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Review

Old-Fashioned, but Still a Superfood—Red Beets as a Rich Source of Bioactive Compounds

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Abstract: Beetroot (*Beta vulgaris* L.) is a vegetable that is consumed worldwide in the form of juices, soups, or salads. It is also known for its high content of biologically active substances such as betalains, polyphenolic compounds, vitamins, carotenoids, and other nutrients including, sodium, potassium, and magnesium. The distribution of these compounds in the plant is diverse, some occur in greater amounts in the leaves (e.g., vitamin A, B6) and others are in the tubers (e.g., folate, lycopene). The concentration of bioactive compounds in beetroot also depends on its variety and growing conditions. Recent studies have reported on the beneficial effect of beetroot juice and beetroot products on the body's efficiency during prolonged physical exercise. The purpose of this review is to discuss the content of biologically active compounds in beetroot and the impact of beetroot product consumption on the human body, based on the latest literature.

Keywords: red beets; bioactive compounds; betalains; phenolic compounds; antioxidants

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1. Introduction

Beta vulgaris (beet) is an edible plant in the subfamily *Betoideae* of the family *Amaranthaceae*. It has several cultivar groups such as sweet beet, garden beet, chard, and mangoldwurzel. Red beetroots (*Beta vulgaris*) have been cultivated for many hundreds of years in all temperate climates. Surprisingly, the green parts of the beetroot were consumed initially in the form of chard [1]. The dish was so popular that the ancient Greeks and Romans developed a method of growing beetroot also during the hot summer months. It should be emphasized that this variety had only thin and fibrous roots, which were occasionally used in medicine. Consumption of underground beet parts was first reported in Germany and Italy in 1542 [2]. However, that beet variety was significantly different from the one we know today and rather closely resembled a parsnip. The beetroot variety that is still cultivated today appeared in the late 16th century, and is believed to have originated from a prehistoric North African root vegetable. Currently, most beetroots are consumed as a vegetable and also as a juice. Beetroots can also be processed into a powder for use as a food colorant E162 and additive to cosmetics [3–6].

Although beets have been known for centuries, understanding of their value is still limited. New reports about bioactive compounds in beets suggest that they fit the definition of a functional food, as they offer health benefits that extend beyond their nutritional value [7–9]. In addition to proteins, carbohydrates, fat, amino acids, fatty acids, phytosterols, minerals, and fibres, beetroot contains also vitamins, nitrate, polyphenolic compounds, and betalains, a class of red and yellow natural pigments found in plants. Betalains are considered to be strong antioxidant agents as they can decrease oxidative stress by efficiently removing the reactive oxygen species [9–11]. Other health benefits of betalains include antimicrobial, antiviral, and anti-inflammatory activities [12–14]. Several studies showed the tumour-chemopreventive effects of beetroot extracts in laboratory animals [15–17]. This is probably a synergistic effect of both betalains and other compounds present in beetroot, e.g., polyphenolic compounds. The scheme of the main bioactive compounds present in beetroot is depicted in Figure 1.

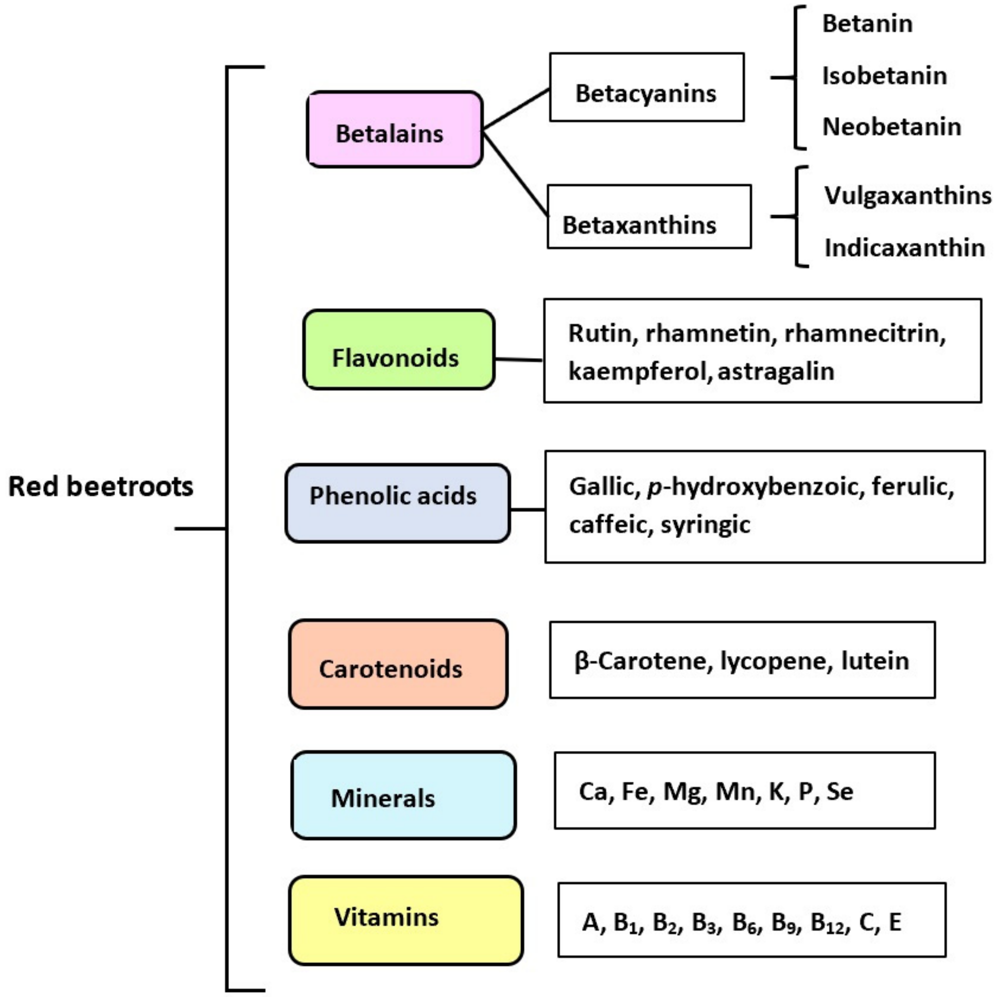

Figure 1. Main bioactive compounds present in red beetroots.

This review aims to collect the latest literature on the content of biologically active compounds in beets and beet products. It also provides an overview of the positive health effect associated with beet consumption.

2. Betalains

Betalains are water-soluble secondary metabolites that occur in many plants of the order *Caryphyllales*. They have a higher solubility in water compared to anthocyanins, and are stable in the pH range of 3–7, thus, can be used in low-acid and neutral foods [18,19]. Betalamic acid is a component of all betalains and its substituent type defines the class of betalain [20]. Betalamic acid can spontaneously condense with cyclo-DOPA (3,4-dihydroxy-phenylalanine, a precursor of betalain pigment in plants) yielding the violet betacyanins, or with amines or amino acids to produce yellow betaxanthins [21]. Their general chemical structures are presented in Figure 2 [18]. Red beets are the main edible source of these compounds. According to Delgado-Vargas et al., betacyanins content in beetroot accounts for 75–95% of the total pigments, the remaining 5–25% corresponds to betaxanthins [22]. The violet betacyanin is the most studied of all the betalain groups. Beetroot contains also its epimer, isobetanin, as well as other pigments like betaxanthins vulgaxanthin I and miraxanthin V [23]. Four betacyanins (betanin, prebetanin, isobetanin, neobetanin) and three betaxanthins (vulgaxanthin I, vulgaxanthin II, indicaxanthin) were identified in the water fractions of crude extracts of beetroot peel [24]. In beetroot juice samples, the presence of red pigments was reported in ranges of 797.5–421.7 mg·L^{-1} for betanin and 321.7–423.1 mg·L^{-1} for vulgaxanthin [25]. Concentrations of both dyes in purchased organic beetroot juice were higher than those in freshly squeezed juice [26]. However, the characteristic color quickly lost its intensity after storage at 20 °C, and after some time it was possible to notice the presence of a flocculent precipitate. Degradation products of betanin are isobetanin, decarboxylated betanin, betalamic acid, and cyclodopa glucoside [27]. Kazimierczak et al. determined higher concentrations of betalains in pure beetroot juices in comparison to those combined with other components (e.g., apple, lemon) [28].

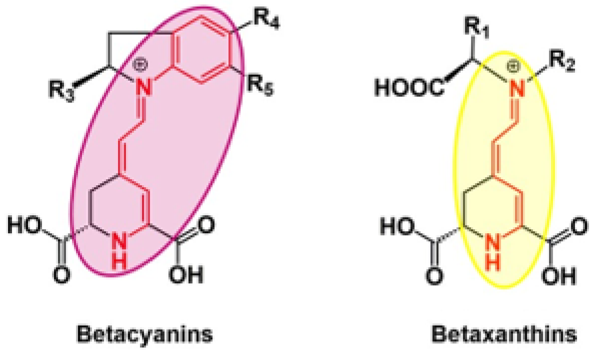

Figure 2. General chemical structures for betacyanins and betaxanthins. Reprinted with permission from [18].

Betalains can exert their action by different mechanisms, such as scavenging free radicals, regulating their content produced during biochemical reactions, and protecting cells from oxidative stress and damage. In food science, the term "antioxidant" is commonly used to describe compounds that prevent oxidative reactions, such as lipid peroxidation, maintaining the freshness of food products. In health science, this term includes free-radical scavenging of reactive oxygen species, reducing agents, and chelators of metal ions; thus, they have roles in preventing different chronic diseases [29]. However, many antioxidants at high concentrations could act as prooxidants and induce toxicity. Several studies confirmed the high radical-scavenging activity of betalains [30–32]. While betanin exhibits a high radical-scavenging activity at pH > 4, the highest activity of betanidin was reported at a pH range of 2–4 [30]. In betacyanins, acylation raises the antioxidant potential, whereas glycosylation decreases their activity. The highest potential was reported for betanin, followed by neobetanin, vulgaxanthin I, and indicaxanthin [32].

The losses of red pigments in the betalain solution (heated at 90 °C for 30 min in a water bath without access to light) increased, along with rising pH levels, due to their degradation [33]. The opposite correlation was observed for yellow pigments; the most pronounced increase in their levels was observed at a pH of 6.5–7.0. However, during heating, the antioxidant capacity of the solution was subject to only minor changes in the pH range of 4–9.

Many studies demonstrated the health-promoting effects of betalains. Most of these reports focus on their antioxidant, anti-inflammatory, and anti-carcinogenic properties, as was mentioned earlier [9,10,12–14]. The first studies investigating the chemopreventive potential of beetroot extract were carried out in mice in 1996 [34]. This study proved that oral administration of beetroot extract contributed to the reduction of the number of skin papillomas. Zhang et al. also proved the chemopreventive effect of betanin in mice [35]. In their study, two carcinogenic substances, vinyl carbamate and benzopyrene, were used to induce lung tumours, and then an oral treatment with an aqueous solution of betanin was administered. As a result, a reduction of cancer cells was observed, explained by the increased expression of caspase-3, a proapoptotic enzyme belonging to the cysteine-protease group, which increases cell apoptosis levels. The anticancer properties of betalains in mice with xenografts from human lung tumour cells were also proved (A549) [36].

According to Martinez et al., a more complex mechanism of betalain action is probably responsible for their antitumor effects [18]. The mechanism of action of *Beta vulgaris* betanin on tumour cells is present in Figure 3. First, the antioxidant properties of betanin increase the activity of antioxidant enzymes that neutralize ROS produced by immune cells. Then, the red pigments, due to their anti-inflammatory capacity, are able to reduce the production of pro-inflammatory cytokines that increase the migration of leukocytes to the tumour area [37]. At the final stage, betanin causes the formation of blood vessels (angiogenesis) around the tumour area, while increasing levels of apoptosis.

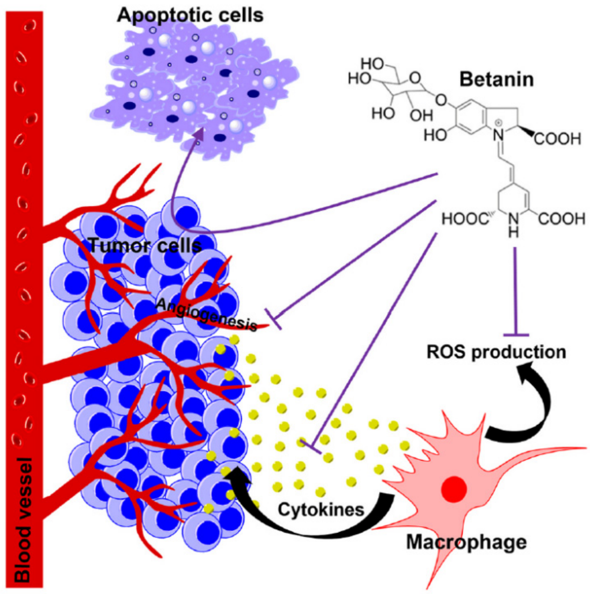

Figure 3. The mechanism of action of *Beta vulgaris* betanin on tumor cells. Reprinted with permission from [18].

The anti-inflammatory properties of betalains are obvious from the use of *B. vulgaris* betanin-rich pigments used as additives in the food industry. Several studies have attempted to explain the mechanism behind the mechanism of action of betalains [13,38,39]. The mechanism that could be responsible for observed anti-inflammatory effects may be the demonstrated in vitro inhibition that betalains exert on the enzymes lipoxygenase and cyclooxygenase, which are involved in the formation of the inflammation-mediating compounds leukotrienes and prostaglandins. The cardioprotective effect of betalains was also proved. Consumption of beetroot chips by rats resulted in a decrease in cholesterol and triglyceride levels in their blood [40]. Novel studies have evaluated the protective effect of betalain against heart failure [41], and the potential impacts of betalain supplementation on some atherosclerotic risk factors in coronary artery disease patients [42]. The effects of betalains on hyperglycemia in diabetic rats have also been reported [43,44].

Even though the results of animal studies clearly show the health-promoting effect of betalains, only a few similar studies on humans have been described. These examined the impact of betalain intake on the body's efficiency and cardiovascular system [42] and the impact of beet juice supplementation in reducing muscle damage following eccentric exercises [45]. The intake of red beetroot improves glucose metabolism and can help in the treatment of people with type 2 diabetes [46].

3. Flavonoids and Polyphenolic Acids

The high antioxidant capacity of beets is due not only to the high content of betalains, but also other phenolic compounds—flavonoids and polyphenolic acids. Significant amounts of catechins and polyphenolic acid (ferulic, protocatechuic, vanillic, p-coumaric, p-HBA, syringic, and caffeic) have been detected in beets [47–50]. However, the composition of plant extract depends on many factors, including the original plant (variety, maturation state), conditions of its cultivation (climate, harvesting), as well as its storage condition [51].

Kavalcowa et al. showed how much the total content of polyphenolic compounds depends on the beet variety and the place of its cultivation [50]. The highest content of total polyphenols was found in the variety of Renova from Sliač, in Slovakia (1280.56 $\mu g \cdot g^{-1}$), followed by red beetroot from Zohor. In addition, the variety of Zohor, obtained from Sihelné, had the lowest concentration of polyphenols (820 $\mu g \cdot g^{-1}$). In the case of the variety Monorubrawe, the highest value of total polyphenols was determined in samples from the area of Sihelné (1201.6 $\mu g \cdot g^{-1}$), followed by red beetroot from Sliač (1023.21 $\mu g \cdot g^{-1}$) and Zohor (988.66 $\mu g \cdot g^{-1}$). The variety-specific differences between the highest and lowest polyphenol contents were 460.56 $\mu g \cdot g^{-1}$ in the Renova variety and 212.94 $\mu g \cdot g^{-1}$ in the Monorubrawe variety. The authors concluded that the observed differences may be due to the high humus (4.0%) and potassium (520 $\mu g \cdot g^{-1}$) content in the soil. Studies conducted by Kujala et al. clearly showed that the total phenolics content decreases in order: peel (50%), crown (37%), and flesh (13%) [52]. The comparison of the phenolic composition in betalain extracts from intact *B. vulgaris* cv. *Detroit Dark Red* plants and hairy root cultures was described by Georgiev et al. [11]. The authors proved that the concentrations of selected polyphenolic compounds were even more than 100 times higher in extracts from hairy root cultures than in extracts obtained from intact plants. Moreover, rutin was present only in hairy root cultures, while chlorogenic acid was found only in intact plants. While quercetin was not reported in this study, Pratimasari and Puspitasari proved its presence in the purified extract of beetroot leaf [53]. In the study performed by Płatosz et al., quercetin was detected in fresh red beet, fermented red beet, and commercial fermented beet juice, in concentrations of 0.023 $\mu g \cdot g^{-1}$, 0.002 $\mu g \cdot g^{-1}$, and 0.009 $\mu g \cdot mL^{-1}$, respectively [47]. The results obtained by Georgiev indicated that the extract of the hairy roots had substantially higher concentrations of the identified phenolic compounds than did the intact plants, as noted above [11]. Moreover, there were differences in the phenolic profiles of the studied extracts. Chlorogenic acid was present only in the extract from intact plants, while rutin was found only in the extract from hairy root cultures. As the authors emphasize, it is a valuable discovery as rutin interacts synergistically with many other biologically active compounds present in the plant material enhancing its antioxidant properties [54]. The fermentation process caused an increase in the content of phenolic acids and a reduction in the content of their conjugated forms, while the same process caused a decrease in the content of free flavonoids [47]. In the case of the studies described by Płatosz, significant differences in the concentrations of polyphenolic acids were observed between the extracts from fresh and fermented beetroot [47]. Such large differences were not observed in the case of flavonoids, their concentrations in most cases were rather similar.

Attention to possible interactions between phenolic compounds in beetroot juice has been also drawn [25]. The content of the main active compounds in beetroot juice was determined by HPLC analysis before and after the addition of these compounds to the study juice, and the antioxidant activities of the obtained solutions were examined. Each of the studied additives had a great impact on the scavenging of the DPPH radicals in the juice. The addition of caffeic acid, rhamnetin, and vitamin B5 resulted in a decrease in this ability, which was shown in Figure 4. Antioxidant interactions can be synergistic, additive, or antagonistic, depending on the specific substances and their concentration ratios. In the case of examined additives, only betanin caused an increase in the ability to neutralize the DPPH radical, in comparison to beetroot juice without any additives. There is a synergistic effect here, which is particularly visible in the initial stage of the kinetic curve. In contrast, an antagonistic effect is observed for the remaining additives. The kind of interaction depends on the specific antioxidants interacting in the system and the condition behind the evaluation, as noted above, however, the knowledge about the interaction between polyphenolic compounds and vitamins as well as non-antioxidant compounds is still poor. A common theme in the scientific literature is that interactions between antioxidant molecules do occur, but a mechanism that allows a prediction of synergistic and antagonistic interactions is not clear [55].

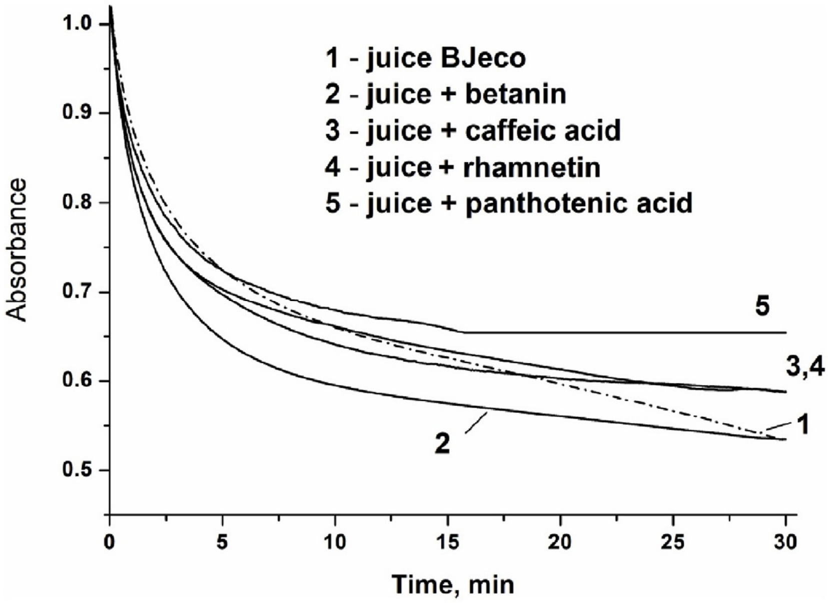

Figure 4. The kinetic curves for DPPH radical scavenging by beetroot juice from ecological cultivar (BJeco) with different additives (concentration of each 10 mg·L^{-1}). The measurements were carried out at λ = 539 nm. Reprinted with permission from [25].

Vulic et al. studied the presence of bioactive compounds in industrial beetroot pomace extract obtained from different cultivars grown in Serbia [56]. The concentrations of total phenolics (45.68 mg gallic acid equivalents per gram), flavonoids (25.89 mg rutin equivalents per gram), and betalains (betanin, 4.09 mg·g^{-1}; vulgaxanthin I, 7.32 mg·g^{-1}) were determined.

Some studies reported that beets from organic cultivation are characterized by a higher content of bioactive compounds [57–59], while others reported the opposite relationship [60,61]. According to Szopińska and Gawęda, these inconsistent results may be due to the differences in the form and amount of fertilizer used, weather conditions, soil type, cultivation, and genetic factors [62]. It is generally accepted that plants from organic farming contain more polyphenolic compounds than those from conventional cultivation. This, in turn, translates into the antioxidant properties of such foods, and their usefulness in preventing oxidative stress by neutralizing free radicals. Different reaction mechanisms between the polyphenolic compounds and radicals have been proposed. They can be divided into two groups: H-atom abstraction and radical adduct formation. Moreover, H-abstraction processes can be divided into four subgroups of mechanisms: hydrogen atom transfer (HAT), proton coupled electron transfer (PCET), sequential proton loss electron transfer (SPLET), and single electron transfer followed by proton transfer (SET-PT). It should be mentioned that all of these mechanisms have the same result [63]. Tosovic et al. mentioned that the mechanisms of action of many important food and beverage ingredients, such as chlorogenic acid, are not fully clarified [64]. Based on the electron-spin resonance spectroscopy [ESR] and density-functional theory [DFT], authors have concluded that in acidic and neutral media, chlorogenic acid rather takes the HAT or RAF pathway. On the other hand, Dimić et al. proved that SPLET is the dominant mechanism for the radical activity towards DPPH radicals in polar solvents [63]. Based on our experience in working with beetroot juice, we know that its pH, depending on the method of preparation and the variety of beetroot from which it was obtained, is in the range of 4–5. This may suggest that, in the case of beetroot juice, the mechanism of free radical neutralization is based on HAT or RAF mechanisms, as was proposed by Tosovic et al. [64].

4. Carotenoids

Carotenoids are another group of bioactive compounds present in beetroots; however, they are present rather in small amounts [65]. The content of these compounds strictly depends on the part of the plant that is being tested; the highest content of carotenoids is found in beetroots peel, followed by pulp, leaves, and stalks [8]. This is because these compounds are accumulated in the green parts of the plants, namely in chloroplasts, as a mixture of α- and β-carotene, β-cryptoxanthin, lutein, zeaxantin, violaxanthin, and neoxanthin [66]. The main carotenoids in red beets are β-carotene and lutein, which pose strong anticancer properties [16]. Red beets are not a very good source of red carotenoid lycopene in comparison to tomatoes, watermelon, or papaya [8]. The lycopene content was 30.0 ± 0.3 µg per 100 g of beet tubers and was not detected in the leaves. α-Carotene was detected in the leaves and tubers of the beetroot, and its concentration in tubers was almost seven times higher than in leaves. However, the leaves are a good source of β-carotene (11.64 µg per 100 g) and lutein (1.503 µg together with zeaxanthin) [67]. The presence of these compounds was not confirmed in beet tubers [8].

A higher concentration of carotenoids was found in organic stalks and cooked pulp in comparison to the conventionally grown plants [68]. This is in line with reports in the literature showing the content of β-carotene is higher in organically cultivated plants in comparison to conventionally grown plants [69]. However, significant differences were only observed between these two parts. After cooking the beet peel and pulp, a decrease in the carotene content was observed; however, its content was still higher in organic beets after this process [68].

5. Minerals

Beetroot contains natural minerals that are essential for the proper functioning of the human body. Wruss et al. analyzed the mineral composition of seven different popular beetroot varieties grown in Upper Austria [49]. Obtained values were in a range similar to those reported in previous studies [70]. However, as the authors highlighted, data regarding the concentration of trace elements and minerals in beet juices are still limited. It is also crucial to note which part of the plant is tested, as the content of individual elements varies among leaves and tubers [8]. The concentration of copper ions was more than two times higher in leaves, in comparison to tubers (0.191 and 0.075 mg per 100 g of beets, respectively) [8]. A greater difference was observed for iron, for which 2.57 mg was found in leaves and 0.80 mg in tubers (values per 100 g of beets). Also, calcium, sodium, potassium, and magnesium were detected in much higher concentrations in leaves. The concentrations of zinc, phosphorus, and manganese did not significantly differ from each other.

Recent studies showed that beetroots and beet products are a great source of selenium [71,72]. Selenium is an important trace element for humans and animals, as it plays a key role in several major metabolic pathways, such as thyroid hormone metabolism and immune functions [73,74]. Its deficiency has been linked with cardiovascular and inflammatory diseases and cancer [71]. The major selenium-containing amino acids occurring naturally in dietary sources are selenomethionine (SeMet) and methyloselenocysteine (MeSeCys), which were also detected in beetroot juice [26,72]. A study involving five juices from conventionally grown beetroot and one from an ecological cultivar reported that all juices differed from each other in terms of selenium content and antioxidant activity, which is shown in Figure 5. Overall, the squeezed juice was lower in selenium compounds and polyphenols, perhaps because commercially available juice is made with a higher weight of beetroot.

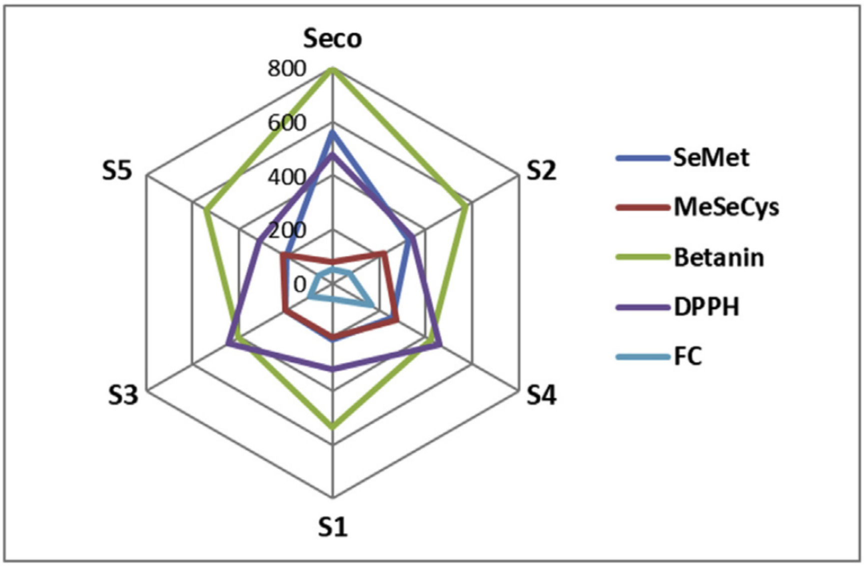

Figure 5. The comparison of selenium species and betanin contents, and antioxidant properties of beetroot juice. Reprinted with permission from [71].

An important aspect is the instability of selenium compounds, which is particularly visible in freshly squeezed juice that has not been pasteurized, especially SeMet, which was oxidized to selenomethionine oxide (SeMetO) [26]. This process resulted in a decrease in the antioxidant activity of the studied juices. The antioxidant activity of selenium species in the DPPH assay decreases in the following order: MeSeCys > SeMet ~ Se(VI) > Se(IV). The values of all species were lower than that of α-tocopherol at the same concentration [75]. From the consumer's point of view, the best way to consume beetroot juices is to drink them immediately after preparation or opening the bottle.

6. Vitamins

Beetroots and beet products are also great sources of vitamin C, vitamin A, and vitamins from the B group. The B-group vitamins are a collection of 8 water-soluble vitamins including thiamine (B1), riboflavin (B2), niacin (B3), pantothenic acid (B5), pyridoxine (B6), biotin (B7), folate (B9), and cyanocobalamin (B12). According to Odoh and Okoro 100 g of this plant contains: vitamin A (2.6 mcg), K, (3.2 mcg), C (4.36 mg), E (0.18 mg) B3 (0.03 mg), B6 (90 mg), B2 (0.034 mg), and B5 (0.151 mg) [67]. These values are in agreement with findings published by Neha et al. [76]. Similar concentrations of vitamins mentioned above were reported by the US Department of Agriculture in the most recent release of the USDA National Nutrient Database for Standard Reference, a major source of food composition data [77]. Analysis of vitamin C in different parts of the beetroot was conducted by Rosseto et al. [68]. According to this study, the highest concentration of ascorbic acid was found in the pulp of the beet and the lowest in its leaf. The concentrations of vitamin C, a well-known antioxidant, vary by plant part; in decreasing order of concentration, the parts are: pulp > skin > leaf > stalk for organic beet and pulp > stalk > skin > leaf for conventionally grown beet. This suggests that the method of cultivation influences the concentration of ascorbic acid in a specific part of the plant. Part-specific concentrations were observed in beets from organic and conventional cultivation. However, the highest level of vitamin C was detected in each part of plants fertilized with organic manure [68].

Ceclu and Nistor also showed the differences in the concentration of vitamins between beet leaves and tubers [8]. In the case of niacin, higher concentrations of vitamins A, B6, and C were detected in leaves, while folate was identified in much higher concentrations in tubers. Vitamins from the B group were also detected in beetroot juices [25]. This study also showed that organic juice is a better source of vitamins in comparison to those obtained from beets from conventional cultivation. It can be seen in the example of pyridoxal (B6), whose concentration in organic juice was about three times higher in comparison to other studied juices. Also, nicotinamide (B3) was detected in organic juice and in one juice from conventionally grown beetroots. In other juices, this vitamin was below the limit of detection (0.03 mg·L^{-1}). It is difficult to compare the obtained results with others in the literature as there is no information from what vegetables the juice was made. However, the published results focused on the analysis of vitamins in the vegetable rather than in the juice made from it. It should also be noted that possible discrepancies in the content of biologically active compounds and vitamins may result from different varieties or growing conditions.

7. Other Compounds

Nitrate (NO_3^-) is one of the most important inorganic compounds in red beets, and their ingestion provides a natural means of increasing in vivo nitric oxide (NO) [8]. This can prevent several pathologies such as hypertension and endothelial dysfunction [78,79]. For a long time, nitrates, which can be converted into nitrosamines, were thought to be harmful substances. These, in turn, lead to endocrinological diseases, defects in human fetuses or cancer [80]. Today it is known that red beetroot nitrates are one of the most important nutrients. In general, nitrates provide ergogenic and cardio-protective properties. Nitrates present in beetroots are converted into nitrite and nitric oxide, which are responsible for lowering blood pressure and vasoprotection [81]. Jonvik et al. reported that beetroot juice lowers blood pressure to a greater extent than sodium nitrate [82]. Many studies have focused on the impact of beetroot juice consumption on the body's efficiency, mainly during intense physical exercise.

Volino-Souza et al. performed a randomized, clinical, crossover, double-blind study which has shown that the consumption of 140 mL of juice from red beets improved macrovascular endothelial function [83]. However, no oxygen saturation parameters in muscle tissue of pregnant women were observed. Other studies showed that one week of supplementation with beetroot juice improved submaximal endurance and reduced blood pressure in older patients with heart failure and preserved ejection fraction [84]. Subsequent works emphasize the beneficial effect of beetroot supplementation on the body's efficiency during physical exertion, as well as its impact on the speed of regeneration [85,86].

The content of nitrates in beetroot depends on its variety. Wruss et al. analyzed nitrates content in seven beetroot varieties grown in Upper Austria [49]. The highest content was detected in the Mona Lisa variety (4626 ± 568 mg·L^{-1}), while the lowest was found in Robuschka (564 ± 129 mg·L^{-1}). The mean value across all analyzed cultivars was 1970 mg·L^{-1}, but the established standard deviation was 1395 mg·L^{-1}, which demonstrates the variability of nitrate content among beet varieties. Gallardo and Coggan studied the nitrate and nitrite content of beet juice products marketed to athletes [87]. The NO_3^- concentration of powders was significantly higher than that of concentrates (174 ± 63 µmol·g^{-1} and 70 ± 39 µmol·mL^{-1}, respectively). A lower concentration of nitrates was found in mixed drinks (13 ± 5 µmol·mL^{-1}) and bulk juices (18 ± 11 µmol·mL^{-1}). Authors highlighted that regardless of the type of product, there was considerable variability in NO_3^- concentration/content between products and, often, between samples of the same product [86]. The evaluation of nitrate and nitrite contents of beetroot from different regions of Brazil and the USA showed the highest nitrate (31.2 ± 0.010 mmol·L^{-1}) and nitrite (0.45 ± 0.005 mmol·L^{-1}) contents in US beets when compared to beetroots from Brazil [88]. In Brazil, Rio de Janeiro was the region that showed the highest nitrate content (17.1 ± 0.020 mmol·L^{-1}), while Rio Grande do Norte presented the highest nitrite content (0.13 ± 0.010 mmol·L^{-1}).

Red beetroots have more sugar than many other vegetables. According to Wruss et al., its average total content was 77.5 ± 10.2 g·L $^{-1}$ (7.8%) [49]. In the roots, sucrose was the most commonly identified sugar (94.8%), followed by glucose (3.3%) and fructose (1.9%). However, glucose was the major sugar in the shoots [89]. Red beetroot can be considered as a part of a healthy diet for diabetic patients. It was found that raw, red beetroot consumption by diabetes mellitus type 2 patients for 8 weeks, has beneficial impacts on cognitive function, glucose metabolism, and other metabolic markers [46]. The list of biologically active compounds in beets and beet products is presented in Table 1.

Unfortunately, in contrast to its health benefits, beetroots contain also oxalic acid; high levels of which lead to the production of kidney stones and their related negative health outcomes [90]. Moreover, oxalate, by chelating metal ions (such as magnesium and calcium), may inhibit their absorption. Thus, the consumption of red beetroots in large amounts may lead to negative health effects.

Table 1. The content of bioactive compounds in red beets and beet juices.

Compound	Concentration *	Sample	References
Betalains			
Betanin	128.7 ± 22.0	beet	[8]
	797 − 421.7	beet juices	[25]
	797 ± 24.0	Organic beet juice	[71]
	406 ± 17.0	Conventional beet juice	[71]
	705 ± 156	Beet extract	[49]
Vulgahantin I	321 − 432.1	Beet juices	[25]
	424 ± 16.0	Organic beet juice	[71]
	311 ± 13.0	Conventional beet juice	[71]
	397 ± 100	Beet extract	[49]
Flavonoids			
Myricetin	0.27 ± 0.091	Organic beets	[28]
	0.30 ± 0.109	Conventional beets	[28]
Luteolin	0.14 ± 0.004	Organic beets	[28]
	0.13 ± 0.003	Conventional beets	[28]
Quercetin	0.13 ± 0.017	Organic beets	[28]
	0.010 ± 0.009	Conventional beets	[28]
	0.0023	Fresh red beets	[47]
	0.009	Commercial juice	[47]
Epicatechin	3.20	Intact beet	[11]
	2.1 ± 0.100	Commercial juice	[25]
	0.253	Fresh beet	[47]
	0.202	Fermented beet	[47]
	0.034	Commercial juice	[47]
Catechin	0.715 ± 0.018	Commercial juice	[25]
	6.73 ± 0.031	Organic juice	[25]
Polyphenolic acids			
Gallic acid	36.40 ± 23.77	Organic beet	[28]
	65.93 ± 45.38	Conventional beet	[28]
	0.147± 0.008	Commercial juice	[25]
	1.24 ± 0.054	Organic juice	[25]
Chlorogenic acid	1.70 ± 0.55	Beet juice	[91]
	4.67 ± 3.67	Organic beet	[28]
	2.29 ± 2.09	Conventional beet	[28]
	1.80	Intact beet	[11]
Caffeic acid	2.22 ± 0.75	Beet juice	[91]
	2.40 ± 0.050	Commercial beet juice	[25]
	0.900 ± 0.008	Organic beet juice	[25]
	0.74 ± 0.40	Organic beet	[28]
	0.77 ± 0.28	Conventional beet	[28]
	3.70	Intact plant	[11]

Table 1. *Cont.*

Compound	Concentration *	Sample	References
Ferulic acid	0.120 ± 0.005 1.81 ± 0.062 0.54 ± 0.37 1.71 ± 0.76	Commercial beet juice Organic beet juice Organic beet Conventional beet	[25] [25] [28] [28]
pHBA	1.2 4.03 ± 0.053 6.83 ± 0.095	Intact plant Commercial beet juice Organic beet juice	[11] [25] [25]
p-coumarc acid	5.27 ± 0.98	Beet juice	[91]
Sinapic acid	1.99 ± 0.80	Beet juice	[91]
Vitamin C	4.55 ± 2.16 5.08 ± 2.10 4.36 7.20 4.90	Organic beet Conventional beet Red beet Red beet Red beet	[28] [28] [67] [8] [76]
Vitamins B			
Riboflavin (B2)	0.034 0.040	Red beet Red beet	[67] [76]
Nicotinamide (B3)	2.85 ± 0.064 2.43 ± 0.040 0.334 0.030	Commercial beet juice Organic beet juice Red beet Red beet	[25] [25] [76] [67]
Pantothenic acid (B5)	2.49 ± 0.041 1.070 ± 0.047 0.151	Commercial beet juice Organic beet juice Red beets	[25] [25] [67]
Pirydoxal (B6)	1.420 ± 0.025 1.67 ± 0.038 90 0.067	Commercial beet juice Organic beet juice Red beets Red beet	[25] [25] [67] [76]
Folate (B9)	0.109	Red beet	[8]
Selenium compounds			
Selenomethionine	0.56 ± 0.020 0.20 ± 0.01	Organic beet juice Conventional beet juice	[71] [71]
Methylselenocysteine	0.08 ± 0.03 0.20 ± 0.01	Organic beet juice Conventional beet juice	[71] [71]
Selenocysteine	0.27 ± 0.02	Conventional beet juice	[71]
Minerals			
Iron	2.57 0.80	Beetroot leaves Tubers	[8] [8]
Copper	0.191 0.075	Leaves Tuber	[8] [8]
Zinc	0.365 ± 0.015 0.38	Tubers Leaves	[8] [8]
Magnesium	23.0 70	Tubers Leaves	[8] [8]

Table 1. *Cont.*

Compound	Concentration *	Sample	References
Carotenoids			
A-carotene	22.0 ± 2.0 3.50 ± 0.5	Tubers Leaves	[8] [8]
B-carotene	0.012 0.001	Leaves Leaves	[67] [67]
Lycopene	0.030	Tubers	[8]
Lutein + zeaxanthin	0.001	Leaves	[8]

* Concentration in beets are expressed as mg per 100 g of raw material and mg·L^{-1} of juice.

8. Conclusions

Red beetroot (*Beta vulgaris*) is known and cultivated in many regions of the world. It is consumed as a component of salads, juices, and dietary supplements or as a natural food colorant. Many studies have been published on beetroots, however data on the bioactive compounds of fresh beets and beet products are still limited. The research described in this paper shows that this is a complicated issue as, depending on the variety and cultivation conditions, the content of individual compounds in beetroot can be significantly different. However, the research results show that red beetroot is a valuable source of several bioactive compounds such as betalains, flavonoids, phenolic acids, carotenoids, vitamins, and minerals, which are necessary for the proper functioning of the human body. It was proved that beetroots have a beneficial effect in the treatment of such serious diseases as diabetes, cardiovascular diseases, and cancer. All parts of the beet, such as the tuber, leaves, or seeds, have these properties. In summary, beetroot can be called a superfood and could be used as a potential material to develop innovative foods.

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