubChem database were organized according to the category reported by the authors. In case the authors did not classify the compounds, we allocated them in the "other compounds" category. All categories and compounds are reported in alphabetical order or numerical order if the name starts with numbers or words denoting them.

The names of compounds were included as they were originally reported in papers, and to allow easy identification thereof, we tagged them with their respective "PUBCHEM Single Compound accession identifier" (CID) when possible. Compounds that were reported by more than one author with different names or terms were grouped under the same Pubchem CID. Authors reporting the same compound were listed according to the year of publication (from earliest to latest). Regarding the concentrations of the compounds, we reported the original units described in papers. However, we converted the original units to mg/100 g of fresh weight (F.W.) or mg/100 g of dry weight (D.W.) when feasible, to make the reports uniform and comparable across studies.

Results

The systematic search in the electronic databases identified 1102 potentially relevant citations. After screening abstracts and full-texts papers, cross-referencing and consulting other sources, we selected 28 articles to include in this review (Figure 1), from which 20 (71%) reported concentrations on the compounds they were identifying.

Cicla was the most studied variety, while the *flavescens* variety was described only in two papers, one reporting carotenoids and the other one flavonoids (Table 1). Twelve authors did not state the cultivar they used for analysis. Among those who did report, the most commonly used were Bright light and Lukullus with three articles, each. We found the leaf as the most studied part, with 21 authors describing results on it alone or together with other parts, mainly stems, stalks, or petioles (Table 1 and Supplemental Table 1). Stems, stalks, or petioles were the second most frequently reported part of the plant, with five articles reporting compounds on them also alone (two articles) or together with leaves. Followed by three papers that described seeds, one that studied roots, and one that used whole plant (tissue). Two articles did not indicate the used part of the Swiss chard for the analysis (Moyo et al. 2017; Ferland and Sadowski 1992).

This systematic review found a total of 192 bioactive components described in Swiss chard, which were categorized into 23 groups (Supplemental Table 2). Among the total compounds, 20% were classified as betalains being this the largest category, followed by 16% classified as fats, lipids and fatty acids, 11% as flavonoids and derivatives, and 8% as terpenes and derivatives (Figure 2). The concentration of the compounds was available in 114 (59%) of the 192 nutrients and phytochemicals included in this study (Supplemental Table 2). The only category with no reported concentrations of the compounds was enzymes (Dinçler and Aydemir 2001; Gao, Hian and Xiao 2009). All the categories were studied in leaves, and five (betalains, flavonoids, minerals, non-flavonoid phenolics, and vitamins) were also described in stems, stalks, or petioles. In seeds, studies reported carboxylic acids, flavonoids

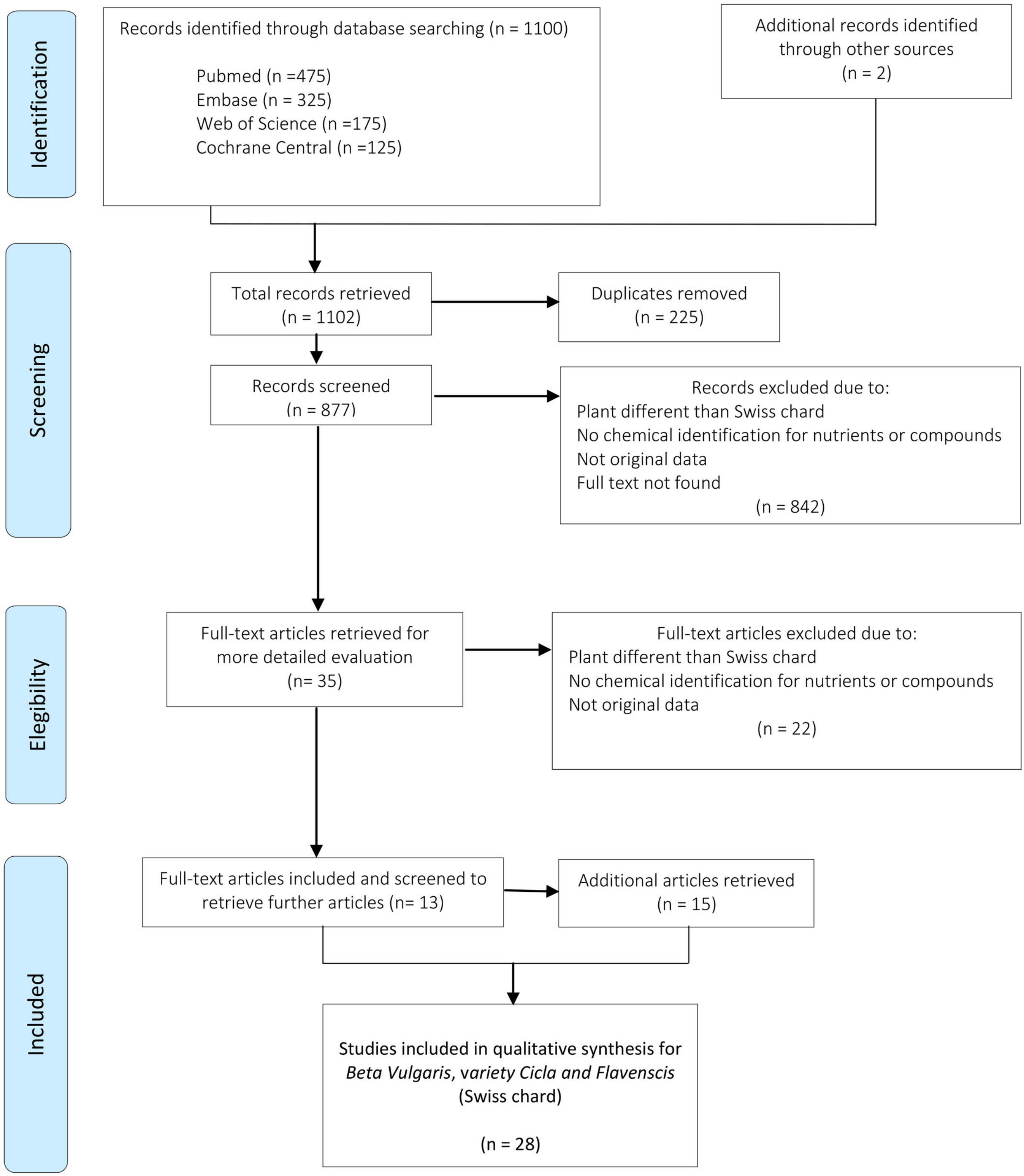

Figure 1. Flowchart of studies reporting nutrients and bioactive composition of *Beta vulgaris var. cicla/flavescens*.

and non-flavonoid phenolics, which was similar to the findings in roots except for the category of carboxylic acids. In the tissue (leaves and stems together) of Swiss chard were analyzed the Proximate composition, carotenoids, flavonoids, minerals, pigments, non-flavonoid phenolics, and vitamins (Supplemental Table 1). The specific results for Swiss chard Proximate composition and the largest compounds categories are presented hereunder.

Proximate composition of Swiss chard

Five authors reported compounds related to the Proximate composition of *Beta vulgaris* in the *cicla* variety (Zeller, Rudolph, and Hoppe 1977; Sacan and Yanardag 2010; Colonna et al. 2016; Ivanovic et al. 2019; Mzoughi et al. 2019). Carbohydrates, fat and protein were reported in leaves and the tissue. The concentration values in the tissue were up to 3.8 fold higher than in leaves, similar to the fat content (Table 2a). Ash and total fiber concentrations were studied only in leaves, and these results can be compared with those reported in the FoodData Central (Swiss chard, raw) of the U.S. Department of Agriculture (USDA 2019). For total carbohydrates (3740 mg/100 g vs. 2158 mg/100 g) and fats (200 mg/100 g vs. 99 mg/100 g, the value reported in the FoodData central (2019) is higher than reported data by Mzoughi et al. (2019). Regarding proteins, the amounts are similar between FoodData Central (1800 mg/100 g) and the amount reported by Colonna et al. (2016) (1500 mg/100 g). The only value in our review that is higher compared to those reported by the USDA is fiber, given that Mzoughi et al. (2019) found 2430 mg/100 g vs. 1600 mg/100 g reported by the USDA.

Betalains

Betalains are water-soluble nitrogen-containing pigments derived from betalamic acid and divided into two groups: betacyanins (red to red-violet tonalities) and betaxanthins (yellow-orange tonalities) (Esquivel 2016). Three articles (Kugler et al. 2007; Kugler, Stintzing, and Carle 2004; Ali, Khandaker, and Oba 2009) reported on this category in the Swiss chard variety *cicla,* with two of them belonging to Kugler et al. (Kugler, Stintzing, and Carle 2004; Kugler et al. 2007). The articles focused on the petioles or stems of the cv. Bright Lights since this is the colored part of the plant. Thirty-five compounds from both groups of betalains were identified (Supplemental Table 2), but only the total concentrations of betacyanins, betaxanthins and betalains were quantified in four different Swiss chard petiole's colors of the cultivar mentioned above (Table 2b). The highest concentration of betaxhantins was found in the yellow petioles (10.74 mg/100 g F.W.), while betacyanins and the total content of betalains were higher in the purple-colored ones (5.87 mg/100 g F.W. and 7.54 mg/100 g F.W., respectively). The higher content of total betaxanthins than total betalains could be due to different methods of analysis used by Kugler et al. in his two papers (Kugler et al. 2007; Kugler, Stintzing, and Carle 2004). Our review did not find any article reporting concentrations for any individual betalains.

Regarding the biological activity in the three articles assessing betalains, only one paper analyzing this chemical group (Ali, Khandaker, and Oba 2009) mentioned and measured its antioxidant activity. The authors compared the antioxidant activity of five leafy vegetables, where Swiss chard ranked third among them.

Fat, lipids, fatty acids, and related compounds

After betalains, this category with 25 compounds described in three papers (Zeller, Rudolph, and Hoppe 1977; Ivanovic et al. 2019; Mzoughi et al. 2019) is the second-ranked list of constituents, and the description was done exclusively in the *cicla* variety. Authors identified seventeen fatty acids, five lipids and three fat-related compounds (Supplemental Table 2) including the total concentration of monounsaturated fatty acids, polyunsaturated fatty acids, saturated fatty acids, and the unsaturated/saturated fatty acids ratio (Supplemental Table 3). The quantitative analysis of this group of compounds was available for 17 fatty acids and three fat-related chemicals analyzed by Mzoughi et al. (2019) in the leaves of an unknown cultivar. The results indicate that linoleic acid is the most concentrated fatty acid in Swiss chard leaves, with 26% of the individual fatty acids in the lipid fraction (Table 2c). Palmitic acid has the second-highest level with 23%, followed by oleic acid (19%), stearic acid (8%) and palmitoleic acid (6%) (Figure 3). The unsaturated/saturated fatty acids ratio reported by Mzoughi et al. (2019) is 1.40, which is favorable to the prevention of cardiovascular diseases. Among the three fat-related compounds, (E)-3-octen-1-ol presents the highest concentration (2.7% of the volatile fraction).

When comparing the concentrations of the fatty acids of our review with those of the USDA FoodData Central (2019), the values of the database for linoleic and oleic acid (63 mg/100 g and 40 mg/100 g, respectively) are twice those reported by Mzoughi et al. (2019) (26.5 mg/100 g and 19.1 mg/100 g, respectively). The concentration for palmitic acid is similar between the two information sources (30 mg/100 g for USDA and 22.9 mg/100 g for Mzoughi et al. 2019). For both the stearic and palmitoleic acid, the USDA (2019) reports no concentration (0 mg/100 g), while Mzoughi et al. (2019) found 8.1 and 6.31 mg/100 g, respectively. These differences could be related to the analyzed plant's variety and cultivar and the methods applied to quantify the concentrations.

As for the functional properties of this category, only one article (Mzoughi et al. 2019) mentioned the importance of oleic acid, which is present in leaves of Swiss chard, for the nervous cell construction and its fundamental role in cardiovascular disease prevention.

Flavonoids and derivatives

Flavonoids are secondary metabolites corresponding to polyphenols, which have varied structures and are distributed in all the plant's parts acting as pigments, defense, or growth regulators (Hernández-Rodríguez, Baquero, and Larrota 2019). Flavonoids are composed of a benzo-g-pyrone structure and three phenolic rings that can present various substitutions (e.g., the type, number, distribution and orientations in space) leading to derivatives with distinct structures and properties (flavonols, flavones, anthocyanidins, catechins, flavanones, and isoflavones) (Li et al. 2019).

Regarding this group of bioactive compounds, 20 phytochemicals and the total flavonoid (TFC) and flavonols concentrations were found in eleven articles (Gil, Ferreres, and Tomás-Barberán 1998; Kim et al. 2004; Pyo et al. 2004; Ninfali et al. 2007; Sacan and Yanardag 2010; Gennari et al. 2011; Ninfali and Angelino 2013; Moyo et al. 2017; Ivanovic et al. 2019; Mohammed et al. 2019; Mzoughi et al. 2019) that studied all the Swiss chard parts in the *cicla* variety (Supplemental Table 2). The most-reported flavonoid was 2″-xylosylvitexin, which was identified by three authors (Gil,

Table 1. General characteristics of the papers included in this review.

Author	Variety	Cultivar	Leaves	Stems	Stalks	Petioles	Seeds	Tissue	Roots	NR	No. of included compounds	Chemical structure category reported	No. of included compounds reported quantitatively
Zeller, Rudolph, and Hoppe (1977)	Cicla	Glatter Silber	x								5	Fat, lipids, fatty acids and related compounds	0
Ferland and Sadowski (1992)	NR	Not reported								x	1	Vitamins	1
Gil, Ferreres, and Tomás-Barberán (1998)	Cicla	Green Yellow	x								7	Flavonoids and derivatives Vitamins	7
Dinçler and Aydemir (2001)	Cicla	Not reported	x								1	Enzymes	0
Pokluda and Kuben (2002)	Cicla	Bright Lights Červený Fordhook Giant Gator Genfer Selma Charlotte Listový zelený Lucullus - Semo Lucullus - Semena Rhubarb Rhubarb Chard Swiss Chard Zürcher Gelber	x		x						5	Minerals/Trace elements/Metals Vitamins	5
Kim et al. (2003)	Cicla	Not reported					x				4	Carboxylic Acids Non-flavonoids phenols/phenolics	0
Moreira, Roura, and del Valle (2003)	Cicla	Bresanne	x								2	Pigments Vitamins	2
Kim et al. (2004)	Cicla	Not reported	x								4	Flavonoids and derivatives Terpenes and derivatives	0
Kugler, Stintzing, and Carle (2004)	Cicla	Bright Lights				x					31	Betalains	3
Pyo et al. (2004)	Cicla	Large w. ribbed CXS 2550	x	x							16	Flavonoids and derivatives Non-flavonoids phenols/phenolics	2
Kugler et al. (2007)	Cicla	Bright Lights				x					26	Betalains	1
Ninfali et al. (2007)	Cicla	Not reported	x								5	Flavonoids and derivatives Non-flavonoids phenols/phenolics	1
Dzida and Pitura (2008)	Cicla	Lukullus	x								5	Minerals/Trace elements/Metals Vitamins	5
Ali, Khandaker, and Oba (2009)	Cicla	Not reported	x								3	Betalains Non-flavonoids phenols/phenolics Pigments	0
Gao, Han, and Xiao (2009)	Cicla	Red	x								1	Enzymes	0
Kolota, Sowinska, and Czerniak (2010)	Cicla	Lukullus Green White Ribbed Vulcan Bresanne Green Silver	x			x					5	Minerals/Trace elements/Metals Vitamins	5
Sacan and Yanardag (2010)	Cicla	Not reported	x								4	Anthocyanins Flavonoids and derivatives Non-flavonoids phenols/phenolics Proteins and aminoacides	4
Bozokalfa et al. (2011)	Cicla	Not reported	x								9	Minerals/Trace elements/Metals	9
Gennari et al. (2011)	Cicla	Not reported					x				7	Flavonoids and derivatives	1

(continued)

Table 1. Continued.

Author	Variety	Cultivar	Leaves	Stems	Stalks	Petioles	Seeds	Tissue	Roots	NR	No. of included compounds	Chemical structure category reported	No. of included compounds reported quantitatively
Ninfali and Angelino (2013)	Cicla	Not reported	x				x		x		2	Non-flavonoids phenols/phenolics Flavonoids and derivatives	2
Reif et al. (2013)	Fla-vescens	Berac Charlotte	x								2	Non-flavonoids phenols/phenolics Carotenoids	2
Miceli and Miceli (2014)	Cicla	Verde da taglio	x								2	Pigments Vitamins	2
Colonna et al. (2016)	Cicla	Agila	x								7	Minerals/Trace elements/Metals Non-flavonoids phenols/phenolics Proteins and aminoacides Vitamins	7
Moyo et al. (2017)	Cicla	Fordhook Giant								x	20	Carotenoids Flavonoids and derivatives Minerals/Trace elements/Metals Non-flavonoids phenols/phenolics	2
Ivanovic et al. (2019)	Cicla	Verca F1 hybrid						x			22	Ash Carbohydrates, soluble sugars and polyols Carotenoids Fat, lipids, fatty acids and related compounds Fibers Flavonoids and derivatives Pigments Proteins and aminoacides Minerals/Trace elements/Metals Non-flavonoids phenols/phenolics	22
Mohammed et al. (2019)	Fla-vescens	Not reported	x								5	Flavonoids and derivatives	0
Mzoughi et al. (2019)	Cicla	Not reported	x								98	Alcohols Aldehydes Alkanes Ash Carbohydrates, soluble sugars and polyols Carboxylic Acids Carotenoids Fat, lipids, fatty acids and related compounds Fibers Flavonoids and derivatives Heterocyclics Ketones Minerals/Trace elements/Metals Non-flavonoids phenols/phenolics Pigments Proteins and aminoacides Tannins Terpenes and derivatives Other compounds	98
Singh, Dunn, and Payton (2019)	Cicla	Magenta sunset	x								2	Minerals/Trace elements/Metals	2

NR, not reported.

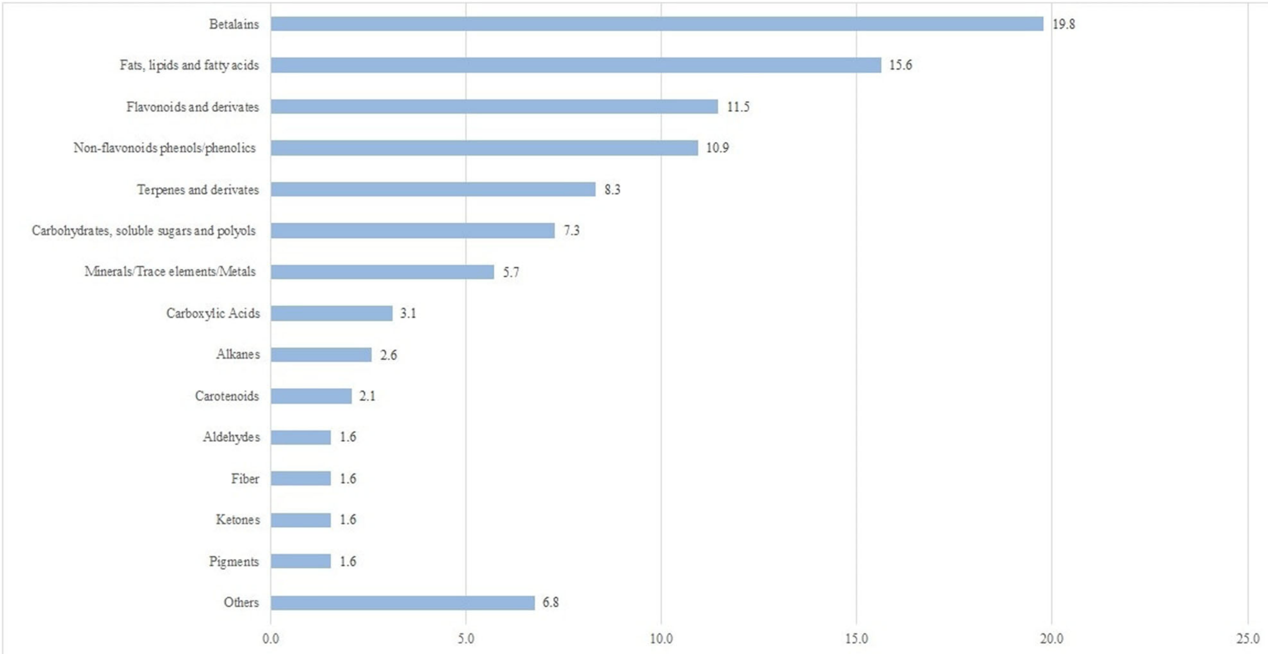

Figure 2. Percentage of total reported compounds by categories of chemicals and bioactive compounds found in *Beta vulgaris var. cicla/flavescens*.

Ferreres, and Tomás-Barberán 1998; Gennari et al. 2011; Ninfali et al. 2007) and is a derivative from apigenin. Apigenin is a compound associated with several biological functions like antioxidant, anti-inflammatory, antimicrobial (antibacterial, antifungal, and antiparasitic) and cancer chemopreventive (anti-mutagenic, anti-proliferative, and inhibitor of the cell cycle progression) (Wang et al. 2019; Patel, Shukla, and Gupta 2007). It has beneficial effects on diabetes, and neuropsychiatric diseases, among others (Salehi et al. 2019). Only five compounds were analyzed quantitatively by Gil et al. (1998) in leaves of green and yellow cv. of Swiss chard. Table 2d shows 2″-xylosylvitexin as the most concentrated flavonoid with 193 mg/100 g F.W. in Green cv., while in the Yellow another derivative of apigenin, 6″-Malonyl-2″-xylosyl vitexin has the highest concentration with 144 mg/100 g F.W. Concerning the TFC of Swiss chard, seven papers reported concentrations in different units and plant's part (Sacan and Yanardag 2010; Ninfali and Angelino 2013; Moyo et al. 2017; Ivanovic et al. 2019; Mzoughi et al. 2019; Gil, Ferreres, and Tomás-Barberán 1998; Pyo et al. 2004) (Supplemental Table 3). Two authors described TFC in mg/100 g F.W. (Gil, Ferreres, and Tomás-Barberán 1998; Pyo et al. 2004); however, the results show big disparities because Gil et al. (1998) found a maximal concentration of 276 mg/100 g F.W. in leaves of green cv., while Pyo et al. (2004) reported 28.2 mg/100 g F.W. as the highest concentration in the tissue of the cv. CXS 2550 (red). These discrepancies could be due to several factors like the cultivars, the form in which the plant's part was prepared for extraction, the type of extract studied, and the methods used to quantify the TFC. The TFC was also reported in catechin equivalents (CEs) in four studies (Sacan and Yanardag 2010; Moyo et al. 2017; Ivanovic et al. 2019; Mzoughi et al. 2019). In this case, we are comparing only those papers which described their results in the same units of concentration. When the values were informed as µg (CE)/mg extract, the highest concentration was found on the tissue of the cv. Verca F1 hybrid (12.05), which is slightly higher than the value obtained for the leaves of an unknown Swiss chard cultivar (11.88). Finally, Ninfali and Angelino (2013) was the only author studying TFC in leaves, roots and seeds of an unknown cultivar and reported results in mg/g D.W. The highest amount of total flavonoids was recorded in leaves reaching 7.92 mg/g D.W., which is five and nine times higher than in seeds and roots, respectively.

The above described biological functions associated with apigenin were also mentioned as properties of the flavonoids in six of the eleven reports analyzing this phytochemical group (Gil, Ferreres, and Tomás-Barberán 1998; Kim et al. 2004; Ninfali and Angelino 2013; Moyo et al. 2017; Ivanovic et al. 2019; Mohammed et al. 2019). The most studied property was the antioxidant with four articles reporting it (Sacan and Yanardag 2010; Gennari et al. 2011; Moyo et al. 2017; Ivanovic et al. 2019). Other reported analyses of the Swiss chard flavonoids were related to their antidiabetic (Mohammed et al. 2019; Mzoughi et al. 2019), anticancer (Ninfali et al. 2007; Gennari et al. 2011), antibacterial (Mohammed et al. 2019) and hepatoprotective (Kim et al. 2004) properties.

Non-flavonoids phenols/phenolics

Phenolic compounds are a large group of chemical substances that possess an aromatic ring and a benzene ring with one or more hydroxide groups, including functional derivatives (esters, methyl esters, glycosides, among others). This group of bioactives plays a role as secondary metabolites of plants with various activities like plant growth, reproduction and defense. The most common form of phenolics in nature is glycosides, but they can also be found joined to carboxylic

Table 2. Proximate composition of *Beta vulgaris* (Swiss chard) and most concentrated compounds in the largest chemical categories according to the reported unit of concentration.

Table 2a. Proximate composition (mg/100 g F.W.)

					Mean concentration according to plant's part		
No.	Compound name	PubChem CID	Variety	Cultivar	Tissue	Leaves	Reference
11	Ash	NAp	Cicla	Verca F1 hybrid	1810	NA	Ivanovic et al. (2019)
28	Total carbohydrates	NAp	Cicla	Verca F1 hybrid	6250	NA	Ivanovic et al. (2019)
				NR	NA	2158	Mzoughi et al. (2019)
61	Fat	NAp	Cicla	Verca F1 hybrid	380	NA	Ivanovic et al. (2019)
				NR	NA	99	Mzoughi et al. (2019)
64	Total dietary fiber	NAp	Cicla	NR	NA	2430	Mzoughi et al. (2019)
95	Protein	NAp	Cicla	Verca F1 hybrid	2350	NA	Ivanovic et al. (2019)
				Agila	NA	1500	Colonna et al. (2016)

Table 2b. Betalains content in Swiss chard petioles (mg/100 g F.W.).

					Mean concentration according to cultivar color				
No.	Compound name	PubChem CID	Variety	Cultivar	Purple	Red purple	Yellow	Yellow–orange	Reference
12	Total betaxanthins	NAp	Cicla	Bright lights	NA	NA	10.74	NA	Kugler et al. (2007)
					2.43	2.49	4.97	2.2	Kugler et al. (2007)
13	Total betacyanins	NAp	Cicla	Bright lights	5.87	3.03	trace	1.37	Kugler et al. (2007)
14	Total betalains	NAp	Cicla	Bright lights	7.54	5.06	4.97	3.36	Kugler et al. (2007)

Table 2c. Most concentrated fatty acids in Swiss chard leaves (% of individual fatty acids in the lipid fraction).

No.	Compound name	PubChem CID	Variety	Cultivar	Concentration (mean)	Reference
44	Linoleic acid	5280450	Cicla	NR	26.54	Mzoughi et al. (2019)
39	Palmitic acid	985	Cicla	NR	22.92	Mzoughi et al. (2019)
43	Oleic acid	445639	Cicla	NR	19.15	Mzoughi et al. (2019)
42	Stearic acid	5281	Cicla	NR	8.17	Mzoughi et al. (2019)
40	Palmitoleic acid	445638	Cicla	NR	6.31	Mzoughi et al. (2019)

Table 2d. Reported concentrations of flavonoids and derivatives in Swiss chard leaves (mg/100 g F.W.).

				Mean concentration according to cultivar		
No.	Compound name	PubChem CID	Variety	Green	Yellow	Reference
65	2″-xylosylvitexin	101406315	Cicla	193	75	Gil, Ferreres, and Tomás-Barberán (1998)
66	6″-Malonyl-2″-xylosyl vitexin	44257736	Cicla	34	144	Gil, Ferreres, and Tomás-Barberán (1998)
67	Isorhamnetin 3-gentiobioside	5488387	Cicla	39	ND	Gil, Ferreres, and Tomás-Barberán (1998)
68	Isorhamnetin 3-vicianoside	44258010	Cicla	10	ND	Gil, Ferreres, and Tomás-Barberán (1998)
69	Kaempferol 3-gentiobioside	9960512	Cicla	Trace	Not quantified	Gil, Ferreres, and Tomás-Barberán (1998)

Table 2e. Total phenols/phenolics concentration.

					Mean concentration		
No.	Compound name	PubChem CID	Variety	Cultivar	Plant's part	Value	Reference
mg GAE/100 g D.W.							
90	Total Phenols	NAp	Cicla	NR	Seeds	24677	Gennari et al. (2011)
90	Total Phenols	NAp	Cicla	Agila	Leaves	9658	Mzoughi et al. (2019)
90	Total phenolics	NAp	Cicla	Fordhook Giant	NR	1104	Moyo et al. (2017)
mg/100 g F.W.							
90	Total concentration of phenolics	NAp	Cicla	CXS 2550 (red)	Tissue	157.8	Pyo et al. (2004)
90	Total concentration of phenolics	NAp	Cicla	CXS 2550 (red)	Leaves	128.1	Pyo et al. (2004)
90	Total concentration of phenolics	NAp	Cicla	Large white ribbed	Tissue	124.7	Pyo et al. (2004)

acids, organic acids, amines, lipids, and other phenolic compounds (Barba, Esteve, and Frígola 2014).

Eleven papers (Kim et al. 2003; Pyo et al. 2004; Ninfali et al. 2007; Ali, Khandaker, and Oba 2009; Sacan and Yanardag 2010; Gennari et al. 2011; Ninfali and Angelino 2013; Colonna et al. 2016; Moyo et al. 2017; Ivanovic et al. 2019; Mzoughi et al. 2019) described 18 compounds identified in the *cicla* variety (Supplemental Table 2). Only three phytochemicals (myricitrin acid, p-coumaric acid and rosmarinic acid) were analyzed quantitatively by Mzoughi et al. (2019) in leaves of a non-reported cultivar (Supplemental Table 3). p-Coumaric acid is the most reported compound of this category, with three articles mentioning it (Mzoughi et al. 2019; Pyo et al. 2004; Moyo et al. 2017). The total phenolic content (TPC) was studied in all the parts of the Swiss chard and was measured in F.W. as mg/100 g and D.W. as mg GAE/100 g (gallic acid equivalents). The highest reported concentrations were in the seeds of an unknown cultivar with 24,677 mg GAE/100 g D.W (Gennari et al. 2011) and 157.8 mg/100 g in the tissue of cv. CXS 2550 (red) (Pyo et al. 2004) (Table 2e).

Table 2f. Most concentrated terpenes and derivatives in Swiss chard leaves (% of total volatiles).

No.	Compound name	PubChem CID	Variety	Cultivar	Concentration (mean)	Reference
98	α-terpineol	17100	Cicla	NR	5.8	Mzoughi et al. (2019)
102	β-Pinene	14896	Cicla	NR	5.8	Mzoughi et al. (2019)
108	Limonene	22311	Cicla	NR	5.6	Mzoughi et al. (2019)
107	Geraniol	637566	Cicla	NR	3	Mzoughi et al. (2019)
104	Citronellol	8842	Cicla	NR	2.8	Mzoughi et al. (2019)

Table 2g. Most concentrated minerals.

					Mean concentration according to plant's part			
No.	Compound name	PubChem CID	Variety	Cultivar	Leaves	Stalks/petioles	Tissue	Reference
mg/100 g F.W.								
81	K	5462222	Cicla	Listový zelený	705.1	**759.4**	NA	Pokluda and Kuben (2002)
				Verca F1 hybrid	NA	NA	366.2	Ivanovic et al. (2019)
84	Na	5360545	Cicla	Listový zelený	**337.9**	140.1	NA	Pokluda and Kuben (2002)
				Zürcher Gelber	236.6	179	NA	Pokluda and Kuben (2002)
				Verca F1 hybrid	NA	NA	130.2	Ivanovic et al. (2019)
82	Mg	5462224	Cicla	NR	**307.1**	NA	NA	Mzoughi et al. (2019)
				Listový zelený	60.9	14.3	NA	Pokluda and Kuben (2002)
				Verca F1 hybrid	NA	NA	91.8	Ivanovic et al. (2019)
76	Ca	5460341	Cicla	NR	154.1	NA	NA	Mzoughi et al. (2019)
				Červený	63.6	43.8	NA	Pokluda and Kuben (2002)
				Verca F1 hybrid	NA	NA	**168.9**	Ivanovic et al. (2019)
85	P	5462309	Cicla	Agila	19.1	NA	NA	Colonna et al. (2016)
				Verca F1 hybrid	NA	NA	**60.5**	Ivanovic et al. (2019)
mg/100 g D.W.								
81	K	5462222	Cicla	NR	3685	NA	NA	Bozokalfa et al. (2011)
82	Mg	5462224	Cicla	NR	542	NA	NA	Bozokalfa et al. (2011)
84	Na	5360545	Cicla	NR	396	NA	NA	Bozokalfa et al. (2011)
85	P	5462309	Cicla	NR	355	NA	NA	Bozokalfa et al. (2011)
76	Ca	5460341	Cicla	NR	351	NA	NA	Bozokalfa et al. (2011)
Percentage (%) D.W.								
81	K	5462222	Cicla	Lukullus	**9.23**	NA	NA	Dzida and Pitura (2008)
				Ribbed	6.24	8.43	NA	Kolota, Sowinska, and Czerniak (2010)
76	Ca	5460341	Cicla	Lukullus	**1.3**	NA	NA	Dzida and Pitura (2008)
				Green White	0.1	0.18	NA	Kolota, Sowinska, and Czerniak (2010)
85	P	5462309	Cicla	Lukullus	**1.19**	NA	NA	Dzida and Pitura (2008)
				Green White	0.45	0.43	NA	Kolota, Sowinska, and Czerniak (2010)
82	Mg	5462224	Cicla	Lukullus	**0.94**	NA	NA	Dzida and Pitura (2008)
				Bresanne	0.67	0.43	NA	Kolota, Sowinska, and Czerniak (2010)

NAp, not applicable; NA, not analyzed; NR, not reported; ND, not determined or traces.

Seven papers (Pyo et al. 2004; Ali, Khandaker, and Oba 2009; Sacan and Yanardag 2010; Ninfali and Angelino 2013; Colonna et al. 2016; Moyo et al. 2017; Mzoughi et al. 2019) attributed to phenols a central role in the antioxidant property seen in Swiss chard. One article has also assessed and reported that these phytochemicals present anti-inflammatory and anticancer properties (Kim et al. 2003).

Terpenes and derivatives

Terpenes are the largest class of compounds found in essential oils and are made up of isoprene molecules that, according to their structure, can be subdivided into acyclics (linear) or cyclics (ring) (Başer and Demirci 2007). Several terpenes and derivatives are biologically active, and their effects have been studied against cancer, inflammation, and a variety of infectious diseases (Mbaveng, Hamm, and Kuete 2014). Among this category, sixteen compounds were identified (Supplemental Table 2) by two authors (Kim et al. 2004; Mzoughi et al. 2019) who analyzed only the leaves of the *cicla* variety. Mzoughi et al. (2019) quantified the concentrations of fourteen terpenes and derivatives as percentages of the total volatiles. As can be seen in Table 2f and Figure 3, α-terpineol and β-Pinene are both the most concentrated phytochemicals in this category, with 5.8% each of them. None of the papers analyzing this group mentioned any functional properties or conducted assays where terpenes from Swiss chard would play a role.

Carbohydrates, soluble sugars and total polyols

Soluble sugars, which are defined as mono- and disaccharides, play a major role in plant's physiological processes as photosynthesis, transport and heterotrophic energy utilization, and in the metabolic pathways related to the production of reactive oxygen species (Couée et al. 2006). Mzoughi et al (2019) is the only author describing sugars and polyols in leaves of an unknown cultivar of the *cicla* variety (Supplemental Table 2). The total carbohydrate content was already mentioned in the proximate composition section. Regarding sugars, a total of nine compounds were reported (Supplemental Table 3). Sucrose is the most concentrated sugar (1115 mg/100 g F.W.) exceeding by far the amounts of glucose (285 mg/100 g F.W.) and inositol (285 mg/100 g F.W.) (Figure 3).

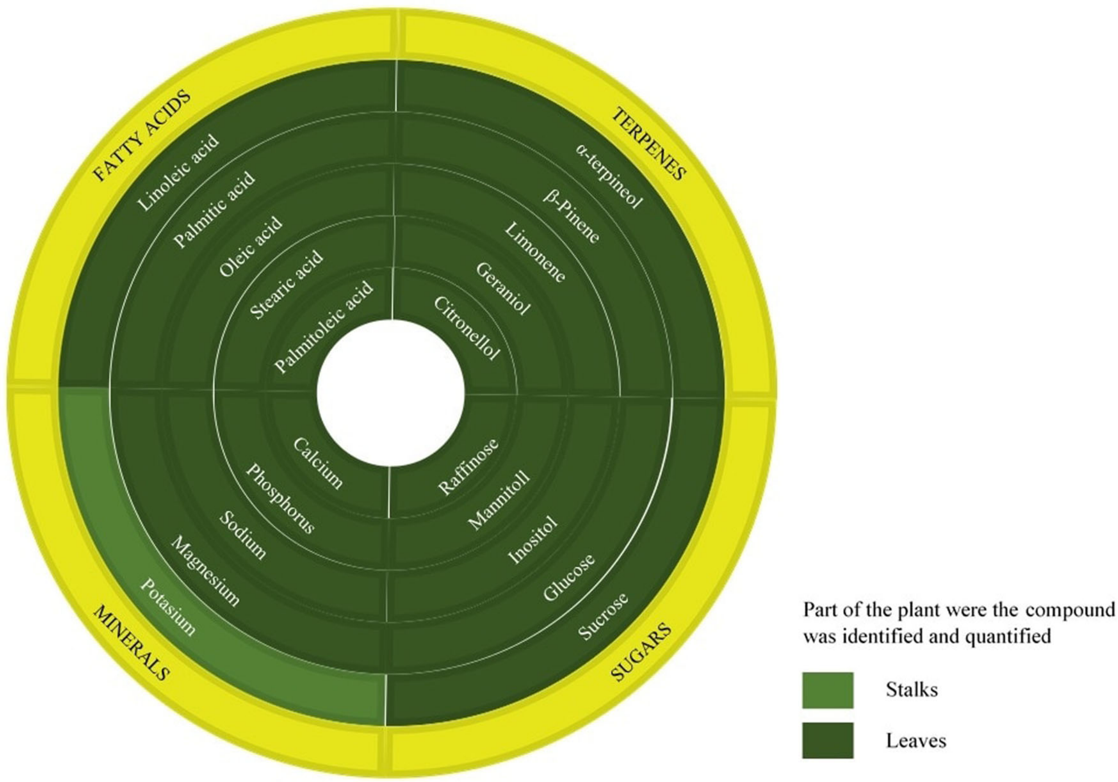

Figure 3. Five main concentrated phytochemicals (mg/100 g) in the largest bioactive compounds' categories for *Beta vulgaris var. cicla*.

Other compounds categories

Due to the nutritional and health importance of other compounds categories that were not among the largest ones, we describe here the results for carotenoids, minerals and trace elements, and vitamins that include 16 compounds.

For the carotenoids category, we found four papers (Reif et al. 2013; Moyo et al. 2017; Ivanovic et al. 2019; Mzoughi et al. 2019) analyzing β-carotene, lutein and lycopene, in leaves of three different types of cultivars belonging to the *cicla* and *flavescens* varieties (Supplemental Table 2). The highest reported value in this category corresponds to lutein (5.13 mg/100 g F.W.) detected in the cv. Charlotte of the *flavescens* variety (Supplemental Table 3). The β-carotene content was highest in the cv. Charlotte of the *flavescens* variety (4.48 mg/100 g F.W.) as reported by Reif et al. (2013); however, this concentration is five times higher than the one found by Mzoughi et al. (0.05 mg/100 g F.W.) (2019). This difference could be due to the plant varieties or the type of solvents used to extract the chemicals (Methanol - acetate solvent for *flavescens* variety and acetone solvent for the *cicla* variety). We compared the values for the cv. Charlotte with those referenced by the USDA (3.64 mg/100 g F.W.) (USDA 2019), and found a minimal difference. It is important to mention that 100 g of Swiss chard leaves (cv. Charlotte) contribute 47% (373 µg/100 g F.W.) of the mean recommended dietary allowance (RDA) for vitamin A in adults (800 µg Retinol Activity Equivalents) (Institute of Medicine (US) Panel on Micronutrients 2001) making this cultivar a significant dietary source of vitamin A.

Concerning the minerals, trace elements and metals category, the concentrations of eleven elements were determined in the leaves, petioles or stalks, and the whole tissue in 21 cultivars of the *cicla* variety by nine authors (Pokluda and Kuben 2002; Dzida and Pitura 2008; Kolota, Sowinska, and Czerniak 2010; Bozokalfa et al. 2011; Colonna et al. 2016; Moyo et al. 2017; Ivanovic et al. 2019; Mzoughi et al. 2019; Singh, Dunn, and Payton 2019) (Supplemental Table 2). Potassium was the most reported mineral being described for all the authors included in this category and followed by calcium and magnesium with eight papers analyzing each of them. We found that the concentrations were expressed in different units, as showed in Table 2g. For those minerals reported in mg/100 g of F.W., the highest amount corresponds to potassium in the stalks of the cv. Listový zelený (759.4 mg/100 g), although the difference comparing with the content in leaves of the same cultivar is not large (705.1 mg/100 g). Sodium is ranked as the second most concentrated mineral, followed by magnesium, calcium, and phosphorous; all of them have higher levels in leaves than in stalks (Figure 3). When comparing parts of the plant with the tissue (leaves and stems together), concentrations are higher in the latter for calcium and phosphorus. Nevertheless, it is important to highlight that the studies reporting for every part of the plant (Pokluda and Kuben 2002; Mzoughi et al. 2019) or the tissue (Ivanovic et al. 2019) are different, which implies dissimilarities in the utilized cultivar, cultivation methods and chemical assays on the plants. When reviewing the data described in mg/100 g D.W. by Bozokalfa et al. (2011), who analyzed only leaves of an unknown cultivar, potassium ranks first once more with 3685 mg followed in this case by magnesium with 542 mg; it is also worth noting that the concentration of sodium in D.W. is quite close to the one reported in F.W for the same element and in the same plant's part. Lastly, this category was also reported in % of D.W. and analyzed in leaves and stalks. Again, potassium is first among all the other studied elements and likewise indicating that this one is the most concentrated mineral in Swiss chard. Similar to the results reported in mg/100 g F.W., the higher concentrations in % of D.W. occur in leaves. We calculated mean values of the five most concentrated minerals reported per 100 g F.W. in leaves to compare them with those of the USDA (2019). Except for magnesium (mean 52.7 mg/100 g vs. 81 mg/100 g USDA) and phosphorous (mean 19.1 mg/100 g vs. 46 mg/100 g USDA), all the values were quite similar.

In the vitamins category, reports were done for vitamin C and vitamin K or (Phylloquinone) (Vitamin A was analyzed as β-carotenoid; hence it is part of the "carotenoids" category). These vitamins were analyzed in eight papers (Gil, Ferreres, and Tomás-Barberán 1998; Pokluda and Kuben 2002; Moreira, Roura, and del Valle 2003; Dzida and Pitura 2008; Kolota, Sowinska, and Czerniak 2010; Miceli and Miceli 2014; Colonna et al. 2016; Ferland and Sadowski 1992) that studied leaves, stalks, and petioles of twenty cultivars in the *cicla* variety for vitamin C. For vitamin K the analyzed cultivar and part are not stated in the article (Supplemental Table 2). Regarding vitamin C, the mean value in leaves is the highest one with 40 mg/100 mg F.W., which is almost two-fold the value found by Ivanovic et al. (2019) in tissue (25.2 mg/100 g F.W.) and almost six-fold the amount registered in stalks (mean 7.22 mg/100 g F.W.) (Supplemental Table 3). Comparing the mean value for leaves with the one from the USDA (30 mg/100 g F.W.) (USDA 2019), the difference is not remarkable. On vitamin K, we found only one author (Ferland and Sadowski 1992). The described content in an unknown part of the plant is 0.917 mg/100 g of F.W., which is 11% higher than the shown by the USDA (0.83 mg/100 g) (USDA 2019). When comparing the content of vitamin K that we found to the mean Adequate Intake (AI) for adults (Institute of Medicine (US) Panel on Micronutrients 2001), one leaf of this plant, equivalent to 48 g, provides four times the current AI value, making the Swiss chard a valuable source of Vitamin K.

Highest concentrated bioactive compounds in Beta vulgaris var. cicla

We have summarized the bioactive compounds with the twenty highest concentrations reported in mg/100 g F.W. in Table 3. In cases where a comparison among different parts of the plant or the whole tissue was possible for a compound, we included only the highest value reported between all authors for every plant's part. Macronutrients, fiber, and some minerals (potassium, sodium and magnesium) are in the ten most concentrated compounds. As expected, the highest quantities of carbohydrates, proteins and fat are found in the whole tissue of Swiss chard; however, a comparison between the plant's part is not possible since we did not find any articles analyzing macronutrients in stalks, stems or petioles. Minerals seem to be distributed among all the parts of the Swiss chard with sodium and magnesium being more present in leaves, calcium and phosphorous in the whole tissue and potassium in stalks. The total content of categories like flavonoids and phenolics are also among the twenty most concentrated compounds, yet a comparison for the TFC among the plant's part would not be adequate since the two authors describing the highest values for this item (Pyo et al. 2004; Gil, Ferreres, and Tomás-Barberán 1998) present dissimilar results. Regarding the TPC, the highest values quantified by the same author (Pyo et al. 2004) indicate that stalks are the richest part of the plant containing this type of phytochemicals. Some other compounds appearing in the top twenty most concentrated are soluble sugars (sucrose, glucose, inositol, and raffinose), flavonoids (2″-xylosylvitexin and 6″-Malonyl-2″-xylosyl vitexin), total chlorophyll and ascorbic acid. None of the bioactive chemicals reported in the *flavescens* variety reached the twenty most concentrated compounds.

Discussion

We identified 192 compounds across 28 articles included in this systematic review, which describes the nutritional and phytochemical composition of *Beta vulgaris, var. cicla or flavescens*. The most common chemicals reported in the literature are betalains, fatty acids, flavonoids, minerals, non-flavonoid phenols, and terpenes.

However, most of our findings are based mainly on leaves of the *cicla* variety, since only two papers (Reif et al. 2013; Mohammed et al. 2019) studied the *flavescens* variety. We also identified a lack of research using other parts of the plants like stems/stalks/petioles and seeds for compounds other than minerals, phenolics and flavonoids. Likewise, our systematic search could not identify any article regarding the nutritional and phytochemical composition of Swiss chard sprouts, which are available for human consumption in markets as microgreens. Regarding certain compounds groups like flavonoids, further research is needed to better understand its contribution to diet as part of Swiss chard given that we only found one study (Gil, Ferreres, and Tomás-Barberán 1998) identifying individual flavonoids, and it was published more than twenty years ago. Anthocyanins are an important group of phytochemicals since they possess strong biological functions such as anti-inflammatory, antitumor, antimutagenic and antioxidant activities (Kong et al. 2003); still, certain plants (order Caryophyllales) do not produce anthocyanin but betalains (Tanaka, Sasaki, and Ohmiya 2008). The motive for this condition is unknown, and according to some experts, no plant has yet been found that produces both betalain and anthocyanin pigments (Stafford 1994; Strack, Vogt, and Schliemann 2003). This could be the reason why we only found one article (16) reporting total anthocyanin content in Swiss chard leaves. Furthermore, none of the papers identifying betalains quantified them individually. Besides vitamin C, K, and vitamin

Table 3. Twenty most concentrated compounds reported in mg/100 g F.W in *Beta vulgaris var. cicla/flavescens* (Swiss chard).

Rank	No.	Category	Compound name	PubChem CID	Variety	Cultivar	Concentration mg/100 g F.W. (mean)			Reference
							Leaves	Stalks/stems	Tissue	
1	28	Carbohydrates, soluble sugars and total polyols	Total carbohydrates	NAp	Cicla	Verca F1 hybrid	NA	NA	6250[a]	Ivanovic et al. (2019)
						NR	2158	NA	NA	Mzoughi et al. (2019)
2	65	Fiber	Total dietary fiber	NAp	Cicla	NR	2430[b]	NA	NA	Mzoughi et al. (2019)
						Verca F1 hybrid	NA	NA	770	Ivanovic et al. (2019)
3	96	Proteins and aminoacides	Protein	NAp	Cicla	Verca F1 hybrid	NA	NA	2350[a]	Ivanovic et al. (2019)
						Agila	1500	NA	NA	Colonna et al. (2016)
4	23	Carbohydrates, soluble sugars and total polyols	Sucrose	5988	Cicla	NR	1115	NA	NA	Mzoughi et al. (2019)
5	82	Minerals/trace elements/metals	K	5462222	Cicla	Listový zelený	705.1	759.4[c]	NA	Mzoughi et al. (2019)
						Verca F1 hybrid	NA	NA	366.2	Ivanovic et al. (2019)
6	61	Fat, lipids, fatty acids and related compounds	Total lipids	NAp	Cicla	Verca F1 hybrid	NA	NA	380[a]	Ivanovic et al. (2019)
			Fat	NAp	Cicla	NR	99	NA	NA	Mzoughi et al. (2019)
7	84	Minerals/trace elements/metals	Na	5360545	Cicla	Listový zelený	337.9[b]	140.1	NA	Pokluda and Kuben (2002)
						Zürcher Gelber	236.6	179	NA	Pokluda and Kuben (2002)
						Verca F1 hybrid	NA	NA	130.2	Ivanovic et al. (2019)
8	93	Pigments	Chlorophyll contents	6449992	Cicla	Bressanne	321.3	NA	NA	Moreira et al. (2003)
9	82	Minerals/Trace elements/Metals	Mg	5462224	Cicla	NR	307.1[b]	NA	NA	Mzoughi et al. (2019)
						Listový zelený	60.9	14.3	NA	Pokluda and Kuben (2002)
						Verca F1 hybrid	NA	NA	91.8	Ivanovic et al. (2019)
10	18	Carbohydrates, soluble sugars and total polyols	Glucose	5793	Cicla	NR	285	NA	NA	Mzoughi et al. (2019)
11	70	Flavonoids and derivatives	Total flavonoid content	NAp	Cicla	Green	276[b]	NA	NA	Gil, Ferreres, and Tomás-Barberán (1998)
						CXS 2550 (red)	25.2	2.6	28.2	Pyo et al. (2004)
12	65	Flavonoids and derivatives	2′′-xylosylvitexin	101406315	Cicla	Green	193	NA	NA	Gil, Ferreres, and Tomás-Barberán (1998)
13	19	Carbohydrates, soluble sugars and total polyols	Inositol	892	Cicla	NR	182	NA	NA	Mzoughi et al. (2019)
14	76	Minerals/trace elements/metals	Ca	5460341	Cicla	Verca F1 hybrid	NA	NA	168.9[a]	Ivanovic et al. (2019)
						NR	154.1	NA	NA	Mzoughi et al. (2019)
						Červený	63.6	43.8	NA	Pokluda and Kuben (2002)
15	90	Non-flavonoids phenols/phenolics	Total concentration of phenolics	NAp	Cicla	CXS 2550 (red)	128.1	157.8[c]	29.7	Pyo et al. (2004)
16	66	Flavonoids and derivatives	6′′-Malonyl-2′′-xylosyl vitexin	44257736	Cicla	Yellow	144	NA	NA	Gil, Ferreres, and Tomás-Barberán (1998)
17	20	Carbohydrates, soluble sugars and total polyols	Mannitol	6251	Cicla	NR	82	NA	NA	Mzoughi et al. (2019)
18	111	Vitamins	Ascorbic acid	54670067	Cicla	Verde da taglio	70.6[b]	NA	NA	Mzoughi et al. (2019)
						Verca F1 hybrid	NA	NA	25.2	Ivanovic et al. (2019)
						Bright Lights	NA	9.9	NA	Pokluda and Kuben (2002)
18	21	Carbohydrates, soluble sugars and total polyols	Raffinose	439242	Cicla	NR	61	NA	NA	Mzoughi et al. (2019)
20	85	Minerals/trace elements/metals	P	5462309	Cicla	Verca F1 hybrid	NA	NA	60.5[a]	Ivanovic et al. (2019)
						Agila	19.1	NA	NA	Colonna et al. (2016)

NI, not included in PUBCHEM; NR, not reported; NA, not analyzed; Nap, not applicable.
[a]Higher content in tissue of Swiss chard.
[b]Higher content in leaves among different Swiss chard parts.
[c]Higher content in stems/stalks/petioles among different Swiss chard parts.

Table 4. Nutritional and phytochemical composition of the leaves of Beta vulgaris (Swiss chard) and other commonly consumed leafy vegetables (mg/100 g F.W.).

Plant nutrient/phytochemical (reference)	Swiss chard	Chicory	Green lettuce	Red chard	Spinach	Amaranth, leaves
Proteins (Colonna et al. 2016)	1500	2100	1700	1900	1600	2460[a]
Fat (Mzoughi et al. 2019)	99	300[a]	150[a]	200[a]	390[a]	330[a]
Total carbohydrates (Mzoughi et al. 2019)	2158	4700[a]	2870[a]	3740[a]	3630[a]	4020[a]
Total dietary fiber (Mzoughi et al. 2019)	2430	4000[a]	1300[a]	1600[a]	2200[a]	Not analyzed
Potasium (Colonna et al. 2016)	243.5	446.5	528.5	402	626.1	611[a]
Magnesium (Colonna et al. 2016)	14.9	19.7	27.4	38.9	52.0	55[a]
Calcium (Colonna et al. 2016)	12.1	29.9	22.9	16.4	25.4	215[a]
β-Carotene (Reif et al. 2013)	4.48	4.88[b]	2.55[b]	3.64[a]	7.28[b]	Not analyzed
Total phenols[c] (Colonna et al. 2016)	33.3	34.9	21.7	53.6	49.3	Not analyzed

[a]Source: U.S. Department of Agriculture (2019).
[b]Highest value reported by Reif et al., 2013 for the vegetable.
[c](mg gallic acid/100 g D.W.).

A (analyzed as β-carotene), our search did not find more chemicals belonging to this group, demonstrating that measures for other types of vitamins in Swiss chard are lacking in the scientific literature. Given the type of studies included in this review, we could not assess their quality since there are no validated tools for this purpose, and therefore our results should be interpreted with caution.

Some of the included articles in this review have broadly compared the nutritional and phytochemical composition of Swiss chard with other leafy vegetables such as chicory, green lettuce, red chard, spinach, and amaranth (Ali, Khandaker, and Oba 2009; Colonna et al. 2016; Reif et al. 2013). In Table 4, we present the proximal composition of Swiss chard leaves and its content of potassium, calcium, magnesium, and total phenols and compare this information with the leafy vegetables above mentioned as summarized by Colonna et al. (2016). We also compare the β-carotene content reported for the same plants by Reif et al. (2013). When the mentioned authors did not analyze the chemical and nutritional profile of a vegetable, we used the data from the USDA database (USDA 2019). Swiss chard has the lowest values for carbohydrates (2158 mg/100 F.W.), and total fat (99 mg/100 g F.W.) which makes it adequate for diets attempting weight reduction. While protein had also the lowest value (1500 mg/100 F.W.), the leaves of Swiss chard ranked second in the fiber content after chicory leaves (4000 and 2430 mg/100 F.W., respectively). Regarding the mineral content, the Swiss chard has the lowest values among the six compared GLVs. However, the higher values reported for potassium, magnesium and calcium in our review correspond to those described by Mzoughi et al. (2019) and they are at least three times larger than those founded by Colonna et al. (2016). As for β-carotene, Swiss chard leaves are positioned in third place after spinach and chicory (4.48, 7.28, and 4.88 mg/100 F.W., respectively). Lastly, Swiss chard leaves have also the third-highest value of total phenols content (33.3 mg gallic acid/100 g D.W.) after red chard (53.6 mg gallic acid/100 g D.W.) and spinach (49.3 mg gallic acid/100 g D.W.) This comparison shows the potential of Swiss chard as part of a healthy diet when consumed alternately with other leafy vegetables.

There are several health benefits linked to the Swiss chard bioactives found in this review. Experiments have shown that flavonoids present in the extract of *Beta vulgaris* var. *cicla* could have a hypoglycemic effect by inhibiting glucose transporters, mainly through the action of quercetin (Song et al. 2002). Vitexin and acacetin 8-C-β-D-glucopyranoside showed superior antidiabetic activities in comparison with Acarbose as a reference drug (Mohammed et al. 2019). An alternative explanation for this property could be an inhibitory effect on α-glucosidase and α-amylase activities observed from an ethanol extract prepared from Swiss chard leaves (Mzoughi et al. 2019). The antioxidant activity of Swiss chard is well studied and similar to the conclusions by Ali et al. (2009), it has been attributed to pigments present in the leaves and stems like chlorophyll, betalains, and carotenoids, but also to the flavonoids (Sacan and Yanardag 2010; Gennari et al. 2011; Moyo et al. 2017; Ivanovic et al. 2019) and non-flavonoids phenols/phenolics compounds and to the ascorbic acid (Kim et al. 2004; Colonna et al. 2016; Ivanovic et al. 2019). Some of the specific actions related to the antioxidant activity can be reviewed in betalains, which have demonstrated an ability to protect human red blood cells from oxidative hemolysis, to scavenge hypochlorous acid produced by neutrophils during the inflammatory response, to protect endothelial cells from the oxidation processes related to inflammatory response and, to inhibit lipid peroxidation of cell membranes in the blood (Ninfali and Angelino 2013).

The phenolic amides present in the extract of Swiss chard seeds have shown an anti-inflammatory effect demonstrated in vitro by inhibiting nitric oxide synthase (Kim et al. 2003). Betanin, a type of betalain, has also shown anti-inflammatory activity throughout the inhibition of cyclooxygenase, and prevention of the conversion of arachidonic acid into chemical mediators of inflammation (Reddy, Alexander-Lindo, and Nair 2005). Betalains also possess anticancer activity by hindering the infiltration capacity of tumoral cells, decreasing cell proliferation, and inducing apoptosis (Ninfali and Angelino 2013; Esquivel 2016). Apigenin-derived flavonoids found in leaves of Swiss chard, especially vitexin, have proven to contribute to the anticancer activity of this plant by inhibiting the proliferation of cancer cells and inducing apoptosis (Ninfali et al. 2007; Gennari et al. 2011). Since excessive nitric oxide production has been linked with cancer, the inhibitory activity of phenolic amides on lipopolysaccharide could be another pathway to exert a protective effect on carcinogenesis (Kim et al. 2003). The antioxidant and anti-inflammatory activities related with Swiss chard, its adequate unsaturated/saturated fatty acids ratio and its high fiber, carotenoids, flavonoids, and potassium content could play a role in the regulation of blood pressure and of the lipid and glucose metabolism. Therefore, the nutrients and phytochemicals present in Swiss chard could contribute to the cardioprotective effect of this plant as part of the leafy green vegetable family (Blekkenhorst et al. 2018).

To our knowledge, this is the first systematic review on the subject that critically appraised the literature following an a priori designed protocol with clearly defined inclusion and exclusion criteria. Using a systematic search in the databases, we found only one classical review conducted by Ninfali and Angelino (2013) evaluating the nutritional and biological properties of Swiss chard. In contrast to systematic reviews, narrative reviews do not involve a systemic search, and they are often focused on a subset of studies in the chosen area based on the availability of the author selection. Therefore, they are more likely to experience selection bias (Garg, Hackam, and Tonelli 2008; Uman 2011).

Conclusions

Swiss chard (*Beta vulgaris* L. var. *cicla* or *flavescens*) can be considered a good source of fiber, betalains, flavonoids, β-carotene, vitamin K, and minerals like potassium and magnesium. Leaves and stems of the plant should be considered as part of a healthy diet. Further research is required for sprouts as they are already being consumed as microgreens. It is also important to broaden the knowledge on other phytochemical categories, like flavonoids, non-flavonoid phenols, minerals, terpenes, and vitamins, on all parts that constitute the plant and in the *flavescens* variety.

Disclosure statement

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