REVIEW

Betanin—A food colorant with biological activity

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Betalains are water-soluble nitrogen-containing pigments that are subdivided in red-violet betacyanins and yellow-orange betaxanthins. Due to glycosylation and acylation betalains exhibit a huge structural diversity. Betanin (betanidin-5-*O*-β-glucoside) is the most common betacyanin in the plant kingdom. According to the regulation on food additives betanin is permitted *quantum satis* as a natural red food colorant (E162). Moreover, betanin is used as colorant in cosmetics and pharmaceuticals. Recently, potential health benefits of betalains and betalain-rich foods (e.g. red beet, *Opuntia* sp.) have been discussed. Betanin is a scavenger of reactive oxygen species and exhibits gene-regulatory activity partly via nuclear factor (erythroid-derived 2)-like 2-(Nrf2) dependent signaling pathways. Betanin may induce phase II enzymes and antioxidant defense mechanisms. Furthermore, betanin possibly prevents LDL oxidation and DNA damage. Potential blood pressure lowering effects of red beet seem to be mainly mediated by dietary nitrate rather than by betanin per se.

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1 Betalains—Structure and occurrence in foods

The water-soluble betalains are immonium derivatives of betalamic acid [1]. The chromophore of betalains is a protonated 1,2,4,7,7-pentasubstituted 1,7-diazaheptamethin system (yellow color) [2]. The three conjugated double bonds give the molecule its characteristic color [3, 4]. The basic structure of betalains is shown in Fig. 1.

Depend on the ligand betalains are divided in two groups: the red-violet betacyanins (λ ≈ 540 nm) and the yellow betaxanthins (λ ≈ 480 nm). When betalamic acid (λ ≈ 406 nm) condenses with *cyclo*-3,4-dihydroxyphenylalanine (*cyclo*-DOPA), betanidin is formed, that is the basic structure of betacyanins (Fig. 2) [2, 5–7]. The C15 epimer of betanidin (2*S*, 15*S*) is called isobetanidin (2*S*, 15*R*) [2]. Due to the connection of the hydroxyl group at positions 5 and 6 of betanidin with glycosides or acylglycosides the structure diversity of betacyanins is enormous [2, 6, 7]. Betacyanins are mostly linked 5-*O*-glucosylated (i.e. betanin) rarely 6-*O*-glucosylated (i.e. gomphrenin II), but never both positions are glucosylated [2, 5]. Betacyanins are classified into four groups: betanin-type, amaranthin-type, gomphrenin-type, and 2-descarboxybetanin-type (Fig. 3) [7–10]. The well-known betacyanin is the red betanin (Fig. 4) that gives red beet (*Beta vulgaris* ssp.) its typical red color. Structurally, betanin is composed of the aglycone betanidin that is linked β-glycosidic with a glucose-unit at C5 [8, 11]. Betaxanthins are formed by condensation of amino acids or biogenic amins with betalamic acid (Fig. 5) [12], i.e. vulgaxanthin in yellow beet (*Beta vulgaris* L.) and indicaxanthin in cactus pear (*Opuntia ficus-indica* (L.) Mill.) [13, 14]. Betalains exist as isomers due to the chiral C-atom of the dihydropyridine unit [2].

Numerous sources of betalains in the plant kingdom are known (Fig. 6). Betalains give flowers and roots from the plant order *Caryophyllales* (except anthocyanin-producing families *Caryophyllaceae* and *Molluginaceae*) and some variety of fungus of *Basidiomycetes* (i.e. *Amanita muscaria*, *Hygrocybe conica*) their typical color [6, 8, 9, 15–17].

The most important source of betanin is the root of red beets (*Beta vulgaris* L. ssp. *vulgaris*) [18–21]. The betanin concentration is decreasing in the following order: peel, crown, and flesh [19, 22]. Red beet contains about 300–600 mg/kg betanin [23]. The betanin content of red beet may be affected

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Abbreviations: cyclo-DOPA, cyclo-3,4-dihydroxyphenylalanine; **HO1**, heme oxygenase 1; **Keap1**, kelch-like ECH-associated protein 1; **Nrf2**, nuclear factor (erythroid-derived 2)-like 2; **PON1**, paraoxonase 1; **SOD**, superoxide dismutase

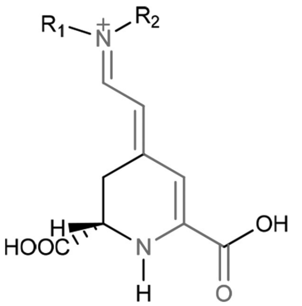

Figure 1. Basic structure of betalains.

by various factors including cultivar, farming conditions (temperature during the growing season, soil fertility, soil moisture etc.) and storage temperature to name a few [14, 19, 22]. A further main compound is the yellow vulgaxanthin I [5, 24]. In addition to these pigments isobetanin, betanidin, isobetanidin, and vulgaxanthin II also occur in red beet [14]. The roots of yellow beet (*Beta vulgaris* L. ssp. *vulgaris*) are suitable for human consumption that contain, i.e. the yellow betaxanthins vulgaxanthin I and miraxanthin V [25]. The bicyclic alcohol geosmin ($C_{12}H_{22}O$; *trans*-1,10-dimethyl-*trans*-(9)-decalol), produced by *Streptomyces*-species and mycobacteria, and various 3-alkyl-2-methoxypyrazines (3-*sec*-butyl-, 3-isobutyl-, and 3-isopropyl-2-methoxypyrazine) are responsible for the earthy-musty aroma and flavor of red beets [26–29]. Moreover, red beet contains high amounts of nitrate. Its nitrate concentration is comparable to salad, radish, rocket, and spinach [9, 30–32]. The elimination of nitrate in juices can be conducted by, i.e. ionic exchangers or microbiological methods. The microbiological denitrification of red beet juice is feasible by Gram-negative bacteria *Paracoccus*

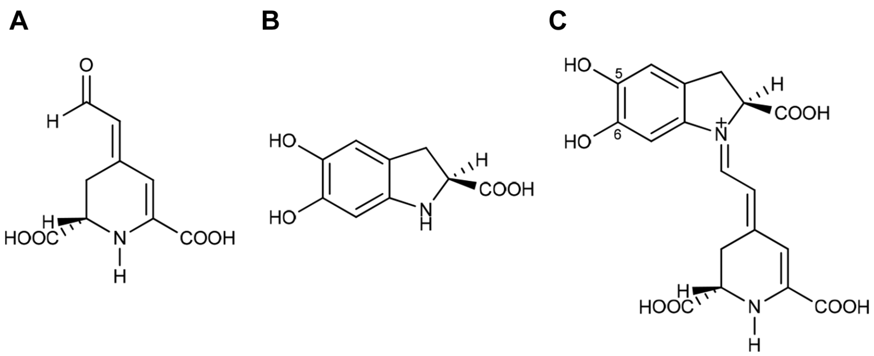

Figure 2. Chemical structures of betalamic acid (A), *cyclo*-DOPA (B), and betanidin (C).

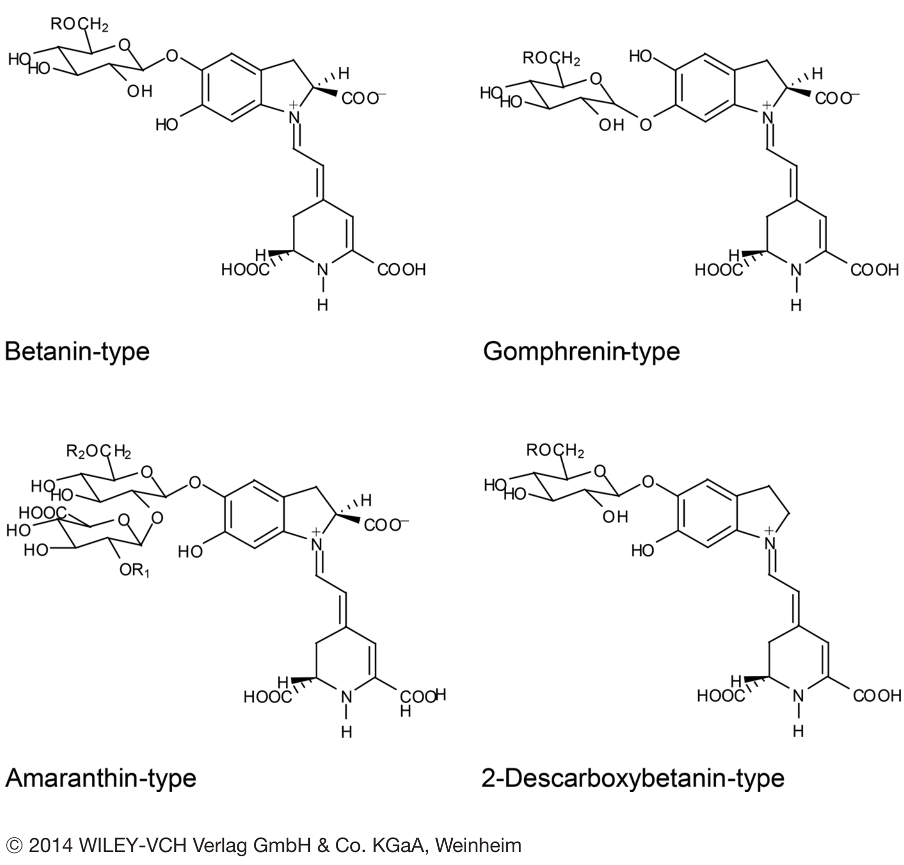

Figure 3. Four groups of betacyanins: betanin-type, amaranthin-type, gomphrenin-type, and 2-descarboxybetanin-type; modified according to [10].

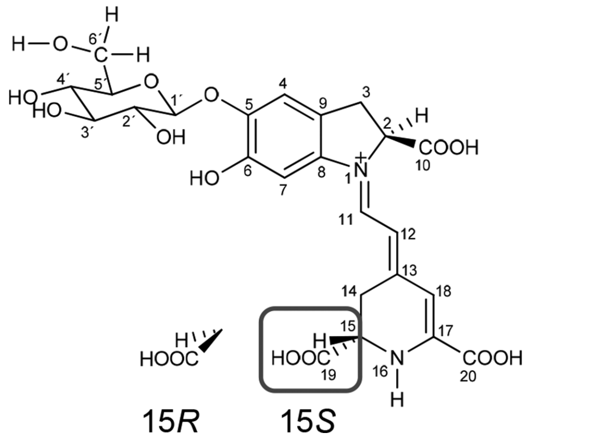

Figure 4. Chemical structure of betanin (15*S*; isobetanin 15*R*).

denitrificans. In this way nitrate ions are converted into gaseous nitrogen [33]. The Scientific Committee on Food and the Joint FAO/WHO (FAO, Food and Agriculture Organization; WHO, World Health Organization) Expert Committee on Food Additives (JECFA) stated an acceptable daily intake for nitrate of 3.7 mg/kg body weight and day, equivalent to 260 mg nitrate (≙ 3.6 mmol/day) per day for an adult [34].

In comparison to red beet the color spectra of Cactaceae like *Opuntia* sp. [13, 25], *Cereus* sp., *Hylocereus* sp., and *Selenicereus* sp. [4, 35, 36] range from yellow-orange to red-violet. The pulp of *Hylocereus* sp. contains betacyanins [5], whereas *Opuntia* sp. contain the red-violet betacyanins and the yellow-orange betaxanthins [25, 37]. Whereas the peel from *Hylocereus* sp. is mostly red, the pulp can be colorless (Fig. 6B (d)) [38]. Especially in *Hylocereus* sp. betanin and phyllocactin are detectable and in lower amounts the acylated betacyan hylocerenin [4]. *Opuntia* sp. contains in addition to betanin/isobetanin the yellow betaxanthin indicaxanthin as one of the major compounds [13]. The betalain content in *Opuntia stricta* is with 800 mg/kg fresh weight around five times higher than in *Opuntia ficus-indica* and partly higher as in red beet.

Moreover, amaranth (*Amaranthus tricolor* L.) [39, 40], Swiss chard (*Beta vulgaris* L. ssp. *cicla*) [41], strawberry blite (*Blitum capitatum*, Syn. *Chenopodium capitatum*) [42], *Ullucus tuberosus* [43, 44], *Rivina humilis* L. berries [45], *Mammillaria* sp. [46], *Talinum triangulare* (Jacq.) Willd. [47], and *Celosia argentea* [48] are betalain-containing foods.

Betalains serve in flowers and fruits as pollinator attractants [49, 50]. Furthermore, betalains keep herbivores from cactus away, protect the ice plant (*Mesembryanthemum crystallinum* L.) from UV-damage and act as osmolytes in *Salicornia europaea* L [11, 51]. In root vegetables like red beet betacyanins increase the pathogen resistance and may enhance viral defense [11, 19].

2 Betanin as a food colorant

The food color is an important purchase criterion for consumers and serves as a so-called "quality indicator." During the past decade a consumer trend toward natural food colorants can be observed. Thus, more and more foods like berries, pepper, or red beet have been used as food colorants. The consumer associates hereby partially healthier food and is willing to pay more for such foods. In recent years, possible health effects of natural food colorants have been increasingly investigated. The use of natural food colorants is regulated by the European Union. According to the German regulation on additives ("Zusatzstoff-Zulassungsverordnung") betanin, the pigment of red beets, is permitted for use in defined amounts in certain foods up to "quantum satis" (e.g. in sausage) as a natural food colorant with the E-number E162. Betanin is applied, i.e. for coloring dairy products such as fruit yogurt and ice-cream as well as jams, chewing gum, sauces, and soups to name a few. Furthermore, betanin is used in cosmetics and pharmaceuticals [29]. The betalain-containing extracts of red beets are also allowed in the USA as natural food colorants in the food industry [52].

As natural red nuances also carmine (E120) and anthocyanins (E163) are used in the food industry. The advantage of betalains, compared to anthocyanins, is based on the fact that their color is largely independent on the pH value. The water soluble betalain pigments are stable in the pH range of 3 and 7 and are thus suitable for coloring from sour to neutral foods, whereas the use of anthocyanins is not

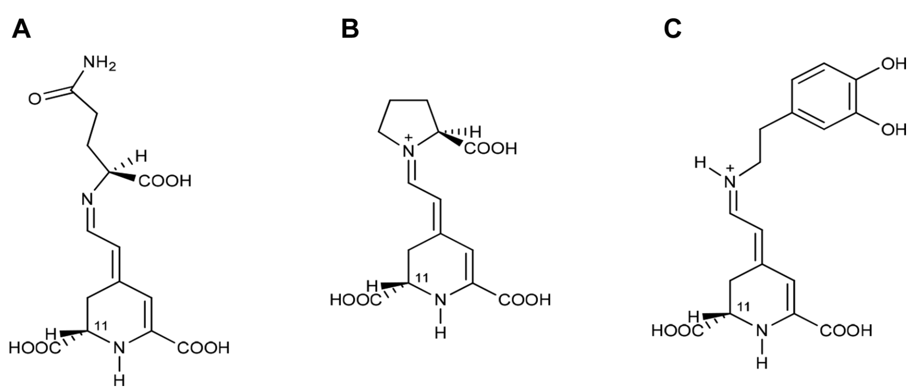

Figure 5. Possible structures of betaxanthins (A: vulgaxanthin I = glutamine-betaxanthin, B: indicaxanthin = proline-betaxanthin, C: miraxanthin-V = dopamine-betaxanthin).

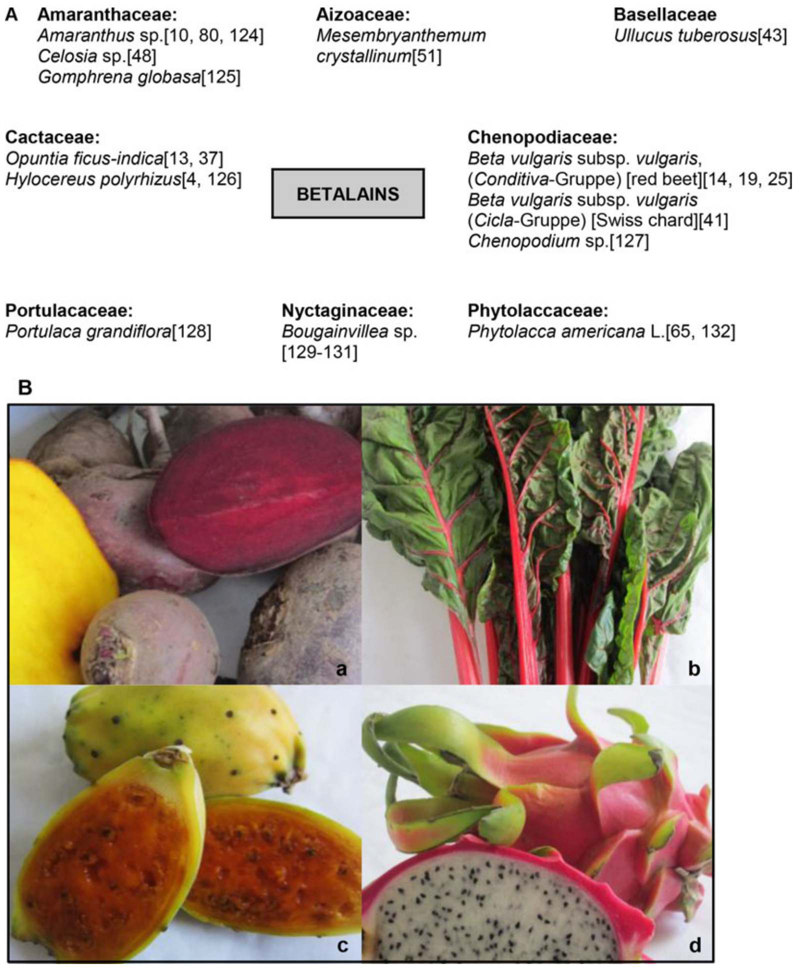

Figure 6. (A) Betalain-rich plant species (Family: *Species*); (B) Red and yellow beet (a), Swiss chard (b), *Opuntia* sp. (c), *Hylocereus* sp. (d).

possible due to the instability at pH values over 3 [8]. Apart from the production of the natural colorant E162 from red beet, its isolation from cactus pear (*Opuntia*) and Amaranthaceae is also possible [10, 53]. The use of *Opuntia* sp. has several advantages such as neutral smell and/or taste as well as the low nitrate content. Thus cactus pears can be used, e.g. in foods with a low pH value such as ice cream or yogurt [54].

3 Biosynthesis and stability of betalains

The biosynthesis of betalains in plants (precursor tyrosine) excludes that of anthocyanins (precursor phenylalanine) [55–57]. A possible reason is the absence of the enzyme anthocyanidin synthase in betalain-producing plants that catalyzes the last step of the anthocyanin biosynthesis [56, 58, 59].

During the biosynthesis of betalains in the cytoplasm three enzymes are involved: Tyrosinase, 4,5-DOPA-extradiol-dioxygenase, and betanidin-glucosyltransferase [60]. The biosynthesis of betalains is shown in Fig. 7. The amino acid L-tyrosine, which is enzymatically formed over the shikimate pathway from arogenic acid [61], is the precursor for the biosynthesis of L-DOPA [62]. Tyrosine is hydroxylated by means of the enzyme tyrosinase to DOPA (**I**) [63] that is formed to betalamic acid or to *cyclo*-DOPA [60]. The biosynthesis of betalamic acid, which is the basic structure of betalains as follow: 4,5-DOPA-extradiol dioxygenase opens the cyclic ring of L-DOPA between carbons 4 and 5, thus producing 4,5-*seco*-DOPA (**II**) [64–66]. This intermediate product occurs naturally [16]. Due to spontaneous intramolecular condensation between the amine group and the aldehyde group of 4,5-*seco*-DOPA betalamic acid is formed (**III**) [62]. The built betalamic acid has a chiral center at position 6 that is relevant for its coloring properties [60, 66].

The condensation of betalamic acid with biogenic amines or an amino acid leads to formation of yellow betaxanthins. After the spontaneous, nonenzymatic addition of the amino group of the amine to the aldehyde group of betalamic acid a dehydration takes place, thereby forming an imine (**IV**) [67].

Under the presence of molecular oxygen L-DOPA is transformed by tyrosinase to *o*-DOPA-quinone (**V**) [63, 68]. However, the developed *o*-DOPA-quinone can be reduced by ascorbic acid or another reducing agent to L–DOPA (**VI**) [68]. The amino group of *o*-DOPA-quinone accomplishes a nucleophilic attack on the ring system, the spontaneous cyclization appears and thereby *cyclo*-DOPA (**VII**) is formed [60].

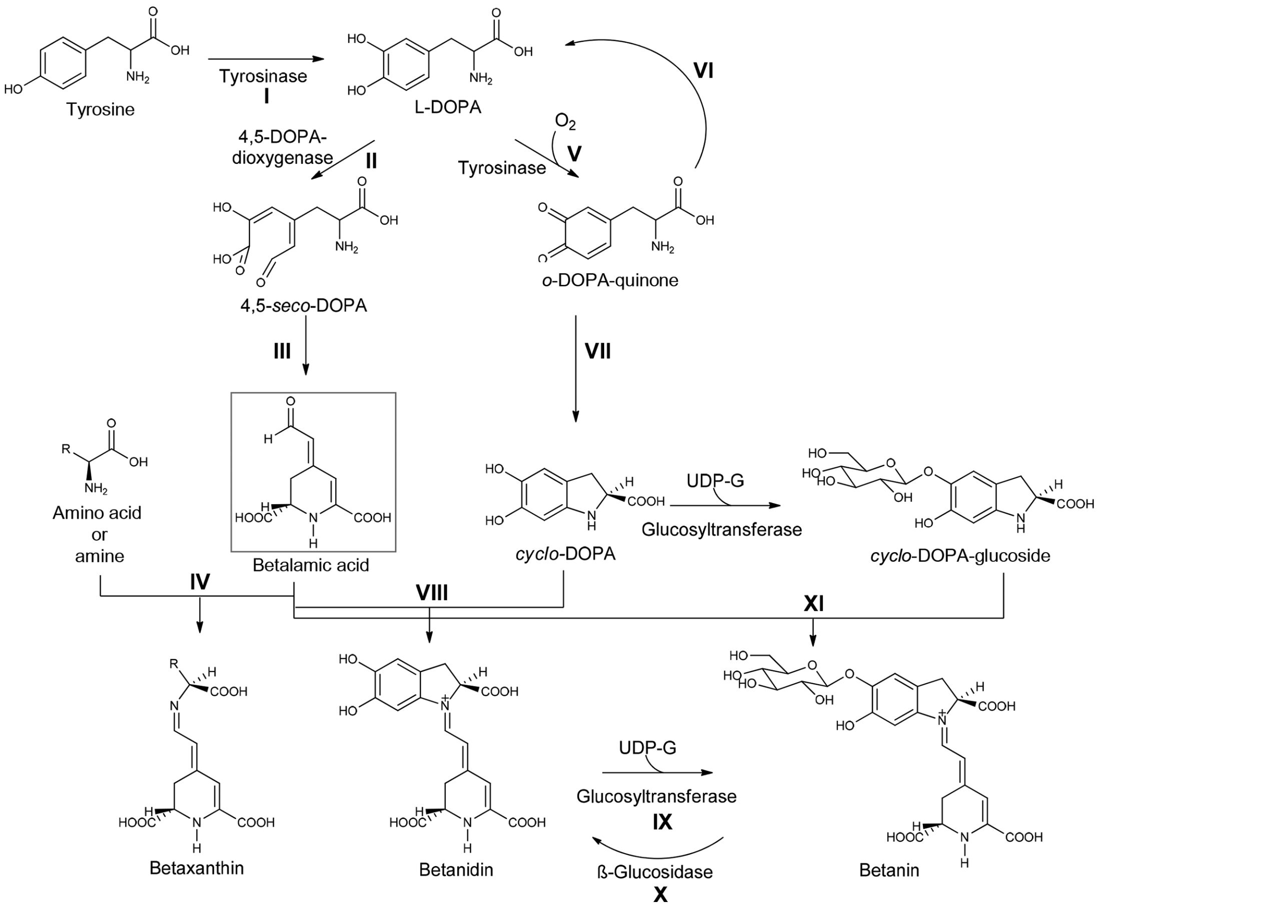

Figure 7. Biosynthesis of betalains (according to [9], [60])

Recently, it was shown that the cyclization from L-DOPA to *cyclo*-DOPA is also possible by means of Cytochrom P450 (CYP76AD1) [69]. *Cyclo*-DOPA condenses with betalamic acid in the same way like amino groups (imine bond) [70] – thus betanidin is formed that is an important starting molecule for the formation of betacyanins (**VIII**). By means of the enzyme betanidin-5-*O*-glucosyltransferase, which connects the glucose unit of uridine diphosphate-glucose to the hydroxyl group in position 5, betanidin is converted to betanin (**IX**) [71, 72]. Further glycosylations and acylations lead to formation of various derivatives of betanidin [73]. However, *ß*–glucosidase reverses this reaction (**X**) [74]. Moreover, it is assumed that *cyclo*-DOPA-5-*O*-glucosyltransferase catalyzes the transport of glucose on *cyclo*-DOPA, whereby over the condensation of *cyclo*-DOPA-glucoside with betalamic acid betanin is built (**XI**) [75].

Decarboxylated betalains can occur also in plants or in vitro in cultures [76, 77]. If DOPA is decarboxylated to dopamine by means of the enzyme DOPA-decarboxylase, the 2-descarboxy-*cyclo*-DOPA is formed with the help of tyrosinase and following cyclization, which condenses with betalamic acid to 2-descarboxy-betanidin (imine bond) [76]. Betalamic acid can also condense with the decarboxylated biogenous amines tyramine and dopamine, whereby tyramine-betaxanthin and dopamine-betaxanthin develop, from which by means of tyrosinase 2-descarboxy-betanidin is formed [60, 77].

Food colors should be stable during production and storage of foods. The stability of betalains is influenced by exogenous factors such as temperature, pH value, oxygen, and light during storage or food production, whereby antioxidants and chelating agents can function as stabilizers [78]. An overview of stabilizing and destabilizing factors of betalains is shown in Fig. 8.

4 Betanin as a free radical scavenger and an inducer of antioxidant defense mechanisms

Betalains as well as betalain-rich foods and extracts may exhibit free radical-scavenging activity [21, 24, 37, 38, 44, 79–84].

In various studies a structure-activity relationship between betalains and their radical-scavenging properties have been suggested. The radical-scavenging properties of betalains is increased with the number of hydroxyl and imino groups [80, 82, 85, 86]. The presence of catechol seems to

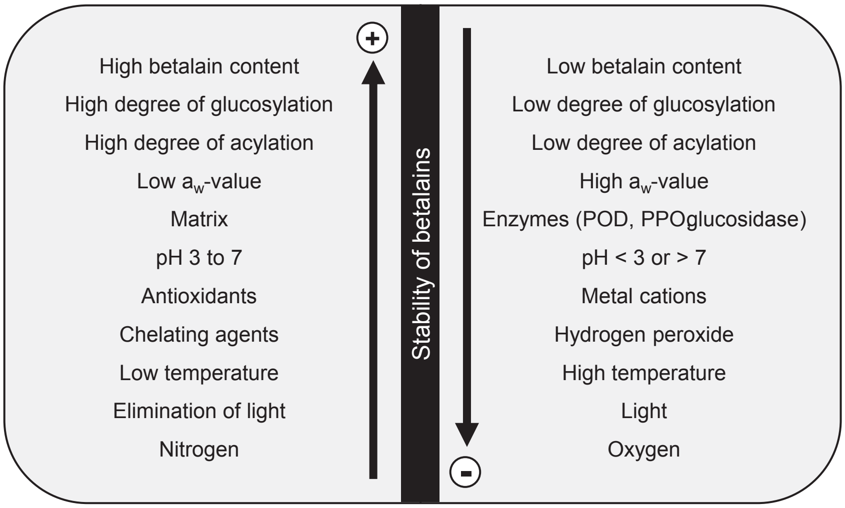

Figure 8. Overview of stabilizing and destabilizing factors of betalains (according to [78]).

be particularly important in term of the radical-scavenging properties of betalains [83, 85, 87]. It was shown that betaxanthins, which do not have phenolic hydroxyl groups exhibit only a moderate radical-scavenging activity [83]. Glycosylation of betalains reduces their radical-scavenging activity [80, 86]. Moreover, the position of glycosylation has an influence on the radical-scavenging potential [80, 85]. Thus, 5-*O*-glycosylated betacyanins shows a lower activity than 6-*O*-glycosylated betacyanins [80]. The cyclic amine group of betalains, similar to the antioxidant ethoxyquin, [88] seems to be relevant for their radical-scavenging properties [80].

In comparison to betaxanthins, betacyanins, i.e. betanin are stronger scavengers of free radicals [81, 89]. The radical-scavenging activity of betacyanins and betaxanthins is in the so-called DPPH-assay (1,1-diphenyl-2-picrylhydrazyl) approx. 3–4 times higher compared to ascorbic acid, catechin, and rutin [80]. In the TEAC-assay (trolox equivalent antioxidant capacity) it was demonstrated that betanin has at pH >4 an approx. 2-times stronger radical-scavenging effect than some anthocyanins, i.e. cyanidin–3–*O*–glucoside [24].

The radical-scavenging properties of betanin, as a pure substance, was also measured by electron spin resonance spectroscopy and spin trapping [90]. It has been shown that betanin acts as a scavenger of DPPH-, galvinoxyl-, superoxide- and hydroxyl-radicals [90]. It needs to be taken into account that in vitro assays such as the TEAC- and DPPH-assays lack specificity [91]. Thus, in vitro measurements regarding antioxidant activity of phytochemicals need to be interpreted with caution [92].

Nevertheless, potential health benefits of betalains have been recently suggested and summarized in Table 1.

Betalains induce the endogenous glutathione synthesis in human erythrocytes [93] and protect erythrocytes against hemolysis [94].

Furthermore, betalains protect LDL particles (low density lipoprotein) against oxidation [23, 93, 95, 96]. Due to their cationic structure, betalains interact with polar components of the LDL particles [96]. LDL–oxidation is counteracted by betalains already at relatively low concentrations as compared to the antioxidants α–tocopherol and catechin [23]. Furthermore, in a human study it was shown that biomarkers of lipid oxidation such as F_2-isoprostanes (in plasma), malondialdehyde (in plasma), and lipid hydroperoxide (in LDL) were decreased by betalains [93].

Table 1. Potential health benefits of betanin and betalain-rich foods

Potential health benefit	Reference
Free radical scavenging of reactive oxygen species	[93, 97]
Protection of LDL against oxidation	[23, 93, 95, 96]
Prevention of DNA-damage	[90, 97–99]
Induction of antioxidant (e.g. paraoxonase 1, glutathione peroxidase, heme oxygenase 1) and phase II detoxifying enzymes (e.g. glutathione *S*-transferase, NAD(P)H dehydrogenase [quinone] 1)	[90, 98, 104, 123]
Gene regulatory activity (e.g. Nrf2-dependent signal transduction pathway)	[104]
Anti-inflammatory activity (e.g. inhibition of cyclooxygenase-2)	[110]

In phorbol 12-myristate13-acetate-stimulated human neutrophil cells, betanin supplementation resulted in a reduction of induced DNA-damage [97]. In a further study, mice were fed with red beet extract. Besides an induction of endogenous antioxidant defense mechanisms (e.g. glutathione, glutathione peroxidase) an inhibition of DNA-damage in lymphocytes as well as in hepatocytes was evident [98]. Furthermore, betalains derived from *Opuntia ficus-indica* mediated a reduction of DNA-damage induced by H_2O_2 in human lymphocytes [99]. Our studies in cultivated enterocytes confirmed a protective effect of betanin in terms of DNA-damage [90]. In fact, DNA-damage due to H_2O_2 in human HT–29 enterocytes (measured by the so-called Comet-assay) was significantly counteracted by 15 μmol/L betanin [90].

The redox-sensitive transcription factor Nrf2 (nuclear factor (erythroid-derived 2)-like 2) is a central player in the cellular defense against oxidative stress [100, 101]. Nrf2 orchestrates the expression of genes encoding antioxidant and phase-II enzymes, which play an important role in the metabolism of xenobiotics [102]. The activity of Nrf2 is partially controlled by the cytosolic protein Keap1 (kelch-like ECH-associated protein 1). Under basal condition Nrf2 is bound to its inhibitor Keap1 in the cytoplasm. If electrophiles react with the redox-reactive cysteine residues of Keap1, the connection between Nrf2 and Keap1 is cleaved. Nrf2 translocates into the nucleus where it binds as a heterodimer with musculoaponeurotic fibrosarcoma proteins. They bind together with further cofactors to the antioxidative responsive element on the DNA and initiate the gene expression of phase-II and antioxidative enzymes, i.e. heme oxygenase 1 (HO1) [102,103]. Recently, Krajka-Kuźniak et al. [104] showed in hepatocytes that betanin led to a significant induction of the transcription factor Nrf2 and detoxifying enzymes (e.g. glutathione *S*-transferase, NAD(P)H dehydrogenase [quinone] 1). Possibly kinase pathways such as serine/threonine kinase, c–Jun N-terminal kinase, and extracellular signal-regulated kinase are centrally involved in the betanin-mediated induction of Nrf2 [104]. Similarly extracts of red beet induced phase II enzymes in laboratory rodents [98].

HO1 is an antioxidative enzyme and a target gene of Nrf2, which catalyzes the decomposition of heme to carbon monoxide, iron, and biliverdin [105,106]. In our studies with Huh7–cells an induction of the Nrf2 target gene HO1 by betanin (1, 5, and 15 μmol/L) could be observed [90].

Paraoxonase 1 (PON1) is an antioxidative enzyme, which is primarily synthesized in the liver. PON1 circulates in the plasma bound to HDL and delays and/or prevents the oxidation of LDL and thus mediates antiatherogenic effects [107]. An adequate PON1-status is associated with a reduced risk of cardiovascular diseases. Genetic factors, lifestyle, and dietary factors determine the PON1-status [107]. Lee et al. (2009) observed in a mice study a higher plasma PON activity feeding a diet that contained betanin-rich red beet leaves [98]. By means of a luciferase reporter gene assay we verified a significant and dose-dependent betanin-mediated (1, 5, and 15 μmol/L) induction of PON1-transactivation in Huh7–liver cells [90].

Targeting the transcription factor Nrf2 may not only ameliorate oxidative stress but could also affect inflammatory processes [108]. In this context, Winkler and coworkers have shown that a red beet extract counteracts pro-inflammatory cascades in peripheral blood mononuclear cells [109]. Accordingly betanin exhibited anti-inflammatory activity in vitro due to the inhibition of cyclooxygenase-2 [110].

5 Bioavailability of betanin

The oral bioavailability of betalains, similar to that of anthocyanins, is estimated as rather low [58, 111]. The exact mechanisms of absorption, metabolism, and excretion of betalains have yet not been fully clarified [23, 94, 95, 111–113]. So far, no glucuronides, sulfates, or methylated betalain conjugates have been detected in plasma and urine [111]. Absorbed betanin is primarily excreted via urine. Nevertheless, the renal excretion of betanin is rather low with <4% of the applied dose [23, 95, 111–113]. Thus, it is assumed that betanin is isomerized to isobetanin that represents the main betanin metabolite in urine [23]. The maximum human plasma concentration of betanin is reached after approx. 3 h [95]. The human plasma betanin concentration after application of betalain-rich *Opuntia* sp. was within the range of 0.2 μmol/L [95]. Indicaxanthin concentrations in plasma seem to be higher as compared to betanin [95] and are within the range of approx. 7 μmol/L [95]. The aglycone betanidin was not detected in plasma and thus suggests that the hydrolysis of the sugar unit is not a requirement for betanin absorption [95].

6 Vasodilatory effects of red beet juice

The vasodilatory effects of red beet juice seem to be partly mediated by a NO–dependent increase of cyclic guanosine monophosphate [114] that relaxes smooth muscle cells. It is assumed that nitrate is mainly responsible for the blood-pressure lowering effects of red beet. Also white beet, which contains no betanin but comparable amounts of nitrate like red beet, leads to a reduction of blood pressure in humans [115]. Interestingly in humans, the consumption of red beet juice mediated a more pronounced blood-pressure lowering effect than equivalent concentrations of nitrate [116]. Therefore, a synergistic interaction between nitrate and betanin concerning their blood pressure lowering activity cannot be fully excluded.

Figure 9 shows the effect of a concentrated red beet juice (10 brix) on the relaxation of porcine arterial rings (with endothelium) in an organ bath. Importantly, a dose-dependent vasorelaxation due to red beet juice was evident.

Moreover, our electron spin resonance spectroscopy studies showed that betanin is a potent scavenger of superoxide radicals in vitro [90]. The availability of vasodilatory endothelial NO is significantly decreased by superoxide radicals ($O_2^{\bullet-}$), since NO reacts with $O_2^{\bullet-}$ to peroxynitrite ($ONOO^-$) [117,118] (Fig. 10). Due to the scavenging of superoxide radicals by betanin, the vasodilatory NO-concentration may increase (Fig. 10). Furthermore, superoxide dismutase (SOD) is a Nrf2 target gene. Studies in laboratory rats indicate that red beet juice induces SOD [119] and thus possibly increases endothelial NO (Fig. 10).

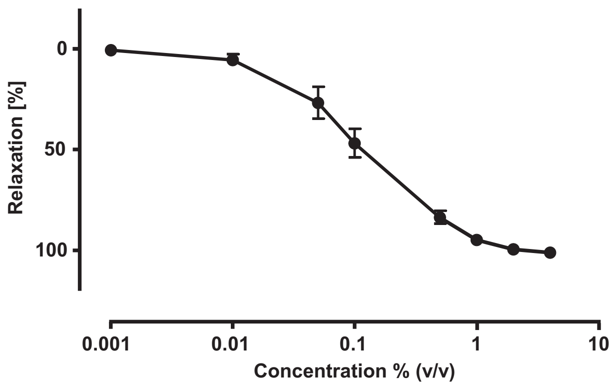

Figure 9. Influence of a concentrated red beet juice (10 brix) on the relaxation of porcine coronary arterial rings (with endothelium) in an organ bath ($n = 5$).

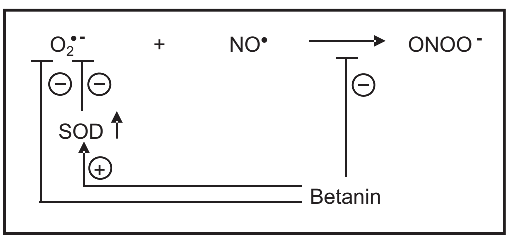

Figure 10. Potential mechanisms by which betanin may lead to an increase of vasodilatory nitric oxide. Betanin scavenges superoxide radicals and thus may prevent the reaction of nitric oxide with superoxide radicals to peroxynitrite. Simultaneously betanin induces superoxide dismutase (SOD) that may be accompanied by an increase of vasodilatory NO.

7 Conclusion

On the basis of literature data it can be concluded that betanin is a food colorant with biological activity. Also for other food colorants including curcumin [120], lycopene [121], and chlorophyllin [122] numerous biological activities have been described. Collectively, it is suggested that betanin acts as a scavenger of reactive oxygen species and induces endogenous antioxidant defense systems as well as phase II enzymes via gene regulatory mechanisms.

However, many studies regarding the potential health benefits of betanin have been conducted in vitro in cultured cells. The betanin concentration used in these in vitro studies is often many times higher than betanin concentration in human plasma following a betanin-rich meal.

Finally, there is increasing experimental evidence in terms of distinct hypotensive effects of red beet. In this context, the underlying cellular and molecular mechanisms as well as the active principals of beet root need to be addressed in more detail in future studies.

The authors declare no conflict of interest.

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