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Antioxidant Activities of Prickly Pear (*Opuntia ficus indica*) Fruit and Its Betalains

Betanin and Indicaxanthin

Maria A. Livrea and Luisa Tesoriere
University of Palermo
Palermo, Italy

I. INTRODUCTION

The importance of diet in reducing the incidence of chronic and degenerative diseases such as cancer and cardiovascular disease is well recognized (1,2). Epidemiological evidence, especially regarding the Mediterranean population (3,4), pointed out on the importance of herbs, fruits, grains, and vegetables. Among other components such as fiber and micronutrients, antioxidants in these foods are thought to be active agents responsible for some of the beneficial effects. Some of the dietary antioxidants are essential nutrients, such as vitamin E, C, and A, and minerals such as Cu, Mn, Zn, and Se, which are cofactors of antioxidant enzymes. In addition, fruits, vegetables, and herbs are particularly rich sources of other nonnutrient antioxidants, including a vast array of phytochemicals (5,6), from carotenoids and bioflavonoids to phytosterols and terpenoids. Other compounds such as betalains, less common in edible species, have more recently been studied (7–10).

The prickly pear cactus, or nopal, is a member of the Cactaceae family widely distributed in Mexico, much of Latin America, South Africa, and the Mediterranean area (11). The metabolism of its crassulacean acid gives this plant a high potential of biomass with low water consumption (12), favoring its growth under semiarid conditions. About 1500 species are in the genus *Opuntia*, many of which produce edible fruit.

Prickly pear has long been known in traditional medicine for treating a number of pathologies from ulcer, fatigue, and dyspnea to glaucoma, liver conditions, and wounds (11,13). Studies with different models and several experimental conditions provided some scientific basis for the popular use of this plant. Various preparations from fleshy stems (cladodes) have been tested for treatment of diabetes symptomatology in animal models (14,15), or in humans (16). The mechanism for this action is still unknown; some results, however, preclude a role for dietary fiber (15). Other studies revealed beneficial effects against ethanol-induced ulcer (17), in the treatment of benign prostatic hypertrophy (18,19), and in hypercholesterolemia in humans (20) and guinea pigs (21). Diuretic activity of cladode, flower, and fruit infusions has been shown in rats (22). Obviously, other investigations are required to gain insight into the active agents in this plant and the mechanisms involved in all the observed effects.

Cladodes of prickly pear are rich in proteins, carbohydrates, minerals, and vitamins, so Mexicans eat the young pads of the plant, also known as nopalitos, cooked as vegetables. In the industrialized countries of the Mediterranean area, cladodes are not a common nutritional source for humans, but the peeled fruits are usually consumed.

The Sicilian cultivars of prickly pear [*Opuntia ficus indica* (L.) Mill.] are characterized by yellow, red, and white fruits, due to the combination of two betalain pigments, the purple-red betanin and the yellow-orange indicaxanthin (23,24). The composition and nutritional properties of the prickly pear fruit have long been reported (11,25–29). In contrast, though it was known that the fruit contains vitamin C (29,30), investigations on other antioxidant components, and on its antioxidant capacities, have started only recently. Antioxidant nutrients have been researched in the authors' laboratory, and antioxidant activities of the fruit extracts and of the purified betalains have been evaluated in a number of models in vitro (9,10). In addition, the effects of the regular ingestion of prickly pear fruits on redox balance and bioavailability of betalain components in healthy humans have been investigated (31). This chapter summarizes findings to date, with special emphasis on betanin and indicaxanthin, the characteristic pigments. These phytochemicals, poorly studied until recently, have appeared as important functional components whose antioxidant activity may be a matter of future development.

II. BETALAIN PIGMENTS

A. Chemistry

Betalains are vacuole pigments restricted to flowers and fruits of 10 families of Cariophyllalae plants and to a few superior fungi of the the genus *Amanita* of the Basidiomycetes (32). Beet (*Beta vulgaris*) and prickly pear cactus are the only foods containing betalains (33,34). Betalains constitute a class of cationized nitrogenous compounds, the colors of which range from the yellow betaxanthins to the violet-red betacyanins. The betaxanthins are conjugates of betalamic acid with amino acids or the corresponding amines (including dopamine), while almost all betacyanins are derivatives of betanidin, the conjugate of betalamic acid with cyclodopa. The hydroxyl groups at the C5 and C6 position of cyclodopa can be esterified with either a carbohydrate or a carbohydrate derivative to form various betacyanins (Scheme 1). Tyrosinase and Dopa dioxygenase are the only enzymes involved in the synthesis of Dopa, cyclodopa, and betalamic acid, to form the basic skeleton of betalains in plant tissues (35–38), whereas the condensation process of betalamic acid with cyclodopa or amino acids/amines appears as a nonenzymatic reaction (39,40). Glucosyl transferase is involved in the attachment of glucose to betanidine (41).

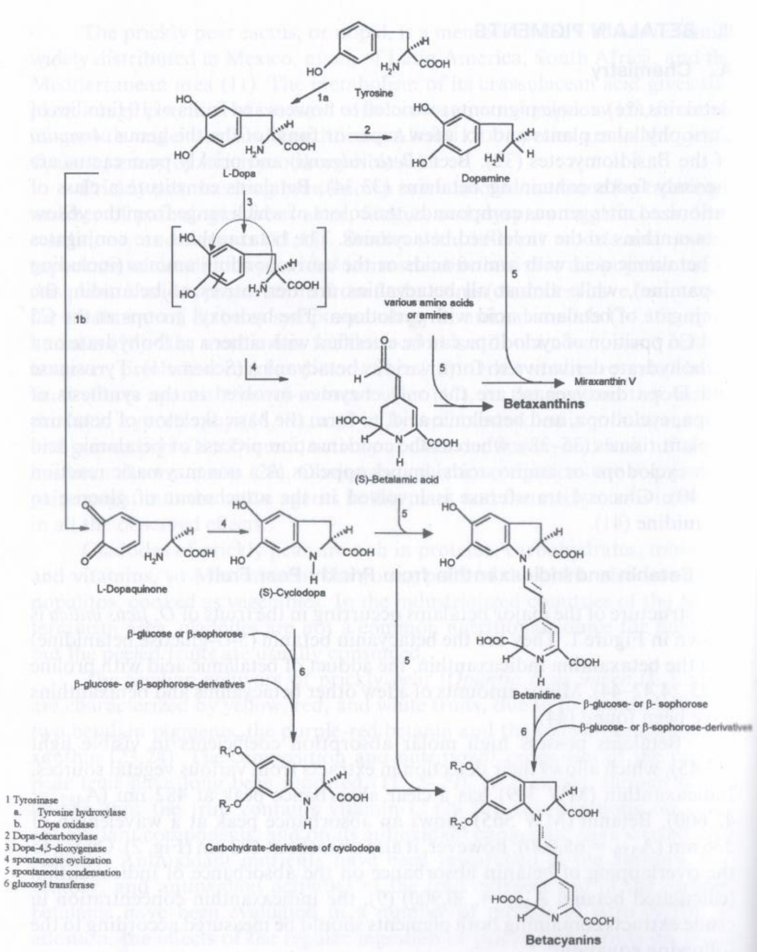
B. Betanin and Indicaxanthin from Prickly Pear Fruit

The structure of the major betalains occurring in the fruits of *O. ficus indica* is shown in Figure 1. They are the betacyanin betanin (5-*O*-glucose betanidine) and the betaxanthin indicaxanthin, the adduct of betalamic acid with proline (9,23,24,42–44). Minor amounts of a few other betacyanins and betaxanthins have been found (44).

Betalains possess high molar absorption coefficients in visible light (33,45), which allows their detection in extracts from various vegetal sources. Indicaxanthin (MW 309) has a clear absorbance peak at 482 nm (A_{482} = 42,600). Betanin (MW 565) shows an absorbance peak at a wavelength of 536 nm (A_{536} = 65,000); however, it also absorbs at 482 nm (Fig. 2). Owing to the overlapping of betanin absorbance on the absorbance of indicaxanthin (calculated betanin A_{482} = 30,900) (9), the indicaxanthin concentration in crude extracts containing both pigments should be measured according to the following equation:

$$[\text{Indicaxanthin}](\mu\text{M}) = 23.8\ A_{482} - 7.7\ A_{536}$$

This was applied to investigate the amounts of both betalains in methanolic extracts from fruit of the white, yellow, and red Sicilian cultivars of prickly pear (9).



SCHEME 1 Biosynthetic pathway of betaxanthins and betacyanins.

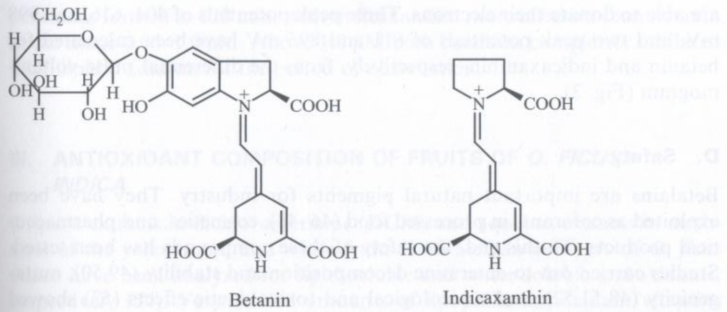


FIGURE 1 Structure of betanin and indicaxanthin.

Simple chromatographic methods have been described to isolate and purify the two major pigments from the fruit of prickly pear (9,42–44).

C. Redox Potential

The oxidation potentials of betanin and indicaxanthin have been evaluated by cyclic voltammetry (9). The cyclic voltammogram showed two and three anodic waves for indicaxanthin and betanin, respectively, indicating that both

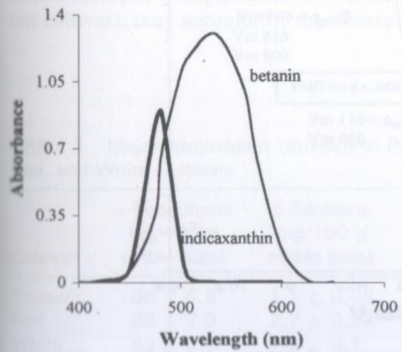


FIGURE 2 Visible-light absorption spectra of indicaxanthin and betanin.

are able to donate their electrons. Three peak potentials of 404, 616, and 998 mV, and two peak potentials of 611 and 895 mV have been calculated for betanin and indicaxanthin, respectively, from the differential pulse voltammogram (Fig. 3).

D. Safety

Betalains are important natural pigments for industry. They have been exploited as colorants in processed food (46–48), cosmetics, and pharmaceutical products. To this end, the safety of these compounds has been tested. Studies carried out to determine decomposition and stability (49,50), mutagenicity (48,51,52), and toxicological and toxicokinetic effects (53) showed that these pigments are not harmful. Some in vivo studies in rats indicated that betalains did not have toxic effects with any of the doses tested, up to 5 g/kg body weight (53).

In the authors' laboratory the potential prooxidant activity of the pure betanin and indicaxanthin was tested in a model of copper-stimulated oxidation of human LDL (10). Neither betalain showed adverse effects when assayed in a concentration range of 0.05–50 μM. Rather, both compounds were able to decrease dose-dependently the conjugated diene lipid hydro-

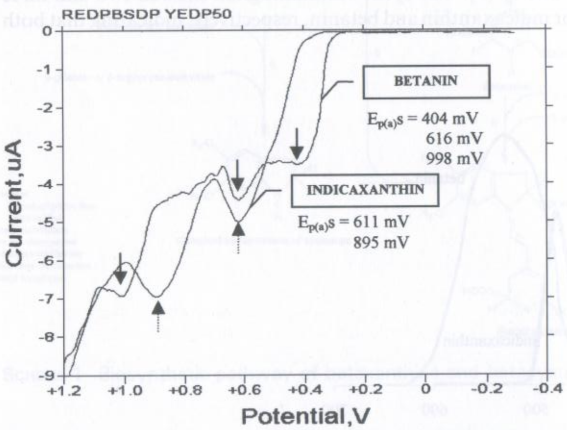


FIGURE 3 Differential pulse voltammetry of betanin and indicaxanthin. The arrows represent the $E_{p(a)}$ of the anodic waves. (Modified from Ref. 9.)

peroxides formed in 120 min, with indicaxanthin more effective than betanin in the range 0.05–1.0 μM. Above 1.0 μM both betalains completely inhibited LDL lipid oxidation for the period of observation.

III. ANTIOXIDANT COMPOSITION OF FRUITS OF *O. FICUS INDICA*

Organic extracts in dichloromethane (DCM) and aqueous extracts in methanol of the yellow, red, and white fruits from Sicilian cultivars of *O. ficus indica* have been analyzed for lipid-soluble and water-soluble antioxidants, respectively (54). Very limited amounts of lipophilic antioxidant vitamins have been found, α-tocopherol, *trans*-β-Carotene, and retinyl palmitate representing the major compounds, with minor variations among the cultivars. Retinyl oleate and *trans*-retinol are absent. In contrast, all cultivars are a good source of vitamin C (Table 1). Negligible amounts of flavonols (237 ± 20 ng/100 g fruit pulp) have been found in the aqueous extracts from the red fruit only (9).

Betalains have been measured in the three cultivars. According Butera et al. (9), the yellow cultivar has the highest content of betalains, indicaxanthin accounting for 89% of the pigments. Betanin is mostly concentrated in the red cultivar, which accounts for 66% of betalains. Finally, the white cultivar, which exhibits the lowest amount of betalain pigments, contains almost exclusively indicaxanthin (Table 2). Other researchers (42,43), who investigated betalains in the red and yellow cultivars, have reported quite different values (Table 2). As observed (9), overestimation of indicaxanthin due to biased spectrophotometric evaluation of crude extracts, and/or different cultivars, may account for the discrepancy.

TABLE 1 Major Antioxidant Vitamins in Prickly Pear Fruit from Yellow, Red, and White Cultivars

Cultivar	α-Tocopherol (μg/100 g edible pulp)	β-Carotene (μg/100 g edible pulp)	Retinyl palmitate (μg/100 g edible pulp)	Ascorbic acid (mg/100 g edible pulp)
Yellow	66 ± 5.8	1.1 ± 0.09	0.13 ± 0.01	30 ± 2.8
Red	69 ± 7.0	2.7 ± 0.22	0.44 ± 0.05	29 ± 1.7
White	65 ± 5.2	1.2 ± 0.1	0.11 ± 0.02	28 ± 2.5

Each value is the mean ± SD of four determinations on different lots of fruits.

Table 2 Indicaxanthin and Betanin in *O. ficus indica*

Cultivar	Content (mg/100 g edible pulp) Indicaxanthin	Betanin
Yellow	8.42 ± 0.51[a]	1.04 ± 0.12[a]
	25[b]	Not detectable[b]
Red	2.61 ± 0.30[a]	5.12 ± 0.51[a]
	30[b]	19[b]
	40[c]	14[c]
White	5.86 ± 0.49[a]	0.10 ± 0.02[a]

[a] *Source*: From Ref. 9.
[b] *Source*: From Ref. 43.
[c] *Source*: From Ref. 42.

IV. ANTIOXIDANT ACTIVITIES OF FRUITS OF *O. FICUS INDICA*

A. In Vitro Studies

1. Chemical Models

The decolorization of the 2,2′-azino-bis(3-ethylbenzthiazoline-6-sulfonic acid) (ABTS) radical cation is an accurate assay for screening the antioxidant activities of either lipophilic substances or food extracts (55). The total antioxidant capacity of either the DCM lipophilic extracts or the methanolic hydrophilic extracts from fruits of the yellow, red, and white Sicilian cultivars of prickly pear has been evaluated by the reaction with the ABTS radical cation, generated by reacting ABTS with potassium persulfate (9), and expressed as Trolox equivalents. Because of the low amount of lipophilic antioxidants, the organic extracts of the prickly pear fruits exhibit a modest radical-scavenging activity, when compared, for example, to extracts from tomato (55), a good source of carotenoids (Table 3). The activity of the extract from the red fruit appears higher than the activity of the yellow and white ones, possibly as a reflection of the relatively higher content of β-carotene. In contrast, the water-soluble extracts from prickly pear fruits appear very active, as compared with a number of other fruits (Table 3). The total antioxidant capacity is higher than that reported for pear, apple, tomato, banana, and white grape, and of the same order of pink grapefruit, red grape, and orange (56). The extract from the yellow fruit is the most effective among the three cultivars. Considering its antioxidant potential evaluated in the ABTS test (57), vitamin C, which occurs in approximately the same amount in the three cultivars of prickly pear, may account for no more than 40% of

Table 3 Total Antioxidant Activity (TAA) of Lipophilic and Water-Soluble Extracts *of O. ficus indica* and Other Fruits

	Lipophilic extract (mmol Trolox equivalent/kg dry wt)	Water-soluble extract (μmol Trolox equivalent/g edible pulp)
Prickly pear		
Yellow	0.010 ± 0.002[a]	5.31 ± 0.49[a]
Red	0.016 ± 0.002[a]	4.20 ± 0.51[a]
White	0.011 ± 0.001[a]	4.36 ± 0.41[a]
Pear		1.34 ± 0.06[b]
Tomato	5.72 ± 0.21[c]	1.89 ± 0.12[c]
Apple		2.18 ± 0.35[b]
Banana		2.21 ± 0.19[b]
Grape		
White		4.46 ± 1.06[b]
Red		7.39 ± 0.48[b]
Grapefruit		
Pink		4.83 ± 0.18[b]
Orange		7.50 ± 1.01[b]

[a] *Source*: From Ref. 9.
[b] *Source*: From Ref. 57.
[c] *Source*: From Ref. 55.

the evaluated antioxidant capacity of the extracts, which has suggested that other hydrophilic constituents, possibly betalain pigments, may act as efficient radical scavengers (9). This seemed to somewhat explain the activity of the extract from the yellow fruit, which contains the highest amounts of betalains (9).

In addition to the activity measured in fruits, ethanol extracts of stems of *O. ficus indica* var. Saboten were found to have radical-scavenging activity in a number of assays generating radicals such as 2,2-diphenyl-1-picrylhydrazyl (DPPH), superoxide anions, and hydroxyl radicals (58). In light of the high amount of phenolics in the stems (180.3 mg/g lyophilized extract), these substances have been suggested to be the active components.

2. Biological Models

Methanolic extracts from the fruits of the yellow, red, and white cultivars of prickly pear have been found capable of preventing lipid oxidation stimulated by organic hydroperoxide in human red blood cells, and by either copper or 2,2′-azobis(2-amidinopropaane) hydrochloride (AAPH) in human low-density lipoproteins (9). Extracts from 0.5–5 mg of fruit pulp dose-dependently inhibited malondialdehyde formation in red blood cells (Fig. 4). With reference to the antioxidant activity of α-tocopherol, the white cultivar has been the most effective at inhibiting lipid oxidation, the extract from 1 mg pulp being as effective as 0.2 μM α-tocopherol. Comparable amounts of extracts from the red and yellow cultivars showed an antioxidant activity equivalent to that of 0.13 μM α-tocopherol (9).

Methanolic extracts of fruit pulp markedly elongated, in a dose-dependent fashion, the period preceding the formation of conjugated diene lipid hydroperoxides of human LDL, submitted to either metal-dependent or -independent oxidation (Fig. 5). As already observed with the red blood cell oxidation model, the extract from the white cultivar was the most effective in both LDL models, followed by the red and the yellow ones.

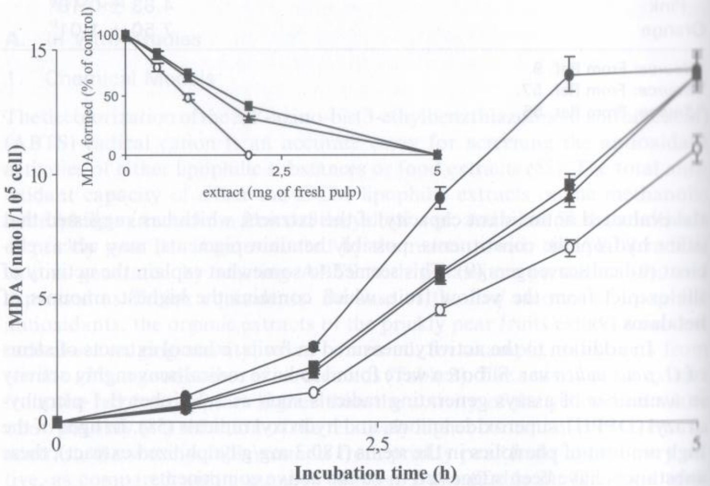


FIGURE 4 Inibitory effect of methanolic extracts from 1 mg fresh pulp of *O. ficus indica* on MDA formation, in *tert*-butyl hydroperoxide-treated RBCs. Human RBCs (HT 1%) were incubated with 50 μM *tert*-butyl hydroperoxide at 37°C either in the absence (●) or in the presence of methanolic extract of edible pulp from white (○), yellow (▲), and red (■) cultivars. Inset. Dose-dependent inhibitory effect of methanolic extracts on MDA formation, after 4-hr incubation.

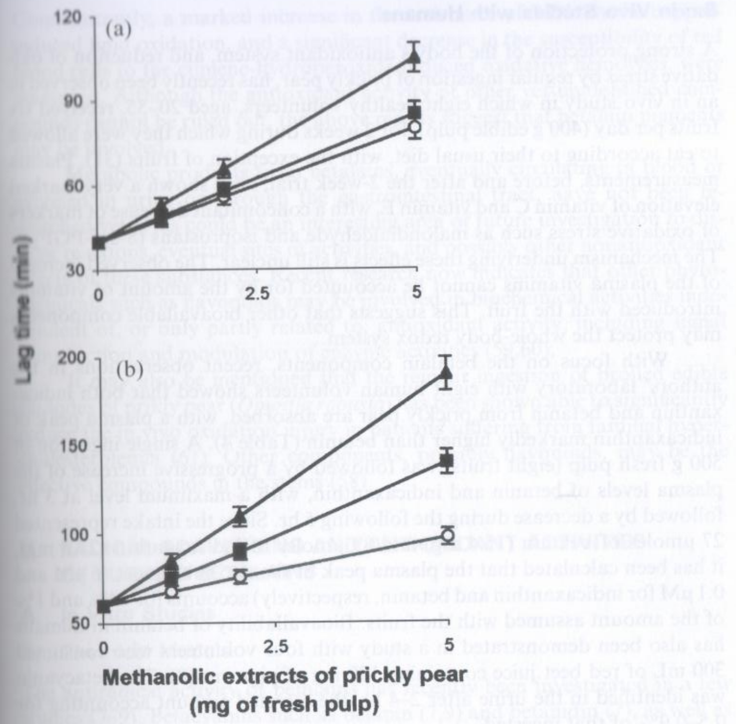


FIGURE 5 Elongation of the lag period during the Cu^{2+}- (a) or AAPH- (b) induced oxidation of human LDL by methanolic extracts of prickly pear. ▲, yellow cultivar; ■, red cultivar; ○, white cultivar.

While taking into consideration the contribution of vitamin C, the involvement of the betalain pigments in the observed antioxidant activity of the extracts has been suggested on the basis of the measured redox potential of betanin and indicaxanthin (9). In addition, it has been pointed out that the extract from the white fruit, in which betanin is virtually absent, has the highest activity in all models of lipid oxidation. This can be an indication that, in addition to betacyanins (8), indicaxanthin may act as an antioxidant compound in biological environments.

B. In Vivo Studies with Humans

A strong protection of the body's antioxidant system, and reduction of oxidative stress by regular ingestion of prickly pear, has recently been observed in an in vivo study in which eight healthy volunteers, aged 20–55, received six fruits per day (400 g edible pulp), for 2 weeks during which they were allowed to eat according to their usual diet, with the exception of fruits (31). Plasma measurements, before and after the 2-week trial, have shown a very marked elevation of vitamin C and vitamin E, with a concomitant decrease of markers of oxidative stress such as malondialdehyde and isoprostans (8-epi-PGF$_{2\alpha}$). The mechanism underlying these effects is still unclear. The observed increase of the plasma vitamins cannot be accounted for by the amount of vitamins introduced with the fruit. This suggests that other bioavailable components may protect the whole-body redox system.

With focus on the betalain components, recent observations in the authors' laboratory with eight human volunteers showed that both indicaxanthin and betanin from prickly pear are absorbed, with a plasma peak of indicaxanthin markedly higher than betanin (Table 4). A single ingestion of 500 g fresh pulp (eight fruits) was followed by a progressive increase of the plasma levels of betanin and indicaxanthin, with a maximum level at 3 hr, followed by a decrease during the following 5 hr. Since the intake represented 27 μmoles of betanin (15.4 mg) and 89 μmoles of indicaxanthin (27.5 mg), it has been calculated that the plasma peak of the two substances (5 μM and 0.1 μM for indicaxanthin and betanin, respectively) accounts for 14% and 1% of the amount assumed with the fruits. Bioavailability of betanin in humans has also been demonstrated in a study with four volunteers who consumed 300 mL of red beet juice containing 120 mg of pigment (8). The betacyanin was identified in the urine after 2–4 hr, the escreted amount accounting for 0.5–0.9% of that ingested.

Both LDL and red blood cells, isolated 3 hr after the ingestion of 500 g fresh fruit pulp, revealed the presence of indicaxanthin and betanin (Table 4).

TABLE 4 Occurrence of Betalains in Humans 3 hr After the Ingestion of 500 g Prickly Pear Pulp

	Plasma (μM)	Red blood cells (nmoles/4.5 × 10^9 RBCs)	LDL (nmoles/mg LDL prot)
Indicaxanthin	5 ± 0.8 (8)	0.5 ± 0.01 (8)	0.1 ± 0.005 (6)
Betanin	0.1 ± 0.02 (8)	(7.5 ± 0.3) × 10^{-3} (8)	(2 ± 0.27) × 10^{-3} (6)

Values are the mean ± SD of (*n*) samples, contributed by different volunteers, analyzed in duplicate.

Concomitantly, a marked increase in the resistance of LDL to the copper-induced lipid oxidation, and a significant decrease in the susceptibility of red blood cells to the cumene-hydroperoxide-induced oxidative hemolysis, were measured. Although the antioxidant activity of other yet-unidentified compounds cannot be ruled out, the above results suggest that betalain pigments may be involved.

Metabolic products from betalains, eventually circulating in blood or excreted in urine or through the gastrointestinal tract, have not been researched yet. This could be an interesting area of future investigation to disclose reactions, eventual sites of activities, and possibly other nonantioxidant effects of these substances. Recent research now indicates that other phytochemicals such as flavonoids may be involved in biochemical activities independent of, or only partly related to, antioxidant activity, including signal transduction and modulation of enzyme activities (59,60).

It may also be mentioned that the regular ingestion of broiled edible cladodes of prikly pear (*Opuntia robusta*) has been shown able to significantly reduce the in vivo oxidation injury in patients suffering from familial hypercholesterolemia (61). Other components, possibly flavonoids, may be the effective compounds in the stems (58).

V. RADICAL-SCAVENGING AND ANTIOXIDANT ACTIVITIES OF PURIFIED BETALAINS

A. In Vitro Studies

1. Chemical Models

The antiradical activity of betalains has recently been investigated in a few studies (7–9). Betacyanins such as betanin (7,9) and betanidin (7), as well as betaxanthins such as indicaxathin (9) and vulgaxanthin (7), have been found capable of reducing the cation radical from ABTS, generated either by horseradish peroxidase/hydrogen peroxide–mediated oxidation (7) or by reaction with potassium persulfate (9). When expressed as trolox equivalents, betanin has appeared very effective (9), with an antiradical activity higher than the two betaxanthins with both experimental sets (7,9) (Table 5). This appears in accordance with the redox potential of indicaxanthin and betanin. By considering the phenolic hydroxyl group, the higher scavenging capacity of betanin has been explained by the ease with which it is possible to withdraw an electron from the betacyanin, and by the stability of the resulting delocalized radical (7). In contrast, the electron abstracted from the betaxanthins could only be from the π-orbitals, this loss being hindered by the positive charge of the N-atom. It should be mentioned that according to the ABTS assay, betanin is much more effective than a number of polyphenol com-

TABLE 5 Antiradical Activity of Betalains and Betalamic Acid Toward $ABTS^{+}$ Radical

	Trolox equivalents	Rate of $ABTS^{+}$ radical disappearance (μmoles $ABTS^{+}$ radical/first min)
Betanin	20.0 ± 0.5[a,b]	45.5[c]
Indicaxanthin	1.76 ± 0.1[a,b]	
Vulgaxanthin I		4.2[c]
Betalamic acid[d]	33 ± 1.0[a]	

[a] Each value is the mean ± SD of four determinations performed in duplicate.
[b] *Source*: From Ref. 9.
[c] Calculated from Ref. 7. Betanin and vulgaxanthin I were assayed at 12 μM, while $ABTS^{+}$ radical was 70 μM. (7).
[d] Prepared according to Ref. 44.

pounds (62). Betalamic acid shows a high radical-scavenging activity (Table 5), suggesting that the products of betalain hydrolysis may have antioxidant activity.

The activity of betalains in reducing the formation of lipoperoxyl radicals has also been reported. Linoleate peroxidation by cyt c was inhibited by betanin and betanidin, with IC_{50} of 0.4 and 0.8 μM, respectively, and by vulgaxanthin, with IC_{50} around 1.0 μM (8). In comparison, vitamin E inhibited lipid oxidation with IC_{50} of 5 μM (8), indicating a relatively higher antioxidant potential of betalains in this system. Oxidation of linoleic acid was also inhibited by betanidin and betanin, when the lipid oxidation was stimulated by H_2O_2-activated metmyoglobin, or by lipoxygenase. In the latter assays the IC_{50} for betanidin and betanin were 0.3 and 0.6 μM, respectively (8). Interestingly, monoelectronic redox reactions between betanin and the oxoferryl catalytic forms of horseradish peroxidase have been shown (63). Such an activity could also be considered in the above-reported reactions in which activated heme proteins are involved (8), as well as to explain why either betanin or betanidin was able to inhibit the decomposition of the myoglobin heme during the oxidation of linoleate (8).

The antioxidant activity of nine betalains has been studied, and the relationship between the structure and antioxidant activity was examined, with the linetol peroxidation model (64). Betaxanthins were shown to have the highest antioxidant activity in this system.

B. Biological Models

The positive charge of betalains could favor interactions with polar head groups of lipids and/or polar sites on the protein surface. Ex vivo plasma spiking of pure either betanin or indicaxanthin has been performed to provide evidence that both betalains can bind to human LDL in a saturable fashion, with a maximum binding of 0.5 nmoles/mg LDL protein (10). The betanin- as well as the indicaxanthin-enriched LDL has been shown more resistant than the homologous native LDL to copper-induced oxidation, as assessed by elongation of the lag period (Fig. 6). In addition, indicaxanthin-enriched LDL has appeared much more resistant than betanin-enriched LDL in this system, possibly as the result of synergistic interactions of indicaxanthin with the LDL vitamin E (10). Consumption of vitamin E was not varied by betanin. In contrast, indicaxanthin prevented vitamin E consumption at the beginning of LDL oxidation, and prolonged the time of its utilization (Fig. 6).

The affinity of betacyanins for microsomal membranes has been demonstrated by evaluating the rate of migration of these compounds through a dialysis tube, either in the absence or in the presence of microsomes (8).

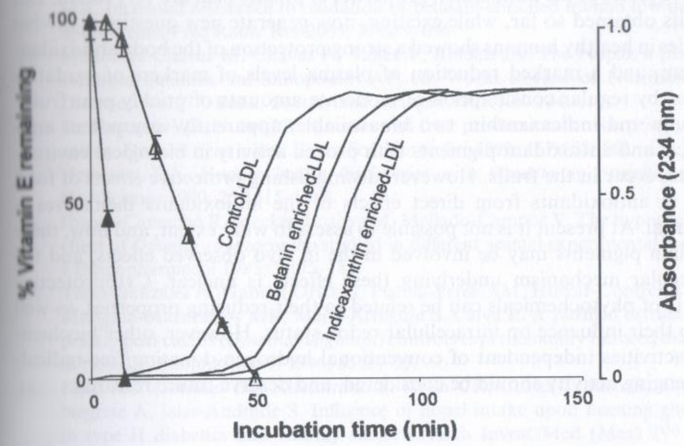


FIGURE 6 Oxidation of human control-LDL, betanin- and indicaxanthin-enriched LDL, and time course of vitamin E consumption in either control- or betanin-enriched LDL (closed triangle) and in indicaxanthin-enriched LDL (open triangle).

In addition, it has been shown that the oxidation of microsomal lipids by either $FeCl_2$/ascorbate or H_2O_2-activated myoglobin was reduced by variable concentrations of betanin (8). However, because of its electron-donating capability, low amounts of betanin (<12.5 μM) were prooxidant in the system catalyzed by iron/ascorbate, as a result of the reduction of ferric to ferrous ions. At high concentrations (25 μM) the antioxidant works also with lipoperoxyl radicals, thus preventing lipid oxidation (8).

VI. CONCLUSIONS

Phytochemicals and phytomedicines are now an expanding research field. A great number of active agents occurring in plants and herbs have been discovered, which is fundamental to finding rationale for the health effects of these herbs, in many cases used for centuries as traditional remedies. The knowledge of the mechanisms and molecular basis of action is the final objective to understand the mode of action of the discovered principles. Many antioxidant substances are listed among the phytochemicals occurring in a varieties of plants and herbs, which have been supposed to have a role in the biochemical potential of these plants and herbs.

Studies of the antioxidant properties of prickly pear are very recent, and results obtained so far, while exciting, now generate new questions. In vivo studies in healthy humans showed a strong protection of the body antioxidant system, and a marked reduction of plasma levels of markers of oxidative stress, by regular consumption of moderate amounts of prickly pear fruits. Betanin and indicaxanthin, two bioavailable, apparently very potent antiradical and antioxidant pigments with proved activity in biological environments, occur in the fruits. However, distinguishing protective effects of food rich in antioxidants from direct effects of the antioxidants themselves is essential. At present it is not possible to assess to what extent, and how, these betalain pigments may be involved in the in vivo observed effects, and the molecular mechanism underlying these effects is unclear. Cytoprotective effects of phytochemicals can be related to their reducing properties, as well as to their influence on intracellular redox status. However, other biochemical activities independent of conventional hydrogen-donating/free-radical-scavenging activity should be considered, and deserve future research.

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