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Chapter

Red Beetroot (Beta Vulgaris L.)

Dóra Székely and Mónika Máté

Abstract

Beetroot has long been a known and consumed vegetable, it was cultivated by the ancient Egyptians, Greeks, and Romans. Beetroot is a type of vegetable belonging to the beet (Beta) genus, which also includes chard, sugar beet, and fodder beet. Beetroot is easy to grow, as it is not one of the vegetables with special needs. The characteristic color of beets is due to red pigments known as betacyanins. Extremely rich in valuable ingredients, it is an extremely good immune booster due to its vitamin A, B, and C content. It is rich in antioxidants and also contains pantothenic acid, lycopene, biotin, silicon, potassium, magnesium, sodium, calcium, zinc, copper, manganese, and iron. Thanks to its content, it even has many health-protective effects, thanks to which it is highly recommended to consume. Beetroot is a deliciously sweet, albeit slightly earthy, superfood. It can be consumed in many ways; raw, as vegetable juice, boiled or fried, fermented, dried, but also as a food supplement in powdered form, and it can also be used as a natural colorant to color different food products.

Keywords: cultivation, nutrient content, traditional and innovative processing

1. Introduction

Red beetroots are becoming more and more important vegetable nowadays due to their many positive nutritional and physiological properties. In addition to its significant potassium and magnesium content, it is associated with low sodium concentrations, which have a beneficial effect on the ionic balance of the human body. The betacyanins in it reduce oxidative stress and the harmful effects of free radicals, have antibacterial and antiviral properties, inhibit the proliferation of cancer cells, and are involved in the prevention of cardiovascular disease. The plant itself can occur almost anywhere, as it is easy to grow and requires no additional care other than hoeing or thinning [1].

Beetroot is a real superfood, which is proven by its wide range of health-protective effects in addition to the diversity of its active ingredients.

The antioxidants in beetroots contribute to the prevention of the formation of tumors and effectively treat existing tumor cells. According to numerous studies, it can be used mainly for colon, prostate, and breast cancer, but it also supports healing in the case of pancreatic cancer [2–4].

It has a detoxifying effect, which is due to the large amount of fiber and saponin in the gut, supports the body’s natural detoxification processes, and cleans the intestines and blood. It improves digestion and the regular, thorough emptying of accumulated waste, which is a prerequisite for the proper absorption of nutrients. In this way, beets
help prevent the development of deficiency diseases. It optimizes the functioning of the liver, it is great for various liver diseases, such as hepatitis or cirrhosis. Beetroot is excellent at reducing inflammation of the intestinal tract, relieving unpleasant symptoms, and speeding up the healing process [3].

Significant amounts of pickles and juice are produced from red beetroot raw material. In addition, dried and concentrated red beetroot juice is used in many foods to increase the intensity of the red color as a natural colorant. Baby food companies prefer to associate beetroots with other vegetables, fruits, or meat. In this case, the manufacturer must pay great attention to the quality of the raw material, as the nitrite and nitrate content of beetroots can be quite high, which is less manageable for the young, developing organism. Furthermore, dietary supplement tablets and syrups containing red beetroots are also known in the market. In addition to the ones listed so far, the consumption of beets as a dried product seems to be a promising solution, as drying is one of the oldest preservation methods that can increase the shelf life of foods without the addition of chemicals [1].

2. Taxonomic classification, origin

Beets (Beta vulgaris L. ssp. Esculenta convar. Crassa provar. conditiva) belong to the Conditiva group, including members of the Caryophyllidae subclass, the Caryophillanae main order, the Chenopodiales order, and member of Chenopodiaceae family [5]. The beetroot is related to sugar beet, fodder beet, and chard [6].

Beetroots have been known and cultivated since ancient times in both white and red versions. Beta maritima is the ancestor of all beet cultivars grown today, including beetroots, which can be originated around the Mediterranean [7]. This species of sea beet has been found since ancient times on the coasts of Europe and North Africa, the Middle East, and parts of Asia. Sea beet leaves have probably been collected since humans first began experimenting with edible green plant parts. It has been used by the peoples since 1000 BC, in the Roman Empire, its leaf was used as food, while its root was used as medicine [8]. However, the usefulness of the tubers was only discovered later. Sea beet was first domesticated in the eastern Mediterranean and the Middle East [9]. It later became popular mainly in India, where not only were its nutritionally important properties exploited, but it was also often used for healing purposes. It was known and consumed by the Greeks and Romans as Sicilian beets.

3. Botanical characterization

The beetroot is a biennial plant, in the first year it develops a carrot body and a rosette, then after the winter dormancy, the seed stalk and flower appear next year, followed by the seed. The bare, simple, glossy leaves can vary in color from dark green to dark red. The length of the petiole and the color content depend significantly on the variety grown. The thinner, dark purple petiole is observed in the smaller-leaved cultivars, while the petioles of the longer-leaved plants are thicker and orange color with purple stripes. The angular, branching soft stem develops in the second year on which a clumpy inflorescence is located [10]. The flowers with five petals are small [11], bivalve, but the stamens ripen earlier than the pistil, so they are foreign pollinators, so fertilization is done by the wind and insects, respectively. The seeds retain their
Red Beetroot (Beta Vulgaris L.)
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ability to germinate for 3–4 years, under favorable conditions for up to 8–10 years. The thousand-seed weight of beets is 13–22 g, depending on the variety [10].

It has a taproot penetrating the soil, on the side of which are the densely spaced, thin side roots 1–2 cm long. The most commonly consumed part is the beetroot body, which can be divided into cylindrical, round and flat groups according to its shape. Spherical cultivars are only attached to the soil by thin taproots, so they are preferred during harvest because they can be harvested with less soil contamination and without damage. By the end of the growing season, one-third of the carcass body is above ground, so picking can be done easily by machine and by hand. The carcass body is characterized by secondary thickening. In the cross-section of the roots of older plants, the tree and spleen elements form concentric circles with a cambium zone between them (Figure 1). The visibility of the rings is caused by the fact that the cells of the spleen have the highest content of red dye characteristic of beets [6].

4. Ecological demand

Beetroots cannot be grown on extreme soil types such as sandy, saline, and stony soils. The best quality and quantity of beetroots can be harvested from loamy, sandy loam, and humus-rich sandy soils. Frequent watering causes loosening of the loose, sandy soil, which strengthens the root of the beet body, degrades the quality of the harvested beetroots and makes them more difficult to clean. The optimal soil pH for the cultivation of the plant is between 6.5–7.5 pH [12]. After sowing the beetroot seeds, the harvest takes place 75–90 days in summer and 100–120 days in winter [13].

Beetroots can be classified as plants with medium water requirements. During germination and in the initial developmental stage of the plant, it requires a higher amount of continuous soil moisture, which is important for even germination (homogeneous stock) and initial development. Except for this period, beetroots are less sensitive to water shortages compared to other root vegetables.

In terms of light requirements, beets are a medium-demand vegetable. It develops well even in weaker, diffused light, but in this case, the beet body has less color and sugar content.

Beetroots have a medium heat demand, which fluctuates significantly during development. According to Markov–Haen’s law, the optimum temperature for beetroots is 19° C. Germination starts at 5–6° C, but germination is fastest at 25–26° C [12]. Lower
temperatures promote the formation of deep red pigments [13]. It is most sensitive to the cold at a young age but develops well during the growing season at much higher and lower than optimal temperatures. If exposed to low temperatures for a long time, it produces seed stalks in the first year and disturbs the development of the beet body. Due to its sensitivity to frost, it should be harvested before frost.

Like all other plants, beetroots have a certain need for nutrients. Knowing this, it is possible to determine which fertilizer and in what amount can be used to obtain the best quality crop. Beetroot is a medium-nutrient vegetable in terms of phosphorus and nitrogen, but it needs more potassium during its development. Per one ton of crop, the specific nutrient requirements of beetroots from the mentioned macronutrients are as follows: 2.4 kg of nitrogen, 1.4 kg of phosphorus, and 6 kg of potassium are needed to grow vegetables of the desired quality [12]. Particular attention should be paid to the addition of nitrogen, because in the event of an overdose, the quality of the beet body will deteriorate, resulting in poorer storage of nitrate and a reduction in color and dry matter content. In addition, the plant’s resistance to disease is reduced by excess nitrogen. Of the trace elements, it is particularly sensitive to manganese deficiency [10].

Both organic and fertilizer can be used to meet the nutrient needs of plants. In the case of beetroots, the use of organic fertilizer is not recommended, as fresh stable manure results in an overdeveloped, deformed crop with an unpleasant taste [14].

It is important that the chemical, biological and physical contamination of the plant is as low as possible in order to validate its positive effects. Of these, the risk of chemical contamination is particularly noticeable in the case of beetroots, as the presence of root vegetables can accumulate a large amount of residues of fertilizers and fungicides (pesticides). That is particularly dangerous because the human body can convert the absorbed material into a substance (that is more dangerous than the original active ingredient instead of emptying it) or store it. Harmful substances accumulated or transformed in this way can cause allergic reactions, immune disorders, gene mutations, and possibly carcinogenic effects even years later [15].

As the most common chemical contaminants in the case of root vegetables, including beetroots, are the accumulation of nitrite and nitrate, efforts should be made to keep their content to a minimum. Inorganic nitrogen from fertilizers, most of which is not incorporated into tissues, can accumulate in plants in significant amounts in the form of nitrite and nitrate. The degree of accumulation can be influenced by number of factors, such as the lettuce has higher nitrate content during cultivation if less sunlight or molybdenum and iron are obtained, which are essential micronutrients [16].

5. Composition values

Its beneficial dietary and medicinal effects are due to the high content of red color content (betacyanins), high vitamins (C, B), minerals, and fiber. Examination of its composition has accelerated since the discovery of antitumor, which has been the subject of numerous studies worldwide [12]. The processing of beets and the consumption of products made from them has increased rapidly since it was recognized as an extremely rich source of antioxidants [17].

5.1 Nutrient content

Numerous studies report that the nutrient content of fresh beetroots is influenced by the variety, growing, and harvesting conditions alike [17]. Table 1 shows that
Red Beetroot (Beta Vulgaris L.)
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Beetroots are a good source of carbohydrates and protein. Because it contains little fat and no cholesterol at all, it results in a low-calorie intake. This is one of the reasons why it fits well into a weight loss diet. Its relatively high carbohydrate and sugar content does not affect this either, as the body immediately converts its easy-to-use sugar content into energy [9]. In terms of sugar content, it is a beneficial property for athletes to contain the highest amounts of sucrose, as it is beneficial for them to consume low concentrations of fructose and high sucrose, thereby increasing their physical capacity [22, 23]. A significant amount of sucrose content is also confirmed by a study conducted by WRUSS et al. [24], which examined the sugar content of seven popular beetroot varieties. The average sugar content of the investigated beetroot variety was 77.5 g/l, which contained 94.8% sucrose, 3.3% glucose, and less than 1.9% fructose.

Beetroots contain significant amounts of essential and non-essential amino acids (Table 2).

5.2 Macroelements

Beetroots contain large amounts of metallic macronutrients. These are potassium, sodium, magnesium, and calcium (Table 3). Magnesium is an activator of energy components Unit RODLER [18] NEELWARNE [19] SOUCI et al., [20] USDA [21]

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Protein</td>
<td>g</td>
<td>1.3</td>
<td>1.61</td>
<td>1.53</td>
<td>1.61</td>
</tr>
<tr>
<td>Fat</td>
<td>g</td>
<td>0.1</td>
<td>0.17</td>
<td>0.10</td>
<td>0.17</td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>g</td>
<td>5.9</td>
<td>9.56</td>
<td>6.76</td>
<td>9.56</td>
</tr>
<tr>
<td>Energy content</td>
<td>kJ</td>
<td>130</td>
<td>45</td>
<td>175</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>kcal</td>
<td>31</td>
<td>41</td>
<td>41</td>
<td>43</td>
</tr>
<tr>
<td>Ash content</td>
<td>g</td>
<td>0.9</td>
<td>—</td>
<td>—</td>
<td>1.08</td>
</tr>
<tr>
<td>Water content</td>
<td>g</td>
<td>90.9</td>
<td>—</td>
<td>86.2</td>
<td>87.58</td>
</tr>
<tr>
<td>Fiber</td>
<td>g</td>
<td>—</td>
<td>2.8</td>
<td>—</td>
<td>—</td>
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</table>

Table 1.
Energy components of beet per 100 g.

<table>
<thead>
<tr>
<th>Amino acid</th>
<th>Quantity mg/100 g</th>
<th>Amino acid</th>
<th>Quantity mg/100 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>tryptophan</td>
<td>0.019</td>
<td>cystine</td>
<td>0.019</td>
</tr>
<tr>
<td>isoleucine</td>
<td>0.048</td>
<td>arginine</td>
<td>0.042</td>
</tr>
<tr>
<td>leucine</td>
<td>0.068</td>
<td>histidine</td>
<td>0.021</td>
</tr>
<tr>
<td>lysine</td>
<td>0.058</td>
<td>alanine</td>
<td>0.060</td>
</tr>
<tr>
<td>threonine</td>
<td>0.047</td>
<td>glutamic acid</td>
<td>0.428</td>
</tr>
<tr>
<td>methionine</td>
<td>0.018</td>
<td>glycine</td>
<td>0.031</td>
</tr>
<tr>
<td>phenylalanine</td>
<td>0.046</td>
<td>proline</td>
<td>0.042</td>
</tr>
<tr>
<td>tyrosine</td>
<td>0.038</td>
<td>aspartic acid</td>
<td>0.116</td>
</tr>
<tr>
<td>valine</td>
<td>0.056</td>
<td>serine</td>
<td>0.059</td>
</tr>
</tbody>
</table>

Table 2.
Amount of each amino acid present in beetroots [25].
many enzymes that catalyze carbohydrate metabolism and amino acid synthesis, an antagonist to potassium, and has a synergistic relationship with phosphorus [26]. Of the trace elements, it contains the largest amount of iron, which plays a key role in the uptake, transport, and storage of oxygen [27].

CSIKKELNÉ et al. [28] found that the microelement content of different parts within the beetroot plant is significantly different. Overall, the leaf usually has the highest mineral content, much less the peel and flesh of beetroot body. While the calcium content of the leaf is 156 mg/100 g, this value is 21 mg/100 g in the peel of beetroot body and 10 mg/100 g in the flesh of beetroot body. Concentrations of potassium, sodium, and magnesium are also much higher in beetroot leaves than in the body. In contrast, in terms of phosphorus content, the peel of beetroot body (66 mg/100 g) and the flesh of beetroot body part (49 mg/100 g) contains higher concentrations than the leaf (37 mg/100 g). Among the trace elements, iron, copper, manganese, and zinc occur in the largest quantities in the leaves.

Vitamins C, B1, B2, B6, and folic acid are significantly detectable in beets (Table 4).

### 5.3 Reducing compounds and other bioactive components

Consumption of beetroot juice is quite advantageous because it contains large amounts of antioxidants and other bioactive components [29]. Beetroots contain betalains [3], ascorbic acid [4], carotenoids [8, 30, 31], polyphenols, flavonoids, saponins [32, 33], and high levels of nitrate [34, 35] (Figure 2). Some bioactive components are present in small amounts, such as glycerin, betanin [36], and folic acid [37].

#### 5.3.1 Phenolic compounds

Beetroots have a significant content of phenolic acid and flavonoids. In a study carried out by KATHIRAVAN and coworkers [38], 50-60 μmol/g DW phenolic acid

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**Table 3.**

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Phosphorus</td>
<td>mg</td>
<td>87</td>
<td>—</td>
<td>38</td>
<td>44</td>
<td>40</td>
</tr>
<tr>
<td>Calcium</td>
<td>mg</td>
<td>35</td>
<td>16</td>
<td>16</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>Potassium</td>
<td>mg</td>
<td>260</td>
<td>325</td>
<td>305</td>
<td>407</td>
<td>325</td>
</tr>
<tr>
<td>Magnesium</td>
<td>mg</td>
<td>87</td>
<td>23</td>
<td>23</td>
<td>20</td>
<td>23</td>
</tr>
<tr>
<td>Sodium</td>
<td>mg</td>
<td>98</td>
<td>78</td>
<td>77</td>
<td>58</td>
<td>78</td>
</tr>
<tr>
<td>Zinc</td>
<td>mg</td>
<td>0.337</td>
<td>0.075</td>
<td>0.35</td>
<td>0.357</td>
<td>0.35</td>
</tr>
<tr>
<td>Cobalt</td>
<td>mg</td>
<td>0.009</td>
<td>—</td>
<td>—</td>
<td>0.0016</td>
<td>—</td>
</tr>
<tr>
<td>Chromium</td>
<td>mg</td>
<td>0.005</td>
<td>—</td>
<td>—</td>
<td>0.003</td>
<td>—</td>
</tr>
<tr>
<td>Manganese</td>
<td>mg</td>
<td>0.540</td>
<td>0.329</td>
<td>—</td>
<td>0.244</td>
<td>0.329</td>
</tr>
<tr>
<td>Nickel</td>
<td>mg</td>
<td>0.052</td>
<td>—</td>
<td>—</td>
<td>0.011</td>
<td>—</td>
</tr>
<tr>
<td>Copper</td>
<td>mg</td>
<td>0.087</td>
<td>0.35</td>
<td>—</td>
<td>0.082</td>
<td>0.075</td>
</tr>
<tr>
<td>Selenium</td>
<td>mg</td>
<td>0.001</td>
<td>—</td>
<td>—</td>
<td>0.0006</td>
<td>0.0007</td>
</tr>
<tr>
<td>Iron</td>
<td>mg</td>
<td>0.60</td>
<td>0.80</td>
<td>0.79</td>
<td>0.890</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Table 3. **Mineral content of beetroot per 100 g.**
content was detected in the beetroot. NEMZER et al. [25] isolated highly unstable phenolic components from the beetroot peel, which were dimers of 5,5,6,6-tetrahydroxy-3,3-biindolyl and 5,6-dihydroxyindole carboxylic acid. In addition, two phenolic amides, N-trans-feruloyltyramine and N-trans-feruloyl homovanillylamine...
were detected in the beet seed wall. MARAIE et al. [39] reported that beetroots contain significant amounts of hydroxybenzoic acid and hydroxyquimalic acid derivatives, including epicatechin, catechin hydrate, rutin, p-coumarin, caffeic acid, proline, and monoterpenes. VASCONCELLOS et al. [40] compared the total phenol content of beetroot juice, beetroot chips, beetroot powder, and roasted beetroot. In their experiment, they found that beetroot juice (3.67 GAE mg/g) and roasted beets (2.79 GAE mg/g) had higher total polyphenol contents than beet chips (0.75 GAE mg/g) and beetroot powder, but the lowest value was detected in raw beetroot.

Flavonoids are among the biologically active components because they have excellent antioxidant potential and a number of positive health effects [17]. Flavonoids are characterized by a C6-C3-C6 backbone. The basic structure offers an extremely large number of variations, 4000 types of flavonoids with different structures are currently known. The degree of antioxidant properties of flavonoids depends fundamentally on the structure of the particular molecule, and the potency of the antioxidant is strongly and positively correlated with the degree of hydrolysis [41]. Flavonoids occur in higher plants and are secondary metabolites responsible for coloring the stems, leaves, flowers, and fruits of plants. Flavonoids can produce a variety of colors, such as yellow, orange, red, violet, and blue, but some are colorless [42]. Numerous studies have shown that beetroots contain significant amounts of flavonoids. It includes among others catechin, epicatechin, rutin, betagarin, and betavulgarin. VULIC et al. [43] reported the main group of flavonoids in beetroot.

Saponins are bioactive compounds that plants produce against pathogens and herbivores. According to previous studies, 11 triterpene saponins are found in beetroot. Each of the saponins contained oleanolic acid derivatives. Betovulgarosides I, II, III, IV, VI, VII, VIII. saponins were identified from the root, while betonulgarosides I, II, III, IV, V, IX, and X saponins were detected in leaves [33, 44]. MIKOLAJCZYK-BATOR et al. [45] also reported the presence of 26 triterpene saponins in beetroot, of which 17 triterpene saponins were not previously isolated in beets and 7 triterpene saponins were identified as new compounds.

5.3.2 Betalains

Betalains are pigments of higher plants, nitrogenous and water-soluble compounds found in plants belonging to the Caryophyllales order [46]. Ten of the families in this order were identified as producing betalain. The Chenopodiaceae family, i.e. the Beta vulgaris family, is one of them. The name comes from the Latin name for beetroots (B. vulgaris), as it was the first plant from which they were identified. Betalaines are generally classified according to their characteristic structure (Figure 3). A total of 70 betalains are known, which have diazoheptamethine base frame. Betalains can be divided into two subgroups: betacyanin compounds, which give a reddish-violet color, and betaxanthines, which are responsible for yellowish colors [48]. The structural resonance of the parent compound of betalains, diazo-heptametin, results in its color. Accordingly, it can be distinguished the two major groups [49]. Betacyanins present in plants include betanin, isobetanine, protetanine, and neobetatin, and betaxanthines include vulgaxanthin, miraxantine, portula xanthin, and indicaxanthin [50]. Plant physiology is uncertain about the role of betalains in plants, but KIMLER [51] reported the fungicidal properties of betalains.

Betalains were initially referred to as “nitrogen anthocyanins,” but it was later found to be incorrect to assume structural similarity between colorant [52].
Both betalains and anthocyanins are water-soluble pigments found in the vacuoles of plant cells. However, betalains are structurally and chemically completely opposite to anthocyanins and no evidence has been found to occur in the same plant. Each betalain is composed of a glycoside sugar and a colored part (Figure 3). Their synthesis is facilitated by light [53]. Factors influencing the stability of betalains are shown in Figure 4.

Each colorant group is characterized by R1-N-R2 moieties. More than 50 betalains have been described with the same basic structure. Betalain has been used as a food colorant.
coloring since the 20th century. Initially, a betalain-containing Phytolacca esculenta was used to imitate the color of red wine [48].

The most abundant betaline compound in beetroots is betanin (Figure 5), a secondary metabolite of betacyanins. The storage is located in the root, where it can reach concentrations of up to 0.5 g/kg [54]. In addition to betanin, its isomer is also found in the colorants of the plant. This compound is isobetanin, and the two substances together can account for up to 88–93% of colorants [55, 56]. For the four beet cultivars analyzed by HPLC by KUJALA et al. [57], the detected vulgaxanthin I and II were between 1.4 ± 0.3 mg/g and 4.3 ± 0.4 mg/g DW; betanin 7.6 ± 0.1 mg/g and 2.9 ± 0.2 mg/g DW, isobetanin 0.02 ± 0.01 mg/g and 3.1 ± 0.1 mg/g DW.

Beetroot colorants are available in the form of a concentrate as a natural colorant, which is typically prepared by vacuum evaporation or spray drying. The chemical degradation of colorant is affected by the duration and temperature of the heat treatment as well as the pH and water activity of the product [25]. By fermentation, approximately 75% of betacyanin content can be maintained by lowering the pH to about 4. With this acidic medium, the negative effect of the heat treatment process on reducing antioxidant capacity can be avoided [58].

5.3.3 Carotenoids

Carotenoids are a group of phytochemicals that are responsible for the color of various fruits and vegetables. The carotenoids present in beetroots also function as antioxidants, anticarcinogens, and immune enhancers, in addition, their protective role and attribute mutagenesis inhibitory activity can reduce the risk of developing cancer [59]. Beetroot leaves contain β-carotene and xanthophylls such as lutein [17]. REBECCA et al. [31] detected 1.9 mg/100 g carotene in beetroots.
6. Effect of nutritional physiology

The results of pharmacological studies performed by several researchers confirm that beetroots can be used effectively and advantageously in the treatment of various diseases [17]. Betacyanins found in large quantities in beetroots counteract the harmful effects of oxidative stress and free radicals, have antibacterial and antiviral properties, inhibit the proliferation of cancer cells, and are involved in the prevention of cardiovascular disease [29, 60]. Because beetroots have many properties that have a positive effect on the human body, it has also become known as an herb. In addition, beetroots also have anti-inflammatory and hepatoprotective effects [61].

Its role in folk medicine is of great importance. A decoction made from the seeds of a vegetable has been used to treat intestinal and genital tumors. Beetroot juice has been thought to help fight tumors, leukemia, or other types of cancer. Among some of the components of the juice, betacyanins play an important role in inhibiting the metabolism of cancer cells. In addition, two very important components of amines are still present: choline and its oxidized form, betaine, in the absence of which experimental results have shown that tumors in the mice body have developed more likely [62].

VÁLI et al. [35] investigated the hepatoprotective properties of beetroot bioactive substances in a rat model of ischemia-reperfusion injury. As a result of feeding, global liver parameters and enzymatic antioxidants (glutathione peroxidase and superoxide dismutase) were significantly increased, indicating a positive effect of treatment. The results show that a diet rich in natural antioxidants has a positive effect on redox homeostasis during hepatic ischemia-reperfusion injury.

A colorant called betanin is known to have primarily lymphatic tumor inhibitor and antihypertensive effects. The proof of its antitumor effect is due to Sándor Ferenczi, who discovered in 1961 in animal experiments that the betanin colorant acts against cancer cells. He advised his patients to consume 1 liter of squeezed beetroot juice daily for 3 months, which not only works against cancer cells but also improves blood counts. In addition, next to Ferenczi, Rudolf Breuss the naturopath also recommended consuming 2.5–3 liters of beetroot, potato, celery, radish, and carrot juice. He discovered that this juice fasting cure helps to suppress tumor cells [63]. NYIRÁDY et al. [64] administered a commercially available natural beetroot preparation in a dose of 2 × 10 g to 24 patients with hormone-resistant and metastatic prostate cancer receiving taxane chemotherapy for 1 month to improve the quality of life. Their results showed that in the vast majority of patients, beetroots had a beneficial effect, and significantly high levels of Zn and free protoporphyrin in tumor patients were reduced, and transmethyl-ation processes were accelerated.

Consumption of beetroots due to their high betanin content can cause beeturia (red urine) and red feces in people who are unable to degrade [65, 66]. The interest of the food industry towards betalaines has increased as they may provide protection against oxidation of low-density lipoproteins [67].

Like many other colorful vegetables, beetroots are considered an antioxidant gold mine [3, 68]. FIDELIS et al. [69] showed that beetroot juice (pH 5.45, 9°Brix) has higher total phenol (1169 mg GAE/l), flavonoid (925 mg catechin equivalent/l), and pigment content (854 mg/l) than citrus fruits, yellow passion fruit, apples and blueberries, which also results in a better antioxidant profile (325 mg AAE/l). WOOTTON-BEARD and RYAN [70] found that betanin and aglycone betanidine
Advances in Root Vegetables Research

have extremely high antioxidant activity, which has been shown to be effective in preventing lipid peroxidation [38]. Beetroot contains a number of bioactive compounds, which result natural anti-anemic, anti-inflammatory, antihypertensive, anti-cancer, antipyretic, antibacterial, detoxifying and diuretic properties [34, 71], as well as stimulating the immune system, and liver protection [72]. SLAVOV et al. [61] demonstrated that betalain pigments play a role in the chemoprevention of lung and skin cancer and inhibit cell proliferation of various human tumor cells. IGLESIAS et al. [73] have also proved their anti-cancer effects and slightly reduce the inflammatory response and modulate the immune response.

Nitrates present in beetroots are able to lower blood pressure, protect against ischemic reperfusion injury and modulation of mitochondrial function [74], and reduce bad cholesterol [29]. NINFALI and ANGELINO [8] also report the antihypertensive effect and hypoglycemic activity of beetroot extracts. A study by MONTEIRO and AZEVEDO [75] found that regular consumption of beetroots reduces the risk of inflammation (instinctive reaction, including infection, erythema, edema, trauma, fever, and cell damage caused by pain).

Beetroots are healthy food for the entire digestive system. The water, in which the beetroots are cooked, can be used to treat skin infections, acne, and ulcers [76]. Beetroot juice helps clean the blood, regenerate and reactivate red blood cells, and provide the body with fresh oxygen [77]. The copper content of beetroots promotes the absorption of iron. Beetroot can also be used to treat fever and constipation [13].

7. Processing of beetroot and effects of processing on its biologically active components

The use of beetroots as food has been studied by many researchers and the food industry alike due to the specific effect of color, taste and nutrients. Beetroots are consumed worldwide, even in Eastern Europe, beetroot soup is popular, while in South America, pickled beets are a traditional dish [13].

Utilization and processing possibilities of beetroots:

- Fresh beetroots: immediate use, storage
- Semi-finished products: aseptic pulp, filtered concentrate (60–68 Bx°), semi-concentrate (40–45 Bx°)
- Heat-preserved products: 100% clarified filtered or fibrous juice, nectar, baby food, baby drinks, pickled beet products, beetroot jelly
- Fermented products: fermented juice, fermented lump preparations
- Dried preparations: conventional, vacuum-dried, microwave-vacuum-dried pieces (rings, cubes, cloves), spray-dried powder, flakes, instant powder, candied beetroots, lyophilized beetroots
- Non-thermal technologies: PEF, HHP, irradiation
Red Beetroot (Beta Vulgaris L.)
DOI: http://dx.doi.org/10.5772/intechopen.106692

- Quick-frozen products: cubes, slices, strips, puree, cream
- Other: colorant (in yoghurts, ice creams, cheeses, sauces, juices, jams), ingredient in food supplements

Cylindrical beetroot is made into sliced, while round beetroot is made into a risky product. As a baby beetroot, the round varieties are preserved. In several European countries, soups and salads are made from the young leaves of beetroots [6]. Due to its high antioxidant content, it is used in the manufacture of several preparations in addition to canned products. Beetroot juice is appearing as a product of more and more manufacturing companies, which is also available in a version made from organic vegetables [78].

In order to preserve the bioactive active ingredients of beetroot as efficiently as possible, producers shall endeavor to give priority to humane technologies, e.g. vacuum technologies, PEF or HHP treatment.

High hydrostatic pressure (HHP) technology allows microorganisms to be gently removed from beet juice, thus prolonging their shelf life by inactivating pathogenic microorganisms. Betaxanthins in beetroot juice were more stable than betacyanins under high pressure. Losses of betalain pigments under high hydrostatic pressure at ambient temperature were small compared to heat treatment. The significant reduction in the number of spoilage and pathogenic microorganisms without the recovery of sublethal-damaged cells and the slight degradation of pigments indicate the possibility of industrial application of high pressure to preserve beetroot juice [79].

One of the best ways to preserve fruits and vegetables is drying. In the case of vegetables, conventional convective drying was the most common; due to its simplicity, economical design and operation costs, however, this method of drying can greatly reduce the content values of vegetables [68].

In an experiment conducted by MALAKAR et al. [80], betalain pigment retention was 63.98% higher for drying with an evacuated tubular solar dryer (ETSD) than for day drying. The color changes were higher when dried in the sun. The mean phenol content and antioxidant capacities were 31.07% and 21.87% higher in ETSD, respectively than in the sun-dried. Therefore, ETSD can efficiently dry other foods with reduced drying time and significant preservation of quality characteristics.

According to a study by MELLA et al. [81], vacuum drying (VD) can be a suitable alternative to freeze-drying (FD). The effect of both drying techniques on the physicochemical properties, betalain pigment, antioxidant potential, and individual phenolic compounds of beetroots have been studied. The results showed that the increase in temperature promotes growth in the drying rate and effectively shortens the drying time. In general, VD samples retained the approximate composition of beets better than FD. Nevertheless, VD (50° C) excels in FD in terms of total polyphenol content (TPC) and oxygen radical absorption capacity (ORAC). In addition, syringic acid was identified in the VD samples at 50° C but not in the FD samples.

Kazimierczak et al. [29] found that beetroots and fermented beetroot juices from organic farming contained more vitamin C than conventional ones. The results reveal that organic and conventionally produced beetroots and fermented beetroot juice have different chemical properties and different effects on cancer cells. During the lactic fermentation of beetroot juices, 75% of betacyanins were retained compared
to their original concentration. By adjusting the pH to about 4, this process also promotes antioxidant activity and avoids the negative effects of heat treatment, which reduces antioxidant content.

Beetroots are suitable as a substitute for synthetic colorants [58] and can thus become a marketing tool in the food industry [82]. This is because synthetic colorants can have negative effects on human health, cause allergies, and long-term consumption can be carcinogenic [83]. Dried and concentrated beetroot juice is also used in many foods to increase the intensity of the red color. Examples of such products are ice creams, jams, desserts, tomato concentrates, beverages, and dairy products [84]. Fresh beetroots, beetroot powder, or extracted pigments are used in soups, sauces, confectionery, ice creams, and breakfast cereals [68, 85]. The choice depends largely on the manufacturing technology, not only on the state of the excipient but also on its heat sensitivity. When exposed to heat, it changes color to brown [86], but it still occurs in heat-treated and then refrigerated beverages, desserts, ice creams, dairy products, and confectionery [87].

Processing methods have a significant effect on antioxidant activity and the availability of its phytochemicals. Some processing methods, such as microwave vacuum drying, fermentation, and irradiation, enhance antioxidant capacity and pigment stabilization, while convective drying reduces color retention [88, 89]. VASCONCELLOS et al. [40] examined the total antioxidant activity of beetroot chips (95.70%), beetroot powder (95.31%), boiled beetroots (85.79%), and beetroot juice (80.48%). According to their results, there was no significant difference between the antioxidant activity of beetroot chips and beetroot powder, and higher values were detected in them than in cooked beetroot and beetroot juice. The liquid chromatography method developed by PIETRZKOWSKI and THRESHER [90] was able to increase the betalain content of the beetroot powder by passing the beetroot juice through a silica gel column before drying. Thus, a concentration of up to 45% w/w betalain is achieved. NEMZER et al. [26] found that the higher betalain content of beetroot powder produced with this new technology is 615 mg/100 g of vitamin C, while the value of beetroot powder produced by the traditional method in an oven is only 1–7 mg/100 g.

Factors that affect the stability of antioxidants or betalains, are storage, pH, temperature, water activity, oxygen, metals, and ion radiation [29, 91]. Optimal stability of betalains is achieved in the pH range of 3–7, suggesting that it is worth using in acidic food preparations. Thus, betalains are stable in foods with a pH 5, even in products below pH 3 the color of betanin changes to violet, and above pH 7 to blue color due to the longer wavelength [91]. Betanin is degraded in an alkaline environment, hydrolysis of aldime to form ferulic acid with an amino group. The degradation of betanin at pH 3 is three times higher than at pH 5 under fluorescent light. Betalain was found to be more stable between pH 5.5 and 5.8 in the presence of oxygen. Under anaerobic conditions, betalain is more stable at pH 4–5 [92–94].

Water activity regulates the rate of biochemical conversion and influences the stability of betanin by regulating the water-dependent hydrolytic reaction of aldime bond cleavage. A decrease in water activity (below 0.63) during various treatment procedures, such as drying and evaporation, enhances the stability of betalains [95]. An increase in water activity raises the rate of betalain degradation from 0.32 to 0.75. However, in the case of encapsulated beetroot pigment, the greatest degradation of betanin occurs at a water activity value of 0.64 [96].

Temperature also affects the stability of betalains. An increase in temperature results in degradation of betalain. However, thermal decomposition is also affected by temperature range, degree of heating, presence of oxygen, and pigment concentration [97].
Colorants are oxidized and degraded in the presence of light. There is an inverse relationship between light intensity in the range of 2200–4400 lux and the stability of betalain. Absorption of ultraviolet and visible light excites the chromophore electrons of betalain, which induces higher reactivity or lower molecular activation energy. However, the effect of light under anaerobic conditions is negligible [92–94]. Some metal cations have been identified that promote or accelerate the degradation of betanin, such as iron, copper, tin, aluminum, and so on. According to a study, beetroot juice is less sensitive to metal ions because it contains metal complexing agents. Chelating agents (citric acid and EDTA) have been shown to stabilize betanin against metal-catalyzed degradation [92–94].

8. Conclusion

Numerous studies show that beetroots contain large amounts of valuable vitamins and minerals, as well as antioxidants, especially potassium, magnesium, iron, vitamins A, C, and B6. Not only the root but also the tender leaves can be eaten, for example, mixed into a salad. Beetroots greatly improve blood circulation, including in our brains, and the compounds in the beetroot are extremely helpful in maintaining the health of the nervous system. By consuming beetroots regularly, the risk of various types of dementia, such as Alzheimer’s can be reduced, and keep the memory sharp. In addition to improving its blood circulation, it also contains substances that, when transformed in our body, also lower blood pressure.

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Red Beetroot (Beta Vulgaris L.)
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