Vegetables and Vegetable Products

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17 Vegetables and Vegetable Products

17.1 Vegetables

17.1.1 Foreword

Vegetables are defined as the fresh parts of plants which, either raw, cooked, canned or processed in some other way, provide suitable human nutrition. Fruits of perennial trees are not considered to be vegetables. Ripe seeds are also excluded (peas, beans, cereal grains, etc.). From a botanical point of view, vegetables can be divided into algae (seaweed), mushrooms, root vegetables (carrots), tubers (potatoes, yams), bulbs and stem or stalk (kohlrabi, parsley), leafy (spinach), inflorescence (broccoli), seed (green peas) and fruit (tomato) vegetables. The most important vegetables, with data relating to their botanical classification and use, are presented in Table 17.1. Information about vegetable production follows in Tables 17.2 and 17.3.

17.1.2 Composition

The composition of vegetables can vary significantly depending upon the cultivar and origin. Table 17.4 shows that the amount of dry matter in most vegetables is between 10 and 20%. The nitrogen content is in the range of 1–5%, carbohydrates 3–20%, lipids 0.1–0.3%, crude fiber about 1%, and minerals close to 1%. Some tuber and seed vegetables have a high starch content and therefore a high dry matter content. Vitamins, minerals, flavor substances and dietary fibers are important secondary constituents.

17.1.2.1 Nitrogen Compounds

Vegetables contain an average of 1–3% nitrogen compounds. Of this, 35–80% is protein, the rest is amino acids, peptides and other compounds.

17.1.2.1.1 Proteins

The protein fraction consists to a great extent of enzymes which may have either a beneficial or a detrimental effect on processing. They may contribute to the typical flavor or to formation of undesirable flavors, tissue softening and discoloration. Enzymes of all the main groups are present in vegetables:

- *Oxidoreductases* such as lipoxygenases, phenoloxidases, peroxidases;
- *Hydrolases* such as glycosidases, esterases, proteinases;
- *Transferases* such as transaminases;
- *Lyases* such as glutamic acid decarboxylase, alliinase, hydroperoxide lyase.
- *Ligases* such as glutamine synthetase.

Enzyme inhibitors are also present, e. g., potatoes contain proteins which have an inhibitory effect on serine proteinases, while proteins from beans and cucumbers inhibit pectolytic enzymes. Protein and enzyme patterns, as obtained by electrophoretic separation, are often characteristic of species or cultivars and can be used for analytical differentiation. Figure 17.1 shows typical protein and proteinase inhibitor patterns for several potato cultivars.

17.1.2.1.2 Free Amino Acids

In addition to protein-building amino acids, nonprotein amino acids occur in vegetables as well as in other plants. Tables 17.5 and 17.6 present data on the occurrence and structure of these amino acids. Information about their biosynthetic pathways is given below.

The higher homologues of amino acids, such as homoserine, homomethionine and aminoadipic acid, are generally derived from a reaction sequence which corresponds to that of oxalacetate

Table 17.1. List of some important vegetables

Number	Common name	Latin name	Class, order, family	Consumed as
Mushrooms (cultivated or wildly grown edible species)				
1	Ringed boletus	*Suillus luteus*	Basidiomycetes/Boletales	
2	Saffron milk cap	*Lactarius deliciosus*	Basidiomycetes/Agaricales	
3	Field champignon	*Agaricus campester*	Basidiomycetes/Agaricales	
4	Garden champignon	*Agaricus hortensis*	Basidiomycetes/Agaricales	
5	Cep	*Xerocomus badius*	Basidiomycetes/Boletales	
6	Truffle	*Tuber melanosporum*	Ascomycetes/Tuberales	Steamed, fried, dried,
7	Chanterelle	*Cantharellus cibarius*	Basidiomycetes/Aphyllophorales	pickled or salted
8		*Xerocomus chrysenteron*	Basidiomycetes/Boletales	
9	Morel	*Morchella esculenta*	Ascomycetes/Pezizales	
10	Edible boletus	*Boletus edulis*	Basidiomycetes/Boletales	
11	Goat's lip	*Xerocomus subtomentosus*	Basidiomycetes/Boletales	
Algae (seaweed)				
12	Sea lettuce	*Ulva lactuca*		Eaten raw as a salad, cooked in soups (Chile, Scotland, West Indies)
13	Sweet tangle	*Laminaria saccharina*		Eaten raw or cooked (Scotland)
14		*Laminaria sp.*		Eaten dried ("combu") or as a vegetable (Japan)
15		*Porphyra laciniata*		Eaten raw in salads, cooked as a vegetable (England, America)
16		*Porphyra sp.*		Dried or cooked ("nari" products, Japan and Korea)
17		*Undaria pinnatifida*		Eaten dried ("wakami") and as a vegetable (Japan)
Rooty vegetables				
18	Carrot	*Daucus carota*	Apiaceae	Eaten raw or cooked
19	Radish (white elongated fleshy root)	*Raphanus sativus var. niger*	Brassicaceae	The pungent fleshy root eaten raw, salted
20	Viper's grass, scorzonera	*Scorzonera hispanica*	Asteraceae	Cooked as a vegetable
21	Parsley	*Petroselinum crispum ssp. tuberosum*	Apiaceae	Long tapered roots cooked as a vegetable, or used for seasoning
Tuberous vegetables (sprouting tubers)				
22	Arrowroot	*Tacca leontopetaloides*	Taccaceae	Cooked or milled into flour for breadmaking

Table 17.1. (Continued)

Number	Common name	Latin name	Class, order, family	Consumed as
23	White (Irish) potato	*Solanum tuberosum*	Solanaceae	Cooked, fried or deep fried in many forms, or unpeeled baked, also for starch and alcohol production
24	Celery tuber	*Apium graveolens, var. rapaceum*	Apiaceae	Cooked as salad, and cooked and fried as a vegetable
25	Kohlrabi, turnip cabbage	*Brassica oleracea convar. acephala var. gongylodes*	Brassicaceae	Eaten raw or cooked as a vegetable
26	Rutabaga	*Brassica napus var. naprobrassica*	Brassicaceae	Cooked as a vegetable
27	Radish (reddish round root)	*Raphanus sativus var. sativus/var. niger*	Brassicaceae	The pungent fleshy root is eaten raw, usually salted
28	Red beet, beetroot	*Beta vulgaris spp. vulgaris var. conditiva*	Chenopodiaceae	Cooked as a salad
Tuberous (rhizomatic) vegetables				
29	Sweet potatoes	*Ipomoea batatas*	Convolvulaceae	Cooked, fried or baked
30	Cassava (manioc)	*Manihot esculenta*	Euphorbiaceae	Cooked or roasted
31	Yam	*Dioscorea*	Dioscoreaceae	Cooked or roasted
Bulbous rooty vegetables				
32	Vegetable fennel	*Foeniculum vulgare var. azoricum*	Apiaceae	Eaten raw as salad, cooked as a vegetable
33	Garlic	*Allium sativum*	Liliaceae	Raw, cooked as seasoning
34	Onion	*Allium cepa*	Liliaceae	Eaten raw, fried as seasoning, cooked as a vegetable
34a	Leek	*Allium porrum*	Liliaceae	The pungent succulent leaves and thick cylindrical stalk are cooked as a vegetable
Stem (shoot) vegetables				
35	Bamboo roots	*Bambusa vulgaris*	Poaceae	Cooked for salads
36	Asparagus	*Asparagus officinalis*	Liliaceae	Young shoots cooked as a vegetable or eaten as salad
Leafy (stalk) vegetables				
37	Celery	*Apium graveolens var. dulce*	Apiaceae	Leafy crispy stalks eaten raw as salad, or are cooked as vegetable
38	Rhubarb	*Rheum rhabarbarum, Rheum rhaponticum*	Polygonaceae	Large thick and succulent petioles are cooked as preserves or baked; used as a pie filling

Table 17.1. (Continued)

Number	Common name	Latin name	Class, order, family	Consumed as
Leafy vegetables				
39	Watercress	*Nasturtium officinale*	Brassicaceae	Moderately pungent leaves are eaten raw in salads or used as garnish
40	Endive (escarole, *chicory*)	*Cichorium intybus L. var. foliosum*	Cichoriaceae	Eaten raw as a salad, or is cooked as a vegetable
41	Chinese cabbage	*Brassica chinensis*	Brassicaceae	Eaten raw in salads, or is cooked as a vegetable
42	Lamb's salad (lettuce or corn salad)	*Valerianella locusta*	Valerianaceae	Eaten raw in salads
43	Garden cress	*Lepidium sativum*	Brassicaceae	Eaten raw in salads
44	Kale (borecole)	*Brassica oleracea convar. acephala var. sabellica*	Brassicaceae	Cooked as a vegetable
45	Head lettuce	*Lactuca capitata var. capitata*	Cichoriaceae	Juicy succulent leaves are eaten raw in salads
46	Mangold (mangel-wurzel, beet root)	*Beta vulgaris spp. vulgaris var. vulgaris*	Chenopidiaceae	Cooked as a vegetable
47	Chinese (Peking) cabbage	*Brassica pekinensis*	Brassicaceae	Cooked as a vegetable
48	Brussels sprouts	*Brassica oleracea convar. oleracea var. gemmifera*	Brassicaceae	Cooked as a vegetable
49	Red cabbage	*Brassica oleracea convar. capitata var. capitata f. rubra*	Brassicaceae	Eaten raw in salads or is cooked as a vegetable
50	Romaine lettuce	*Lactuca capitata var. crispa*	Cichoriaceae	Eaten raw as a salad
51	Spinach	*Spinacia oleracea*	Chenopodiaceae	Cooked as a vegetable or is eaten raw as a salad
52	White (common) cabbage	*Brassica oleracea convar. capitata var. capitata f.alba*	Brassicaceae	Juicy succulent leaves are eaten raw in salads, or are fermented (sauerkraut), steamed or cooked as a vegetable
53	Winter endive	*Cichoricum endivia*	Cichoriaceae	Eaten raw as a salad
54	Savoy cabbage	*Brassica oleracea convar. capitata, var. sabauda*	Brassicaceae	Cooked as a vegetable
Flowerhead (calix) vegetables				
55	Artichoke	*Cynara scolymus*	Asteraceae	Flowerhead is cooked as a vegetable
56	Cauliflower	*Brassica oleracea convar. botrytis var botrytis.*	Brassicaceae	Cooked as a vegetable or used in salads (raw or pickled)
57	Broccoli	*Brassica oleracea convar. botrytis var. italica*	Brassicaceae	The tight green florets are cooked as a vegetable

Table 17.1. (Continued)

Number	Common name	Latin name	Class, order, family	Consumed as
Seed vegetables				
58	Chestnut	*Castanea sativa*	Fagaceae	Cooked as a vegetable, roasted, or milled into a flour and used in soups and bread doughs
59	Green beans	*Phaseolus vulgaris*	Fabaceae	The immature pod is cooked as a vegetable or is steamed or pickled for salads
60	Green peas	*Pisum sativum ssp. sativum*	Fabaceae	The rounded smooth or (wrinkled) Green seeds are cooked as a vegetable or are steamed/cooked for salads
Fruity vegetables				
61	Eggplant	*Solanum melongena*	Solanaceae	Steamed as a vegetable
62	Garden squash	*Cucurbita pepo*	Cucurbitaceae	Cooked as a compote or as a vegetable
63	Green bell pepper	*Capsicum annuum*	Solanaceae	Eaten raw in salads, or is cooked, steamed or baked
64	Cucumber	*Cucumis sativus*	Cucurbitaceae	Eaten raw in salads, cooked as a vegetable or pickled
65	Okra	*Abelmoschus esculentus*	Malvaceae	Its mucilaginous green pods are cooked as a vegetable in soups or stewed, or eaten as a salad
66	Tomato	*Lycopersicon lycopersicum*	Solanaceae	The reddish pulpy berry is eaten raw, in salads, cooked as a vegetable, used as a paste or seasoned puree; immature green tomatoes are pickled and then eaten as salad
67	Zucchini	*Cucurbita pepo convar. giromontiina*	Cucurbitaceae	The cylindrical dark green fruits are peeled and cooked as a vegetable

Table 17.2. Production of vegetables in 2006 (1000 t)

Continent	Vegetables + melons, grand total	Cabbages	Artichokes	Tomatoes
World	903,405	68,991	1270	125,543
Africa	56,498	2038	167	14,336
America, Central	14,192	441	1	3331
America, North	39,296	1262	38	11,829
America, South and Caribbean	39,220	1023	190	10,559
Asia	667,827	52,200	122	66,990
Europe	97,200	12,426	752	21,326
Oceania	3365	42	–	503

Continent	Cauliflower	Pumpkin, squash and gourds	Cucumbers and gherkins	Eggplants (aubergines)
World	18,141	21,003	43,887	31,930
Africa	299	1669	1163	1497
America, Central	365	89	582	50
America, North	1324	924	1173	75
America, South and Caribbean	452	1335	859	88
Asia	13,544	13,168	35,405	29,364
Europe	2325	3672	5271	900
Oceania	196	235	17	4

Continent	Chilies[a] and peppers, green	Onions, air dried	Garlic	Green beans
World	25,924	61,637	15,184	6424
Africa	2468	5441	367	553
America, Central	1732	1322	49	55
America, North	940	3575	211	140
America, South and Caribbean	2252	5140	386	141
Asia	17,056	38,842	13,396	4574
Europe	3154	8383	823	976
Oceania	54	256	1	39

Continent	Green peas	Carrots and turnips	Watermelons	Cantaloupes and other melons (muskmelons)
World	7666	26,830	100,602	27,977
Africa	607	1230	4412	1432
America, Central	65	450	1410	1345
America, North	905	1892	1728	1221
America, South and Caribbean	271	1536	3704	2070
Asia	4599	12,799	85,735	20,827
Europe	1193	8992	4905	2340
Oceania	90	381	119	86

Table 17.2. (Continued)

Country	Vegetables + melons grand total
China	448,446
India	81,947
USA	37,052
Turkey	25,723
Egypt	16,165
Russian Fed.	15,930
Iran	15,760
Italy	15,133
Spain	12,513
Japan	11,624
∑ (%)[b]	75

Country	Cabbages
China	34,826
India	6148
Russian Fed.	4073
Korea Rep.	3068
Japan	2287
Ukraine	1465
Indonesia	1293
Poland	1249
Romania	1113
USA	1100
∑ (%)[b]	82

Country	Artichokes
Italy	469
Spain	200
Argentina	89
Egypt	70
Peru	68
China	60
Morocco	55
France	54
USA	38
Turkey	35
∑ (%)[b]	90

Country	Tomatoes
China	32,540
USA	11,250
Turkey	9855
India	8638
Egypt	7600
Italy	6351
Iran	4781
Spain	3679
Brazil	3278
Mexico	2878
Russian Fed.	2415
Greece	1712
∑ (%)[b]	76

Country	Cauliflower
China	8083
India	4508
USA	1288
Spain	460
Italy	438
France	362
Mexico	305
Poland	250
UK	219
Pakistan	209
∑ (%)[b]	89

Country	Pumpkin, squash and gourds
China	6060
India	3678
Russian Fed.	1185
Ukraine	1064
USA	862
Egypt	690
Iran	591
Italy	512
Cuba	447
Philippines	371
Turkey	365
∑ (%)[b]	75

Country	Cucumbers and gherkins
China	27,357
Turkey	1800
Iran	1721
Russian Fed.	1423
USA	982
Ukraine	685
Japan	628
Egypt	600
Indonesia	553
Spain	500
∑ (%)[b]	83

Country	Eggplants (aubergines)
China	17,530
India	8704
Egypt	1000
Turkey	924
Japan	372
Italy	338
Sudan	272
Indonesia	252
Philippines	192
Spain	175
∑ (%)[b]	93

Country	Chilies[a] and peppers, green
China	13,031
Turkey	1842
Mexico	1681
Spain	1074
USA	894
Indonesia	871
Nigeria	722
Egypt	460
Korea, Rep.	395
Italy	345
∑ (%)[b]	82

Table 17.2. (Continued)

Country	Onions, air dried
China	19,600
India	6435
USA	3346
Pakistan	2056
Russian Fed.	1789
Turkey	1765
Iran	1685
Egypt	1302
Brazil	1175
Japan	1158
Mexico	1151
Spain	1151
Netherlands	983
Korea, Rep.	890
Morocco	882
Indonesia	809
∑ (%)[b]	76

Country	Garlic
China	11,587
India	647
Korea, Rep.	331
Russian Fed.	256
USA	211
Egypt	162
Spain	148
Ukraine	145
Argentina	116
Myanmar	104
∑ (%)[b]	90

Country	Green beans
China	2431
Indonesia	830
Turkey	564
India	420
Egypt	215
Spain	215
Italy	191
Morocco	142
Belgium	110
USA	97
∑ (%)[b]	81

Country	Green peas
China	2408
India	1918
USA	859
France	354
Egypt	290
Morocco	147
UK	133
Turkey	90
Italy	88
Hungary	85
∑ (%)[b]	83

Country	Carrots and turnips
China	8700
Russian Fed.	1918
USA	1588
Poland	833
UK	833
Japan	762
Uzbekistan	745
France	693
Ukraine	640
Italy	615
Spain	600
Germany	504
Netherlands	487
Indonesia	440
Turkey	402
Mexico	383
∑ (%)[b]	75

Country	Watermelons
China	71,220
Turkey	3805
Iran	3259
USA	1719
Brazil	1505
Egypt	1500
Russian Fed.	986
Mexico	969
Algeria	785
Korea, Rep.	778
∑ (%)[b]	86

Country	Cantaloupes and other melons
China	15,525
Turkey	1766
USA	1208
Iran	1126
Spain	1042
India	653
Morocco	648
Italy	625
Mexico	570
Egypt	565
∑ (%)[b]	85

[a] Data including other Capsicum species.
[b] World production = 100 %.

Table 17.3. Production of starch containing roots, rhizomes and tubers in 2006 (1000 t)

Continent	Roots and tubers grand total	Potato	Sweet potato	Cassava (manioc)
World	736,748	315,100	123,510	226,337
Africa	216,059	16,446	12,904	122,088
America, Central	2759	1951	63	508
America, North	25,447	24,709	737	–
America, South and Caribbean	57,276	16,015	1846	37,042
Asia	307,396	129,624	107,320	67,011
Europe	126,869	126,515	77	–
Oceania	3700	1792	626	196

Country	Roots and tubers grand total	Country	Potato	Country	Sweet potato
China	176,433	China	70,338	China	100,222
Nigeria	92,214	Russian Fed.	38,573	Nigeria	3462
Russian Fed.	38,573	India	23,910	Uganda	2628
India	32,485	USA	19,713	Indonesia	1852
Brazil	30,602	Ukraine	19,467	Vietnam	1455
Indonesia	23,139	Germany	10,031	Tanzania	1056
Thailand	22,842	Poland	8982	Japan	989
USA	20,451	Belarus	8329	India	955
Ukraine	19,467	Netherlands	6500	Burundi	835
Congo	15,523	France	6354	Kenya	809
Ghana	14,988	UK	5684	∑ (%)[a]	93
Mozambique	11,615	Canada	4995		
Angola	10,088	Iran	4830		
Germany	10,031	Turkey	4397		
Vietnam	9539	Bangladesh	4161		
Poland	8982	∑ (%)[a]	75		
Belarus	8329				
Uganda	8182				
∑ (%)[a]	75				

Country	Cassava (manioc)
Nigeria	45,721
Brazil	26,713
Thailand	22,584
Indonesia	19,928
Congo	14,974
Mozambique	11,458
Ghana	9638
Angola	8810
Vietnam	7714
India	7620
∑ (%)[a]	77

[a] World production = 100%.

Table 17.4. Average composition of vegetables (as % of fresh edible portion)

Vegetable	Dry matter	N-Compounds (N ×6.25)	Available carbohydrates	Lipids	Dietary fiber	Ash
Mushrooms						
Champignon (cultivated *Agaricus arvensis, campestris*)	9.0	4.1	0.6	0.3	2.0	1.0
Chanterelle	8.5	2.6	0.2	0.5	3.3	1.6
Edible boletus (*Boletus edulis*)	11.4	5.4	0.5	0.4	6.0	0.9
Rooty vegetables						
Carrots	11.8	1.1	4.8	0.2	3.6	0.8
Radish (*Raphanus sativus*, elongated white fleshy root)	7.0	1.0	2.4	0.2	2.5	0.8
Viper's grass, *scorzonera*	23.2	1.4	2.2	0.4	18.3	1.0
Parsley	16.1	2.9	6.1	0.6		1.6
Tuberous vegetables (sprouting tubers)						
White (Irish) potato	22.2	2.0	14.8[a]	0.1	2.1	1.1
Celery (root)	11.6	1.6	2.3	0.3	4.2	1.0
Kohlrabi	8.4	2.0	3.7	0.2	1.4	1.0
Rutabaga	10.7	1.1	5.7	0.2	2.9	0.8
Radish (*Raphanus sativus*, reddish fleshy root)	5.6	1.1	2.1	0.1	1.6	0.9
Red beet, beetroot	13.8	1.6	8.4	0.1	2.5	1.1
Tuberous root vegetables						
Sweet potato	30.8	1.6	24.1[b]	0.6	3.1	1.1
Cassava (manioc)	36.9	0.9	32.0	0.2	2.9	0.7
Yam	31.1	2.0	22.4	0.1	5.6	1.0
Bulbous root vegetables						
Onion	11.4	1.2	4.9	0.3	1.8	0.6
Leek	12.1	2.2	3.3	0.3	2.3	0.9
Vegetable fennel	7.6	1.4	3.0	0.2	2.0	1.0
Stem (shoot) vegetables						
Asparagus	6.5	1.9	2.0	0.2	1.3	0.6
Leafy (stalk) vegetables						
Rhubarb	7.3	0.6	1.4	0.1	3.2	0.6
Leafy vegetables						
Endive (escarole)	5.6	1.3	2.3	0.2	1.3	0.8
Kale (curly cabbage)	14.1	4.3	2.5	0.9	4.2	1.5
Head lettuce	5.1	1.2	1.1	0.2	1.4	0.9
Brussels sprouts	15.0	4.5	3.3	0.3	4.4	1.2
Red cabbage	9.0	1.5	3.5	0.2	2.5	0.7
Spinach	8.5	2.6	0.6	0.3	2.6	1.5
Common (white) cabbage	9.6	1.3	4.2	0.2	3.0	0.7
Flowerhead (calix) vegetables						
Artichoke	17.5	2.4	2.6	0.1	10.8	1.3
Cauliflower	9.0	2.5	2.3	0.3	2.9	0.9
Broccoli	10.9	3.6	2.7	0.2	3.0	1.1

[a] Starch content 14.1%. [b] Starch and saccharose contents 19.6 and 2.8%, respectively.

Table 17.4. (Continued)

Vegetable	Dry matter	N-Compounds (N ×6.25)	Available carbohydrates	Lipids	Dietary fiber	Ash
Seed vegetables						
Chestnut	55.1	2.4	41.2	1.9	8.4	1.2
Green beans	10.5	2.4	5.1	0.2	1.9	0.7
Green peas	24.8	6.6	12.4	0.5	4.3	0.9
Fruity vegetables						
Eggplant	7.4	1.2	2.5	0.2	2.8	0.6
Squash	9.0	1.1	4.6	0.1	2.2	0.8
Green bell pepper	7.7	1.1	2.9	0.2	3.6	0.4
Cucumber	4.0	0.6	1.8	0.2	0.5	0.5
Tomato	5.8	1.0	2.6	0.2	1.0	0.5

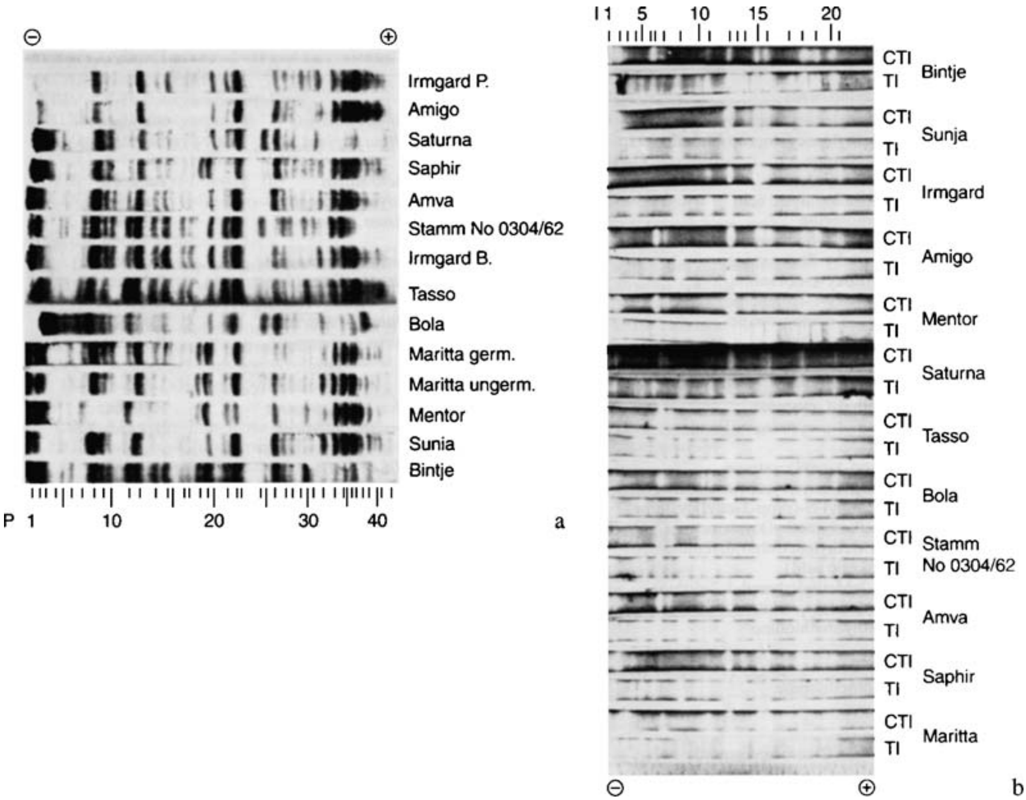
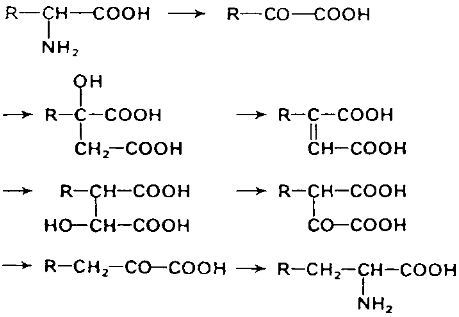


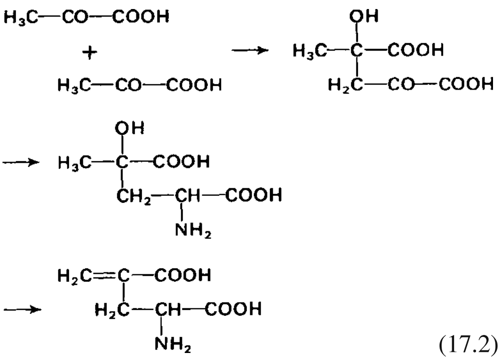
Fig. 17.1. Protein patterns of different potato cultivars obtained by isoelectric focussing on polyacrylamide gel pH 3–10. **a** Protein bands stained with Coomassie Blue; **b** Staining of trypsin and chymotrypsin inhibitors (TI, CTI): Incubation with trypsin or chymotrypsin, N-acetylphenylalanine-β-naphthyl ester and diazo blue B: inhibitor zones appear white on a red-violet background. (according to *Kaiser, Bruhn* and *Belitz*, 1974)

to ketoglutarate in the *Krebs* cycle:



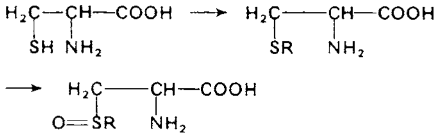
(17.1)

4-Methyleneglutamic acid (Table 17.5: XXXI) is formed from pyruvic acid:



(17.2)

The important precursors of onion flavor, the S-alkylcysteine sulfoxides, are formed as follows:

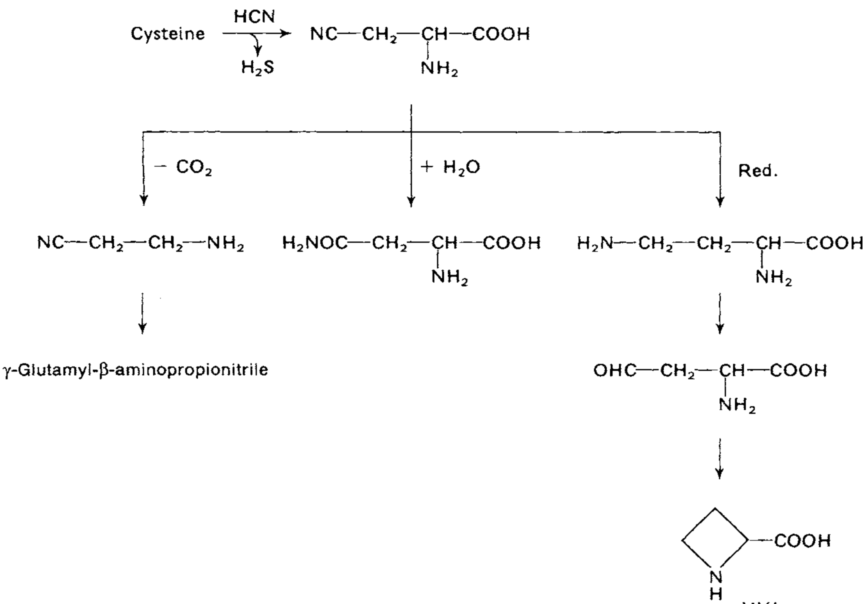


(17.3)

2,4-Diaminobutyric acid and some other compounds are derived from cysteine (cf. Reaction 17.4).

The aspartic acid semi-nitrile formed initially can be decarboxylated to β-amino propionitrile which, just as its γ-glutamyl derivative, is responsible for osteolathyrism in animals.

Hydrolysis of the semi-nitrile yields aspartic acid, hydrolysis and reduction yield 2,4- diaminobutyric acid, the oxalyl derivative of which, like oxalyldiaminopropionic acid, is a human neurotoxin. The main symptoms of neurolathyrism are paralysis of the limbs and muscular rigidity. 2,4-Diaminobutyric acid can be converted via the aspartic acid semialdehyde into 2-azetidine carboxylic acid (XXI), which occurs, for example, in sugar beets (Table 17.5).



XXI

(17.4)

Table 17.5. Occurrence of nonprotein amino acids in plants (the Roman numerals refer to Table 17.6)

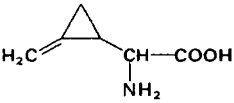
Amino acid		Plant		Family
Neutral aliphatic amino acids				
I	2-(Methylenecyclopropyl)-glycine	litchi	*Litchi chinensis*	Sapidaceae
II	3-(Methylenecyclopropyl)-L-alanine (Hypoglycine A)	akee	*Bligia sapida*	Sapidaceae
III	3-Cyano-L-alanine	common vetch	*Vicia sativa*	Fabaceae
IV	L-2-Aminobutyric acid	garden sage	*Salvia officinalis*	Lamiaceae
V	L-Homoserine	garden pea	*Pisum sativum*	Fabaceae
VI	O-Acetyl-L-homoserine	garden pea		
VII	O-Oxalyl-L-homoserine	vetchling	*Lathyrus sativum*	Fabaceae
VIII	5-Hydroxy-L-norvaline	jackbean	*Canavalia ensiformis*	Fabaceae
IX	4-Hydroxy-L-isoleucine	fenugreek	*Trigonella foenum-graecum*	Fabaceae
X	1-Amino-cyclopropane-1-carboxylic acid	apple pear	*Malus sylvestris* *Pyrus communis*	Rosaceae Rosaceae
Sulfurcontaining amino acids				
XI	S-Methyl-L-cysteine	garden bean	*Phaseolus vulgaris*	Fabaceae
XII	S-Methyl-L-cysteinesulfoxide	radish, cabbage cauliflower, broccoli	*Brassica oleracea*	Brassicaceae
XIII	S-(Prop-l-enyl)cysteine	garlic	*Allium sativum*	Liliaceae
XIV	S-(Prop-1-enyl)cysteinesulfoxide	onion	*Allium cepa*	Liliaceae
XV	γ-Glutamyl-S-(prop-1-enyl)cysteine	chive	*Allium schoenoprasum*	Liliaceae
XVI	S-(Carboxymethyl)cysteine	radish	*Raphanus sativus*	Brassicaceae
XVII	3,3′-(Methylenedithio)dialanine (Djenkolic acid)	djenkol bean	*Pithecolobium lobatum*	Fabaceae
XVIII	3,3′(-2-Methylethenyl-1,2-dithio)-dialanine (as γ-Glutamyl derivative)	chive	*Allium schoenoprasum*	Liliaceae
XIX	S-Methylmethionine	jackbean white cabbage asparagus	*Canavalia ensiformis* *Brassica oleracea* *Asparagus officinalis*	Fabaceae Brassicaceae Liliaceae
XX	Homomethionine	white cabbage	*Brassica oleracea*	Brassicaceae
Imino acids				
XXI	Azetidine-2-carboxylic acid	sugar beet	*Beta vulgaris ssp.*	Chenopodiaceae
XXII	tr-4-Methyl-L-proline	apple	*Malus sylvestris*	Rosaceae
XXIII	cis-4-Hydroxymethyl-L-proline	apple peel	*Malus sylvestris*	Rosaceae
XXIV	trans-4-Hydroxymethyl-L-proline	loquat	*Eriobotrya japonica*	Rosaceae
XXV	trans-4-Hydroxymethyl-D-proline	loquat	*Eriobotrya japonica*	Rosaceae
XXVI	4-Methylene-D,L-proline	loquat	*Eriobotrya japonica*	Rosaceae
XXVII	cis-3-Amino-L-proline	morel	*Morchella esculenta*	Ascomycetes
XXVIII	Pipecolic acid	many plants		
XXIX	3-Carboxy-6,7-dihydroxy-1,2,3,4-tetrahydroisoquinoline	cowage	*Mucuna sp.*	Fabaceae
XXX	1-Methyl-3-carboxy-6,7-dihydroxy-1,2,3,4-tetrahydroisoquinoline	cowage	*Mucuna sp.*	Fabaceae
Acidic amino acids and related compounds				
XXXI	4-Methyleneglutamic acid	peanut	*Arachis hypogaea*	Fabaceae
XXXII	4-Methyleneglutamine	peanut	*Arachis hypogaea*	Fabaceae
XXXIII	N^5-Ethyl-L-glutamine (L-Theanine)	tea	*Thea sinensis*	Theaceae
XXXIV	L-threo-4-Hydroxyglutamic acid			

Table 17.5. (continued)

Amino acid		Plant		Family
XXXV	3,4-Dihydroxyglutamic acid	garden cress	*Lepidium sativum*	Brassicaceae
		rhubarb	*Rheum rhabarbarum*	Polygonaceae
		carrot	*Daucus carota*	Apiaceae
		currant	*Ribis rubrum*	Saxifragaceae
		spinach	*Spinacia oleracea*	Chenopodiaceae
		longwort	*Angelica archangelica*	Apiaceae
XXXVI	L-2-Aminoadipic acid	many plants		
Basic amino acids and related compounds				
XXXVII	N^2-Oxalyl-diaminopropionic acid	vetchling	*Lathyrus sativus*	Fabaceae
XXXVIII	N^3-Oxalyl-diaminopropionic acid	vetchling	*Lathyrus sativus*	Fabaceae
XXXIX	2,4-Diaminobutyric acid (as N^4-Lactyl compound)	sugar beet	*Beta vulgaris ssp.*	Chenopodiaceae
XL	2-Amino-4-(guanidinooxy)butyric acid (Canavanine)	jackbean	*Canavalia ensiformis*	Fabaceae
		soybean	*Glycine max*	Fabaceae
XLI	4-Hydroxyornithine	common vetch	*Vicia sativa*	Fabaceae
XLII	L-Citrulline	watermelon	*Citrullus lanatus*	Cucurbitaceae
XLIII	Homocitrulline	horse bean	*Vicia faba*	Fabaceae
XLIV	4-Hydroxyhomocitrulline	horse bean	*Vicia faba*	Fabaceae
XLV	4-Hydroxyarginine	common vetch	*Vicia sativa*	Fabaceae
XLVI	4-Hydroxylysine	garden sage	*Salvia officinalis*	Lamiaceae
XLVII	5-Hydroxylysine	lucern	*Medicago sativa*	Fabaceae
XLVIII	N^6-Acetyl-L-lysine	sugar beet	*Beta vulgaris*	Chenopodiaceae
XLIX	N^6-Acetyl-allo-5-hydroxy-L-lysine	sugar beet	*Beta vulgaris*	Chenopodiaceae
Heterocyclic amino acids				
L	3-(2-Furoyl)-L-alanine	buck wheat	*Fagopyrum esculentum*	Polygonaceae
LI	3-Pyrazol-l-ylalanine	watermelon	*Citrullus lanatus*	Cucurbitaceae
LII	1-Alanyluracil (Willardin)	cucumber	*Cicumis sativus*	Cucurbitaceae
		garden pea	*Pisum sativum*	Fabaceae
LIII	3-Alanyluracil (Isowillardin)	garden pea	*Pisum sativum*	Fabaceae
LIV	3-Amino-3-carboxypyrrolidine	musk melon	*Cucurbita monlata*	Cucurbitaceae
LV	3-(2,6-Dihydroxypyrimidine-5-yl)-alanine	garden pea	*Pisum sativum*	Fabaceae
LVI	3-(Isoxazoline-5-one-2-yl)alanine	garden pea	*Pisum sativum*	Fabaceae
LVII	3-(2-β-D-Glucopyranosyl-isoxazoline-5-one-4-yl)alanine	garden pea	*Pisum sativum*	Fabaceae
Aromatic amino acids				
LVIII	N-Carbamoyl-4-hydroxy-phenylglycine	horse bean	*Vicia faba*	Fabaceae
LIX	L-3,4-Dihydroxyphenylalanine	horse bean	*Vicia fabea*	Fabaceae
		cowage	*Mucuna sp.*	Fabaceae
Other amino acids				
LX	γ-Glutamyl-L-β-phenyl-β-alaninie	adzuki bean	*Phaseolus angularis*	Fabaceae
LXI	Saccharopine	yeast	*Saccharomyces cerevisiae*	Saccharomy-cetaceae

Freshly harvested mushrooms contain aprox. 0.1% agaritin, β-N-(γ-L(+)-glutamyl)-4 hydroxymethylphenylhydrazine. Enzymes present can hydrolyze agaritin and oxidize the released 4-hydroxymethyl-phenylhydrazine to the diazonium salt.

Table 17.6. Structures of nonprotein amino acids in plants (structures and Roman numerals refer to Table 17.5)



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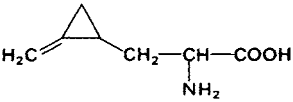

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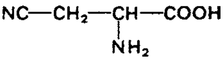

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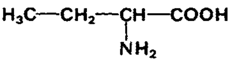

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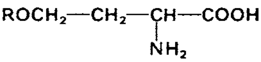
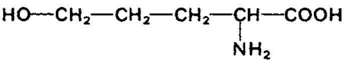


V: R = H
VI: R = H_3C—CO
VII: R = HOOC—CO



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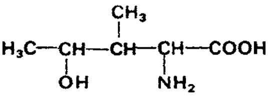

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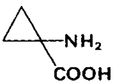

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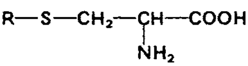
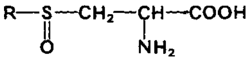
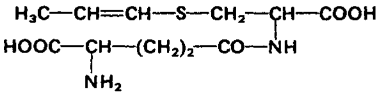


XI: R = CH_3
XIII: R = H_3C—CH=CH
XVI: R = HOOC—CH_2



XII: R = CH_3
XIV: R = H_3C—CH=CH



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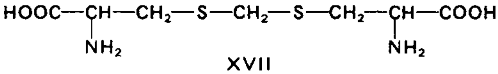

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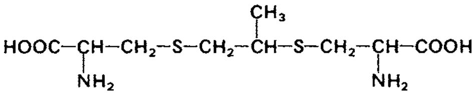

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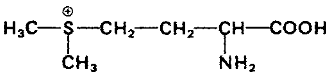

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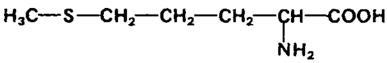

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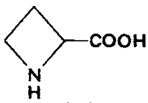
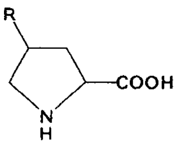
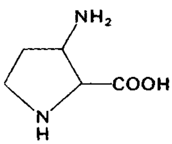


XXI



XXII: R = CH_3
XXIII, XXIV, XXV: R = $HOCH_2$



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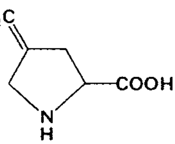

XXVI

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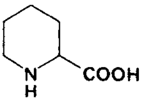

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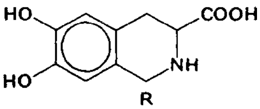
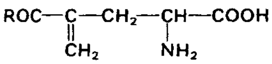
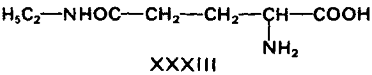


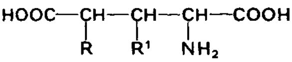
XXIX: R = H
XXX: R = CH_3



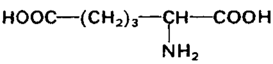
XXXI: R = OH XXXII: R = NH_2



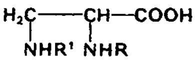
XXXIII



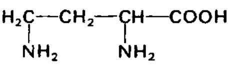
XXXIV: R = HO, R[1] = H
XXXV: R, R[1] = HO



XXXVI



XXXVII: R = HOOC—CO, R[1] = H
XXXVIII: R[1] = HOOC—CO, R = H



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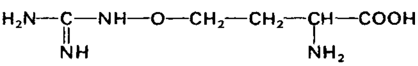
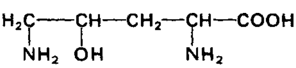
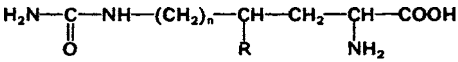


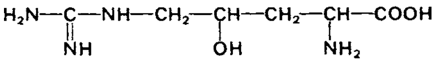
XL



XLI



XLII: n = 1, R = H
XLIII: n = 2, R = H
XLIV: n = 2, R = OH



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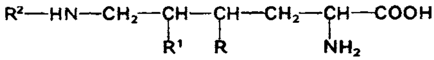
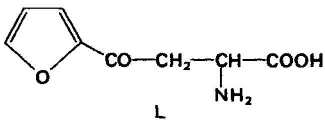


XLVI: R = OH, R[1], R[2] = H
XLVII: R[1] = OH, R, R[2] = H
XLVIII: R, R[1] = H, R[2] = CH_3CO
XLIX: R = H, R[1] = OH, R[2] = CH_3CO



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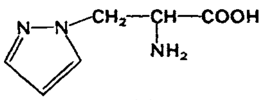

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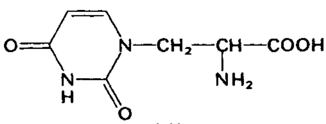
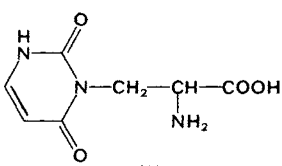


LII



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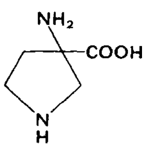

LIV

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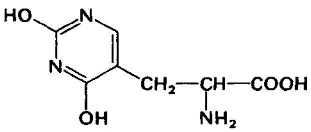

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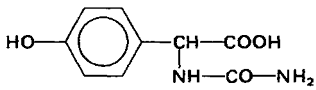
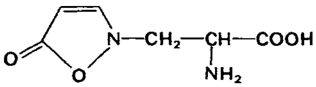


LVIII



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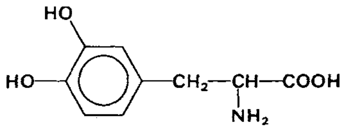

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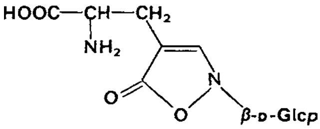

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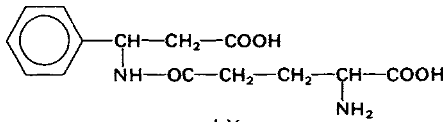
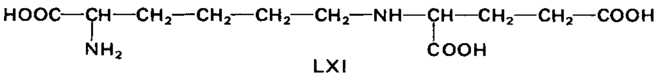


LX



LXI

17.1.2.1.3 Amines

The presence of amines has been confirmed in various vegetables; e. g., histamine, N-acetylhistamine and N,N-dimethylhistamine in spinach; and tryptamine, serotonin, melatonin and tyramine in tomatoes and eggplant (cf. 18.1.2.1.3).

17.1.2.2 Carbohydrates

17.1.2.2.1 Mono- and Oligosaccharides, Sugar Alcohols

The predominant sugars in vegetables are glucose and fructose (0.3–4%) as well as sucrose (0.1–12%). Other sugars occur in small amounts; e. g. glycosidically bound apiose in *Umbelliferae* (celery and parsley); 1^F-β- and 6^G-β-fructosylsaccharose in the allium group (onions, leeks); raffinose, stachyose and verbascose in *Fabaceae*; and mannitol in *Brassicaceae* and *Cucurbitaceae*.

17.1.2.2.2 Polysaccharides

Starch occurs widely as a storage carbohydrate and is present in large amounts in some root and tuber vegetables. In *Compositae* (e. g., artichoke, viper's grass, bot. *Scorzonera*), inulin, rather than starch, is the storge carbohydrate.

Other polysaccharides are cellulose, hemicelluloses and pectins. The pectin fraction has a distinct role in the tissue firmness of vegetables. Tomatoes become firmer as the total pectin content and the content of some minerals (Ca, Mg) increases, and as the degree of esterification of the pectin decreases. In processing cauliflower (cf. 17.2.3), 70 °C is favorable for preserving tissue firmness. The reason for this effect is the presence of pectinmethylesterase which, in vegetables, is fully inactivated only at temperatures above 88 °C, while at 70 °C it is active and provides a build-up of insoluble pectates. For the conversion of protopectin to pectin during plant tissue maturation or ripening see 18.1.3.3.1.

Table 17.7. Carotenoids[a] in vegetables[b]

	Green bell pepper	Red pepper (paprika)	Tomato	Watermelon
Total carotenoids[b]	0.9–3.0	12.7–28.4	5.1–8.5	5.5
Phytoene (I)	–	0.03	1.3	–
Phytofluene (II)	0.01	0.56	0.7	
α-Carotene (VI)	0.01	0.1	–	–
β-Carotene (VII)	0.54	2.7	0.59	0.23
γ-Carotene (V)	–	–	–	0.09
ζ-Carotene (III)	0.01	0.45	0.84	–
Lycopene (IV)			4.7	4.5
α-Cryptoxanthin, β-Cryptoxanthin	0.7	1.3	0.5	0.46
Lutein (IX)	0.6	–	0.12	0.01
Zeaxanthin (VIII)	0.02	3.9	–	–
Violaxanthin (XIII)	0.6	2.4	–	–
Capsanthin (X)		9.4	–	–
Neoxanthin (XX)	0.23	0.16	–	–

[a] Roman numerals refer to structural formula presented in Chapter 3.8.4.1.
[b] Values in mg carotene/100 g fresh weight.

17.1.2.3 Lipids

The lipid content of vegetables is generally low (0.1–0.9%). In addition to triacylglycerides, glyco- and phospholipids are present. Carotenoids are occasionally found in large amounts (cf. 18.1.2.3.2). Table 17.7 provides data on carotenoid compounds in green bell and paprika peppers, tomato and watermelon. For the occurrence of bitter cucurbitacins in *Cucurbitaceae*, see 18.1.2.3.3.

17.1.2.4 Organic Acids

The organic acids present in the highest concentration in vegetables are malic and citric acids (Table 17.8). The content of free titratable acids is 0.2–0.4 g/100 g fresh tissue, an amount which is low in comparison to fruits. Accordingly, the pH, with several exceptions such as tomato or rhubarb, is relatively high (5.5–6.5). Other acids of the citric acid cycle are present in negligible amounts. Oxalic acid occurs in larger amounts in some vegetables (Table 17.8).

Table 17.8. Organic acids in vegetables (mg/100 g fresh weight)

Vegetable	Malic acid	Citric acid	Oxalic acid
Artichoke	170	100	8.8
Eggplant	170	10	9.5
Cauliflower	201	20	–
Green beans	177	23	20–45
Broccoli	120	210	–
Green peas	139	142	–
Kale	215	220	7.5
Carrot	240	12	0–60
Leek	–	59	0–89
Rhubarb	910	137	230–500
Brussels sprouts	200	350	6.1
Red beet	37	195	181
Sorrel	–	–	360
White common cabbage	159	73	–
Onion	170	20	5.5
Potato	92	520	–
Tomato	51	328	–
Spinach	42	24	442

17.1.2.5 Phenolic Compounds

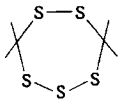
The phenolic compounds in plant material are dealt with in detail in 18.1.2.5. Hydroxybenzoic and hydroxycinnamic acids, flavones and flavonols also occur in vegetables. Table 17.9 provides data on the occurrence of anthocyanins in some vegetables.

17.1.2.6 Aroma Substances

Characteristic aroma compounds of several vegetables will be dealt with in more detail. The number following each vegetable corresponds to that given in Table 17.1. For aroma biosynthesis see 5.3.2.

17.1.2.6.1 Mushrooms (4)

The aroma in champignons originates from (R)-l-octen-3-ol derived from enzymatic oxidative degradation of linoleic acid (cf. 3.7.2.3). A small part of the alcohol is oxidized to 1-octen-3-one in fresh champignons. This compound has a mushroom-like odor when highly diluted and a metallic odor in higher concentrations. It contributes to the mushroom odor because its threshold value is lower by two powers of ten. Heating of champignons results in the complete oxidation of the alcohol to the ketone. Dried morels are a seasoning agent. The following compounds were identified as typical taste-compounds: (S)-morelid, (mixture of (S)-malic acid 1-O-α- and (S)-malic acid 1-O-β-D-glucopyranoside), L-glutamic acid, L-aspartic acid, γ-aminobutyric acid, malic acid, citric acid, acetic acid. (S)-Morelid intensifies the taste of L-glutamic acid and of NaCl. The mushroom *Lentium ediodes*, which is widely consumed in China and Japan, has a very intense aroma. The presence of 1,2,3,5,6-pentathiepane (lenthionine) has been confirmed, and it is a typical impact compound:



(17.5)

Its threshold values are 0.27–0.53 ppm (in water) or 12.5–25 ppm (in edible oil) It is derived biosynthetically from an S-alkyl cysteine sulfoxide, lentinic acid. Truffles, edible potato-shaped fungi, contain approx. 50 ng/g 5α-androst-16-ene-3 α-ol, which has a musky odor that contributes to the typical aroma (cf. 3.8.2.2.1).

Table 17.9. Anthocyanins in vegetables

Vegetable	Anthocyanin
Eggplant	Delphinidin-3-(p-coumaroyl-L-rhamnosyl-D-glucosyl)-5-D-glucoside
Radish	Pelargonidin-3-[glucosyl(1 → 2)-6-(p-coumaroyl)-β-D-glucosido]-5-glucoside
	Pelargonidin-3-[glucosyl(1 → 2)-6-(feruloyl)-β-D-glucosido]-5-glucoside
Red cabbage	Cyanidin-3-sophorosido-5-glucoside (sugar moiety esterified with sinapic acid, 1–3 moles)
Onion	Cyanidin glycoside
(red shell)	Peonidin-3-arabinoside

17.1.2.6.2 Potatoes (23)

3-Isobutyl-2-methoxypyrazine and 2,3-diethyl-5-methylpyrazine belong to the key aroma substances in raw potatoes. These two pyrazines are also essential for the aroma of boiled potatoes. The substances responsible for the aroma of boiled potatoes are shown in Table 17.10.
The potato aroma note can be reproduced with an aqueous solution (pH 6) of methanethiol, dimethylsulfide, 2,3-diethyl-5-methylpyrazine, 3-isobutyl-2-methoxypyrazine and methional in the concentrations given in Table 17.10. Although it smells of boiled potatoes, methional only rounds off this aroma quality. In the drying of blanched potatoes to give a granulate, the concentrations of the two pyrazines decrease and, therefore, the intensity of the potato note also decreases.

17.1.2.6.3 Celery Tubers (24)

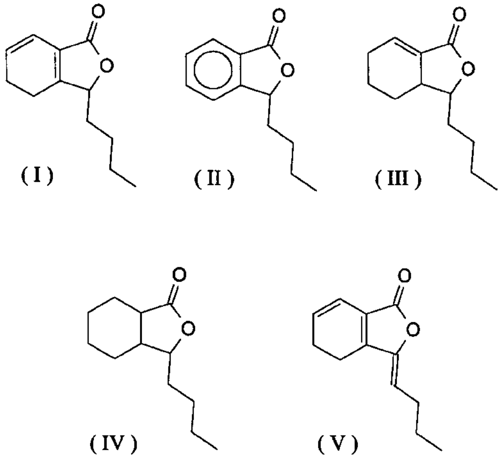
Celery aroma is due to the occurrence of phthalides in leaves, root, tuber and seeds. The

Table 17.10. Odorants in boiled potatoes[a]

Odorants	Concentration[b] (μg/kg)
Methylpropanal	4.4
2-Methylbutanal	5.7
3-Methylbutanal	2.6
Hexanal	102.0
(E,E)-2,4-Decadienal	7.3
trans-4,5-Epoxy-(E)-2-decenal	58.0
Methional	65.0
Dimethyltrisulfide	1.0
Methanethiol	15.4
Dimethylsulfide	8.8
2,3-Diethyl-5-methylpyrazine	0.17
3-Isobutyl-2-methoxypyrazine	0.07
4-Hydroxy-2,5-dimethyl-3(2H)-furanone (HD3F)	67.0
3-Hydroxy-4,5-dimethyl-2(5H)-furanone (HD2F)	2.2
Vanillin	1000

[a]Potatoes, boiled in water for 40 min, then peeled.
[b]Reference: fresh weight; water content: 78%.

main compound 3-butyl-4,5-dihydrophthalide (sedanolide: I, Formula 17.6) occurs in amounts of 3–20 mg/kg. In addition, 3-butylphthalide-(II, 0.6–1.6 mg/kg), 3-butyl-3a,4,5,6-tetrahydrophthalide (III, 1.0–4.4 mg/kg), 3-butylhexahydrophthalide (IV) and (Z)-3-butyliden-4,5-dihydrophthalide (Z-ligustilide: V, 0.6–2 mg/kg) have been identified. The (S)-enantiomer of II plays a big part in the aroma and it not only predominates, but also has a much lower odor threshold when compared with the (R)-enantiomer (S: 0.01 μg/kg; R: 10 μg/kg, water). Of the eight possible stereoisomers of the phthalide IV, the enantiomers 3R,3aR,7aS and 3S,3aR,7aS dominate in celery. But their contribution to the aroma must be low because of the high odor threshold (>125 μg/kg). Apart from the phthalides, the participation of (E,Z)-1,3,5-undecatriene in the aroma is under discussion.



(17.6)

17.1.2.6.4 Radishes (27)

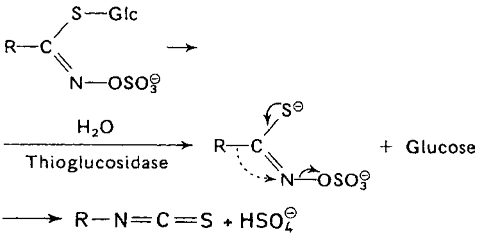
The sharp taste of the radish is due to 4-methylthio-trans-3-butenyl-isothiocyanate, which is released from the corresponding glucosinolate after the radish is sliced. Glucosinolates are widely distributed among *Brassicaceae* and some other plant families. Their occurrence in some types of cabbage is presented in Table 17.11.

Table 17.11. Glucosinolates in different types of cabbage (mg/kg fresh weight)

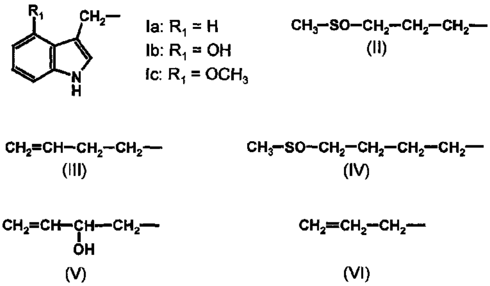
Compound[a]	Broccoli	Red cabbage	Brussels sprouts	Cauliflower	Savoy cabbage	White cabbage
Glucobrassicin (Ia)	20	16	31	21	46	22
4-Hydroxy-glucobrassicin (Ib)	5					
4-Methoxy-glucobrassicin (Ic)	4					
Glucoiberin (II)	4	11	24	16	52	23
Gluconapin (III)	n.d.	8	5	0.1	0.3	2
Glucoraphanin (IV)	21	21	4	0.7	1	4
Progoitrin (R-V)	n.d.	18	11	3	2	8
Sinigrin (VI)	n.d.	14	44	17	46	30

[a] The chemical structures are shown in Formula 17.7 und 17.10.
n.d.: not detected.

Glucosinolates are hydrolyzed by myrosinase, a thioglucosidase enzyme, to the corresponding isothiocyanates (mustard oils) on disintegration of the tissue (Formula 17.7). The residue R for the glucosinolates presented in Table 17.11 is shown in Formula 17.8.

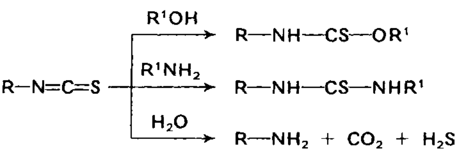


(17.7)



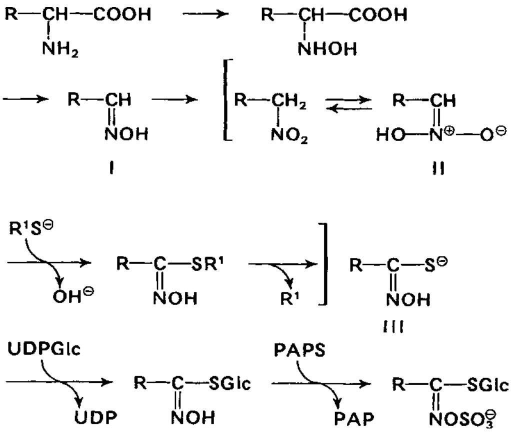
(17.8)

The decomposition corresponds to a *Lossen's* rearrangement of a hydroxamic acid. In addition to isothiocyanates, rhodanides and nitriles have been observed among the reaction products.
The isothiocyanates can react further, e. g., with hydroxy compounds or thiols, to form thiourethanes or dithiourethanes. In the presence of amines, thioureas result; while hydrolysis yields the corresponding amines and releases CO_2 and H_2S:



(17.9)

Biosynthesis of glucosinolates (reaction 17.10) starts from the corresponding amino acids, and proceeds via an oxime (I) and thiohydroximic acid (III). The intermediate reactions between steps I and III are not yet clarified. Tests with ^{14}C- and ^{35}S-labelled compounds suggest that the aci-form of the corresponding nitrocompound (II) functions as a thiol acceptor. Cysteine may be involved as a thiol donor. The sulfation is achieved by 3′-phosphoadenosine-5′-phosphosulfate (PAPS). The biosynthetic pathway for cyanogenic glycosides branches at the aldoxime (I) intermediate (cf. 16.2.6).



(17.10)

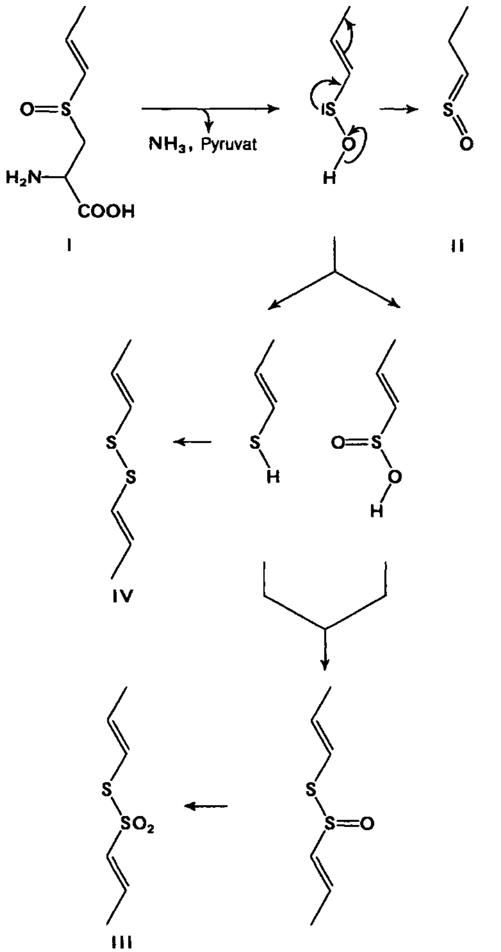
17.1.2.6.5 Red Beets (28)

Geosmin (structure cf. 5.1.5) is the character impact compound of the red beet.

17.1.2.6.6 Garlic (33) and Onions (34)

The compound which causes tears (the lachrymatory factor) is (Z)-propanethial-S-oxide (II) which, once the onion bulb is sliced, is derived from trans-(+)-S-(1-propenyl)-L-cysteine sulfoxide (I) by the action of the enzyme alliinase. Alliinase has pyridoxalphosphate as its coenzyme (cf. reaction sequence 17.11). Chopping of onions releases 3-mercapto-2-methylpentan-1-ol, which, with its very low threshold of 0.0016 µg/l (water), smells of meat broth and onions. Raw onions contain 8–32 µg/kg, and onions which have been cut, stored for 30 minutes and then cooked contain

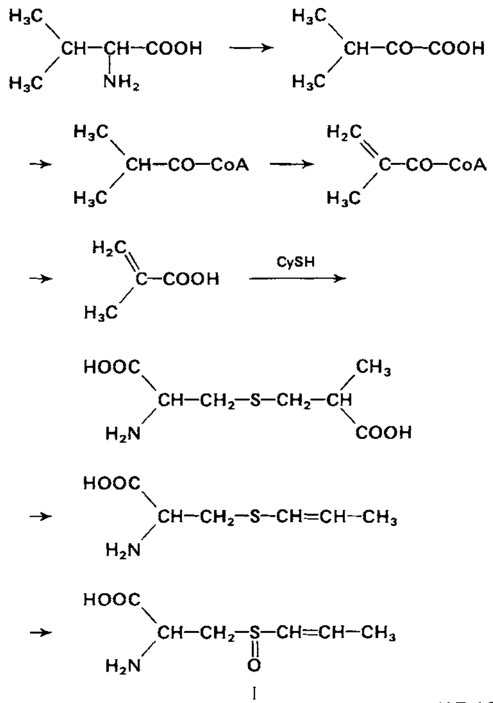
34–246 μg/kg. The formation involves the attachment of H_2S to the aldol condensation product of propanal and enzymatic reduction of the carbonyl group.



(17.11)

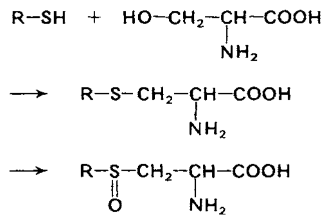
Alkylthiosulfonates (III) are also responsible for the aroma of raw onions, while propyl- and propenyl disulfides (IV) and trisulfides are also supposed to play a role in the aroma of cooked onions. The aroma of fried onions is derived from dimethylthiophenes.

Precursors of importance for the aroma of onions, other than compound I, are S-methyl and S-propyl-L-cysteine sulfoxide. Precursor I is biosynthesized from valine and cysteine (cf. reaction sequence 17.12).



(17.12)

The key precursor for garlic aroma is S-allyl-L-cysteine sulfoxide (alliin) which, as in onions, occurs in garlic bulbs together with S-methyl- and S-propyl-compounds. The allyl and propyl-compounds are assumed to be synthesized from serine and corresponding thiols:



(17.13)

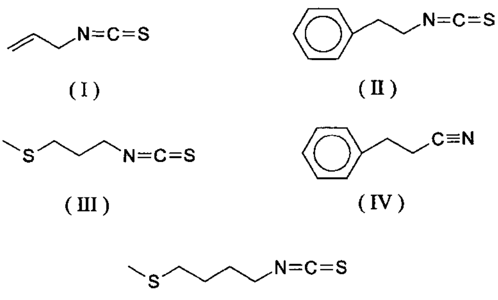
Diallylthiosulfinate (allicin) and diallyldisulfide are formed from the main component by means of the enzyme alliinase. Both are character impact compounds of garlic.

17.1.2.6.7 Watercress (39)

Phenylethylisothiocyanate is responsible for the aroma of this plant of the mustard family (*Brassicaceae*). Decomposition of the corresponding glucosinolate gives phenylpropionitrile, the main component, and some other nitriles, e. g., 8-methylthiooctanonitrile and 9-methylthiononanonitrile.

17.1.2.6.8 White Cabbage, Red Cabage and Brussels Sprouts (52, 49, 48)

Mustard oil is more than 6% of the total volatile fraction of cooked white and red cabbages. There is such a high proportion of allylisothiocyanate (I, Formula 17.14) present that it participates in the aroma of boiled white cabbage in spite of its high odor threshold of 375 μg/kg (water). In addition, 2-phenylethylthiocyanate (II, odor threshold 6 μg/kg, water), 3-methylthiopropylisothiocyanate (III, 5 μg/kg) and 2-phenylethylcyanide (IV, 15 μg/kg) could be involved in the aroma.
Dimethylsulfide is another important odorant formed during the cooking of cabbage and other vegetables. It also appears that 3-alkyl-2-methoxypyrazine plays a role in cabbage aroma.



(17.14)

The total impact of the aroma in cooked frozen Brussels sprouts is less satisfactory than in cooked fresh material. In the former case, analysis has revealed comparatively little allyl mustard oil and more allylnitrile. Isothiocyanates in low concentrations are pleasant and appetite-stimulating, while nitriles are reminiscent of garlic odor. The shift in the concentration ratio of the two compounds is attributed to myrosinase enzyme inactivation during blanching prior to freezing. As a consequence of this, allylglucosinolate in frozen Brussels sprouts is thermally degraded only on subsequent cooking, preferentially forming nitriles. Goitrin is responsible for the bitter taste that can occur in Brussels sprouts (cf. 17.1.2.9.3).

17.1.2.6.9 Spinach (51)

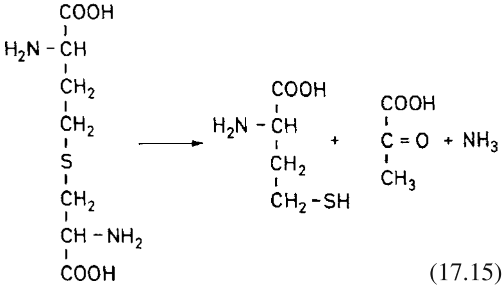
The compounds (Z)-3-hexenal, methanethiol, (Z)-1,5-octadien-3-one, dimethyltrisulfide, 3-isopropyl-2-methoxypyrazine and 3-*sec*-butyl-2-methoxypyrazine contribute to the aroma of the fresh vegetable. In cooked spinach, (Z)-3-hexenal decreases and dimethylsulfide, methanethiol, methional and 2-acetyl-1-pyrroline are dominant.

17.1.2.6.10 Artichoke (55)

1-Octen-3-one, the herbaceous smelling 1-hexen-3-one (odor threshold 0.02 μg/kg, water) and phenylacetaldehyde contribute to the aroma of boiled artichokes with high aroma values.

17.1.2.6.11 Cauliflower (56), Broccoli (57)

In cooked cauliflower and broccoli, the aroma compounds of importance are the sulfur compounds mentioned for white cabbage. 3-Methylthiopropylisothiocyanate, 3-methylthiopropylcyanide (odor threshold 82 μg/kg, water) and nonanal contribute to the typical aroma of cauliflower and 4-methylthiobutylisothiocyanate (V, cf. Formula 17.14), 4-methylthiobutylcyanide as well as II and IV to the aroma of broccoli.
During blanching of these vegetables, cysta thionine-β-lyase (EC 4.4.1.8, cystine lyase) must be inactivated because this enzyme, which catalyzes the reaction shown in formula 17.15, produces an aroma defect. The undesirable aroma substances are formed by the degradation of the homocysteine released.



(17.15)

17.1.2.6.12 Green Peas (60)

The aroma of green peas is derived from aldehydes and pyrazines (3-isopropyl-, 3-*sec*-butyl- and 3-isobutyl-2-methoxypyrazine).

17.1.2.6.13 Cucumbers (64)

The following aldehydes play an important role in cucumber aroma: (E,Z)-2,6-nonadienal and (E)-2-nonenal. Linoleic and linolenic acids, as shown in Fig. 3.31, are the precursors for these and other aldehydes (Z)-3-hexenal, (E)-2-hexenal, (E)-2-nonenal.

17.1.2.6.14 Tomatoes (66)

Among a large number of volatile compounds, (Z)-3-hexenal, β-ionone, hexanal, β-damascenone, 1-penten-3-one, and 3-methylbutanal are of special importance for the aroma of tomatoes (cf. Table 17.12).

Table 17.12. Odorants in tomatoes and tomato paste

Compound	Aroma value[a]	
	Tomato	Tomato-paste
(Z)-3-Hexenal	5×10^4	<30
β-Ionone	6.3×10^2	–[b]
Hexanal	6.2×10^2	–
(E)-β-Damascenone	5×10^2	5.7×10^3
1-Penten-3-one	5×10^2	–
3-Methylbutanal	130	152
(E)-2-Hexenal	16	–
2-Isobutylthiazole	10	–
Dimethylsulfide	–	1.4×10^3
Methional	–	650
3-Hydroxy-4,5-dimethyl-5(2H)-furanone (HD2F)	–	213
4-Hydroxy-2,5-dimethyl-3(2H)-furanone (HD3F)	–	138
Eugenol	–	95
Methylpropanal	–	40

[a] The aroma values were calculated on the basis of the odor threshold in water.
[b] The compound does not contribute to the aroma here.

In tomato paste, for example (cf. Table 17.12), it was found that the changes in aroma caused by heating are primarily due to the formation of dimethylsulfide, methional, the furanones HD2F and HD3F and the increase in β-damascenone, and a substantial decrease in (Z)-3-hexenal and hexanal.

17.1.2.7 Vitamins

Table 17.13 provides data on the vitamin content of some vegetables. The values given may vary significantly with vegetable cultivar and climate. In spinach, for example, the ascorbic acid content varies from 40–155 mg/100 g fresh weight. Freshly harvested potatoes contain 15–20 mg/100 g of vitamin C. The content drops by 50% on storage (4 °C) for 6–8 months and by 40–60% on peeling and cooking.

17.1.2.8 Minerals

Table 17.14 reviews the mineral content of some vegetables. Potassium is by far the most abundant constituent, followed by calcium, sodium and magnesium. The major anions are phosphate, chloride and carbonate. All other elements are present in much lower amounts. For nitrate content see 9.8.

17.1.2.9 Other Constituents

Plant pigments other than carotenoids and anthocyanins, e. g., chlorophyll and betalains, are also of great importance in vegetables and are covered in this section together with goitrogenic compounds occurring in *Brassicaceae*.

17.1.2.9.1 Chlorophyll

The green color of leaves and unripe fruits is due to the pigments chlorophyll a (blue-green) and chlorophyll b (yellow-green), occurring together in a ratio shown in Table 17.15 (see Formula 17.16). Figure 17.2 shows the absorption spectra of chlorophylls a and b. Removal of magnesium

Table 17.13. Vitamin content in vegetables (mg/100 g fresh weight)

Vegetable	Ascorbic acid	Thiamine	Riboflavin	Nicotinicacid	Folacid	α-Tocopherol	β-Carotene
Artichoke	8	0.14	0.01	1.0	–	0.19	0.10
Eggplant	5	0.05	0.05	0.6	0.03	0.03	0.04
Cauliflower	78	0.09	0.10	0.7	0.09	0.07	0.01
Broccoli	100	0.10	0.18	0.9	0.11	0.61	0.9
Kale	105	0.10	0.26	2.1	0.19	1.7	5.2
Cucumber	8	0.02	0.03	0.2	0.02	0.06	0.4
Head lettuce	10	0.06	0.09	0.3	0.06	0.6	1.1
Carrot	8	0.06	0.05	0.6	0.03	0.4	7.6
Green bell pepper	138	0.05	0.04	0.3	0.06	2.5	0.5
Leek	26	0.09	0.06	0.5	0.10	0.5	0.7
Radish	26	0.03	0.03	0.4	0.02	–	0.01
Brussels sprouts	102	0.10	0.16	0.7	0.10	0.6	0.5
Red beet	10	0.03	0.05	0.2	0.08	0.04	0.01
Red cabbage	61	0.06	0.04	0.4	0.04	1.7	0.02
Celery	8	0.05	0.06	0.7	0.01	–	2.9
Asparagus	20	0.11	0.10	1.0	0.11	2.0	0.5
Spinach	51	0.10	0.20	0.6	0.15	1.3	4.8
Tomato	23	0.06	0.04	0.5	0.02	0.8	0.6

Table 17.14. Minerals in vegetables (mg/100 g fresh weight)

Vegetable	K	Na	Ca	Mg	Fe	Mn	Co	Cu	Zn	P	Cl	F	I
Potato	418	2.7	6.4	21	0.4	0.15	0.001	0.09	0.3	50	50	0.01	0.003
Spinach	554	69	60	117	3.8	0.6	0.002	0.1	0.6	46	54	0.08	0.012
Carrot	321	61	37	13	0.4	0.2	0.001	0.05	0.3	35	59	0.02	0.002
Cauliflower	328	16	20	17	0.6	0.2	–	0.05	0.2	54	19	0.01	0.006
Green beans	256	1.7	51	26	0.8	0.2	–	0.1	0.3	37	13	0.01	0.003
Green peas	296	2	26	33	1.9	0.4	0.003	0.2	0.9	119	40	0.02	0.004
Cucumber	141	8.5	15	8	0.5	0.1	–	0.04	0.2	17	37	0.01	0.003
Red beet	336	86	29	1.4	0.9	0.2	0.01	0.08	0.4	45	0.2	0.01	0.005
Tomato	297	6.3	14	20	0.5	0.1	0.01	0.06	0.2	26	30	0.02	0.002
White common cabbage	227	13	46	23	0.5	0.2	0.01	0.03	0.2	36	37	0.01	0.005

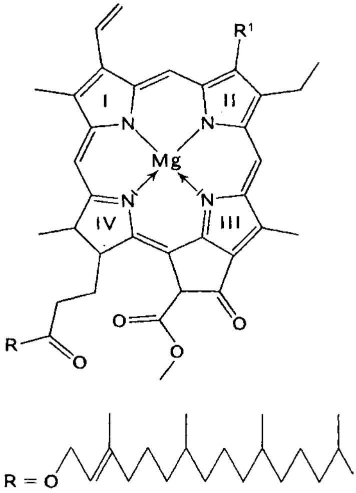
Table 17.15. Chlorophylls a and b in vegetables and fruit

Food	Chlorophyll a (mg/kg)[a]	Chlorophyll b
Green beans	118	35
Kale	1898	406
White cabbage	8	2
Cucumber	64	24
Parsley	890	288
Green bell pepper	98	33
Green peas	106	22
Spinach	946	202
Kiwi	17	8
Gooseberry	5	1

[a] Refers to fresh weight.

from the chlorophylls gives pheophytins a and b, both of which are olive-brown. Replacing magnesium by metal ions such as Sn^{2+} or Fe^{3+} likewise yields greyish-brown compounds. If, however, $Mg^{2\oplus}$ is replaced by $Zn^{2\oplus}$ and $Cu^{2\oplus}$ (weight ratio 10:1), a green colored complex is formed, which is very stable at pH 5.5. Upon removal of the phytol group, for example by the action of the chlorophyllase enzyme, the chlorophylls are converted into chlorophyllides a and b, while the hydrolysis of pheophytins yields pheophorbides a and b.

Chlorophylls and pheophytins are lipophilic due to the presence of the phytol group, while chlorophyllides and pheophorbides, without phytol,

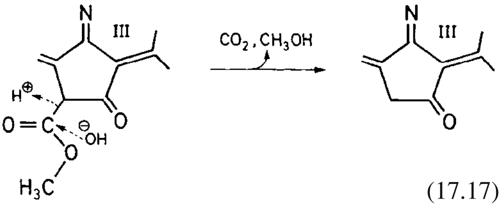


Chlorophyll a: $R^1 = CH_3$
Chlorophyll b: $R^1 = CHO$ (17.16)

are hydrophilic. Conversion of chlorophylls to pheophytins, which is accompanied by a color change, occurs readily upon heating plant material in weakly acidic solutions and, less readily, at pH 7. Color changes are encountered most visibly in processing of green peas, green beans, kale, Brussels sprouts and spinach. Table 17.16 shows that higher temperatures and shorter heating times provide better color retention than prolonged heating at lower temperatures.

Chlorophyllase is mostly inactivated when vegetables are blanched, hence chlorophyllides and pheophorbides are rarely detected. However, in the fermentation of cucumbers, chlorophyllase is active. The result is a color change from dark-green to olive-green, caused by large amounts of pheophorbides.

On stronger heating (sterilization, drying), a part of the pheophytins undergoes hydrolysis, releasing carbonic acid monomethylester which decomposes into CO_2 and methanol:



(17.17)

The corresponding pyropheophytins are formed which can be determined next to the pheophytins by using HPLC (Fig. 17.3). For example, Table 17.17 shows the changes in the chloropigments of spinach as a function of the duration of heat sterilization.

A change in color occurs during storage of dried vegetables, its extent increases with increasing water content. The conversion of chlorophylls to pheophytins continues in blanched vegeta-

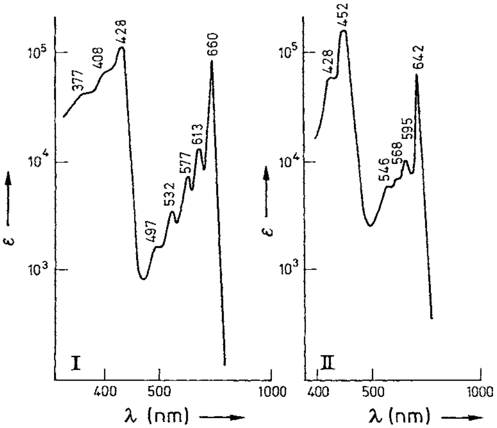


Fig. 17.2. Absorption spectra of chlorophylls a (I) and b (II). Solvent: diethyl ether (I) or diethyl ether +1% CCl_4 (II)

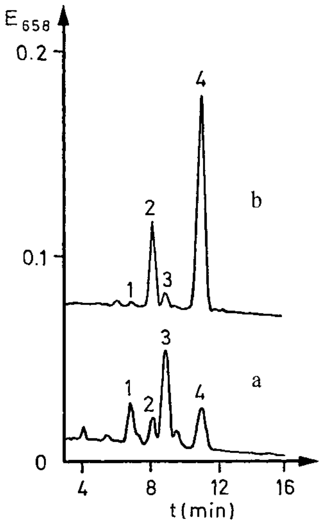


Fig. 17.3. HPLC of chloro-pigments from sterilized cans. Green beans *(a)*, spinach *(b)* (according to *Schwartz* and *von Elbe*, 1983). *1* Pheophytin b, *2* pyropheophytin b, *3* pheophytin a, *4* pyropheophytin a

Table 17.16. Changes in the chlorophyll fraction during processing (values in % of the total pigment content of unprocessed vegetables)

Vegetable	Process	Chlorophylls		Chlorophyllides		Pheophytins		Pheophorbides	
		a	b	a	b	a	b	a	b
Green beans	Untreated	49	25	0	0	18	8	0	0
	Blanched, 4 min/100 °C	37	24	0	0	19	10	0	0
Cucumbers	Untreated	51	30	0	0	15	5	0	0
	Blanched, 4 min/100 °C	34	24	6	3	22	1	5	7
Cucumbers	Untreated	67	33	0	0	0	0	0	0
	Fermented (pickled), 6 days	4	7	3	5	10	3	47	15
	Fermented (pickled), 24 days	0	0	0	0	16	7	57	28

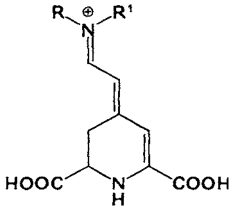
Table 17.17. Effects of the heat sterilization of spinach on the composition of chloropigments (mg/g solids)

Heating to 121 °C (min)	Chlorophyll		Pheophytin		Pyropheophytin	
	a	b	a	b	a	b
Control	6.98	2.49	0	0	0	0
2	5.72	2.46	1.36	0.13	0	0
4	4.59	2.21	2.20	0.29	0.12	0
7	2.81	1.75	3.12	0.57	0.35	0
15	0.59	0.89	3.32	0.78	1.09	0.27
30	0	0.24	2.45	0.66	1.74	0.57
60			1.01	0.32	3.62	1.24

bles even during frozen storage. In beans and Brussels sprouts, immediately after blanching (2 min at 100 °C), the pheophytin content amounts to 8–9%, while after storage for 12 months at −18 °C it increases to 68–83%. Pheophytin content rises from 0% to only 4–6% in paprika peppers and peas under the same conditions.

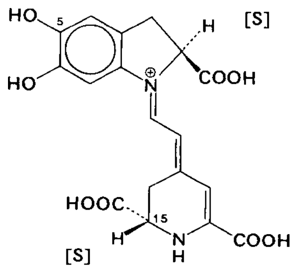
17.1.2.9.2 Betalains

Pigments known as betalains occur in centrospermae, e. g., in red beet and also in some mushrooms (the red cap of fly amanita). They consist of red-violet betacyanins ($\lambda_{max} \sim 540$ nm) and yellow betaxanthins ($\lambda_{max} \sim 480$ nm). They have the general structure:

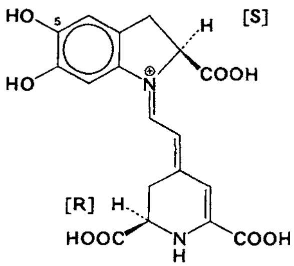


(17.18)

About 50 betalains have been identified. The majority have an acylated sugar moiety. The acids involved are sulfuric, malonic, caffeic, sinapic, citric and *p*-coumaric acids. All betacyanins are derived from two aglycones: betanidin (I) and isobetanidin (II), the latter being the C-15 epimer of betanidin:

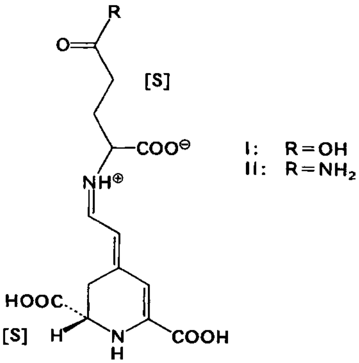


I



II

(17.19)

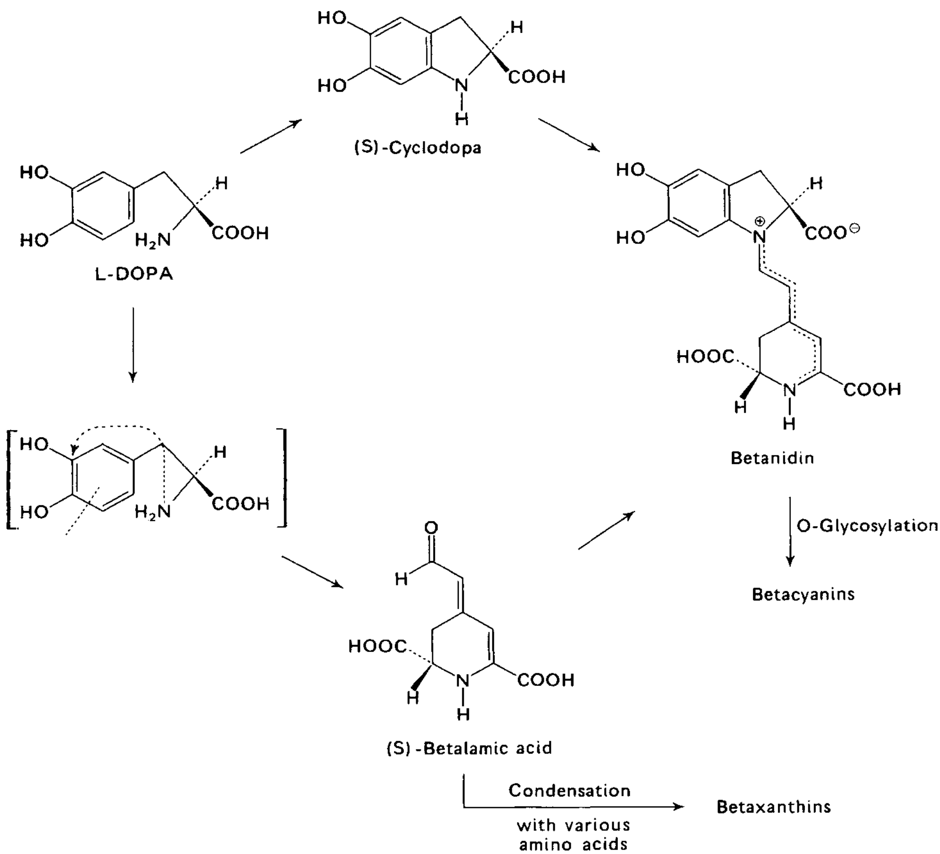


(17.20)

Betanin is the main pigment of red beet. It is a betanidin 5-0-β-glucoside. The betaxanthins have only the dihydropyridine ring in common. The other structural features are more variable than in betacyanins. Examples of betaxanthins are natural vulgaxanthins I and II, also from red beet (*Beta vulgaris*):

Betalain biosynthesis starts with dopa by opening of its benzene ring, followed by cyclization to a dihydropyridine. The (S)-betalamic acid which is formed undergoes condensation with (S)-cyclodopa to betacyanins or with some other amino acids to betaxanthins (cf. reaction sequence 17.21).

Red betanin is water soluble and is used to color food. Its application is, however, limited because it hydrolytically decomposes into the colorless cyclodopa-5-0-β-glucoside and the yellow (S)-betalamic acid. This reaction is reversible. Since the activation energy of the forward reaction ($72\,kJ \times mol^{-1}$), greatly exceeds that of the back reaction ($2.7\,kJ \times mol^{-1}$), a part of the betanin is regenerated at higher temperatures. Betanin is also sensitive to oxygen.

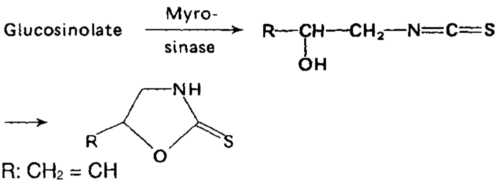


(17.21)

17.1.2.9.3 Goitrogenic Substances

Brassicaceae contain glucosinolates which decompose enzymatically, e. g., into rhodanides. For example, in savoy cabbage the rhodanide content is 30 mg/100 g fresh weight, while in cauliflower it is 10 mg and in kohlrabi 2 mg. Since rhodanide interferes with iodine uptake by the thyroid gland, large amounts of cabbage together with low amounts of iodine in the diet may cause goiter.

Oxazolidine-2-thiones are also goitrogenic. They occur as secondary products in the enzymatic hydrolysate of glucosinolates when the initially formed mustard oils contain a hydroxy group in position 2:



(17.22)

The levels of the corresponding glucosinolates are up to 0.02% in yellow and white beets and up to 0.8% in seeds of *Brassicaceae* (all members of the cabbage family; kohlrabi, turnip; rapeseed). The leaves contain only negligible amounts of these compounds.

There are 3–15 mg/kg of 5-vinyloxazolidine-2-thione in sliced turnips. Direct intake of thiooxazolidones by humans is unlikely since the vegetable is generally consumed in cooked form. Consequently, the myrosinase enzyme is inactivated and there is no release of goitrogenic compounds. However, brussels sprouts are exceptions, as higher amounts (70–110 mg/kg) of bitter tasting goitrin is formed from progoitrin during cooking. An indirect intake is possible through milk when such plants are used as animal feed, resulting in a goitrogenic compound content of 50–100 μg/l of milk. The oxazolidine-2-thiones inhibit the iodination of tyrosine, an effect unlike that of rhodanides, which may be offset not by intake of iodine but only by intake of thyroxine.

17.1.2.9.4 Steroid Alkaloids

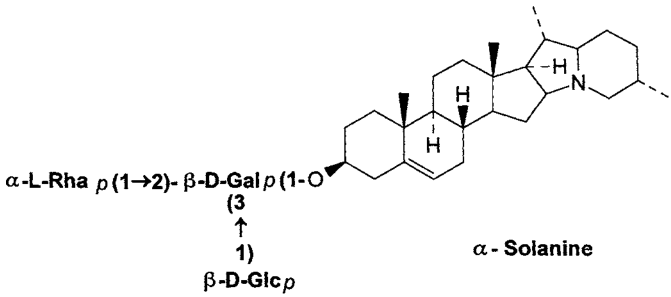
Steroid alkaloids are plant constituents having a C_{27} steroid skeleton and nitrogen content. *Solanaceae* contain these compounds, their occurrence in potatoes being the most interesting from a food chemistry point of view.

The main compounds in the potato tuber are α-solanine (Formula 17.23) and α-chaconine, which differs from the former compound only in the structure of the trisaccharide (substitution of galactose and glucose with glucose and rhamnose). α-Solanine and α-chaconine and their aglycone solanidine have a bitter/burning taste (Table 17.18) and these sensations last long. The taste thresholds have to be determined in the presence of lactic acid due to a lack of water

Table 17.18. Taste of the steroid alkaloids occurring in potatoes

Compound[a]	Taste threshold (mg/kg)	
	Bitter	Burning
α-Solanine	3.1	6.25
α-Chaconine	0.78	3.13
Solanidine	3.1	–
Caffeine	12.5	–

[a] Dissolved in 0.02% lactic acid.



(17.23)

solubility. Caffeine was used as a comparison. In potatoes, the bitter taste appears if the concentration of the steroid alkaloids exceeds 73 mg/kg. Stress during growth and the exposure of the potatoes to light after harvesting stimulate the formation of these bitter substances.

17.1.3 Storage

The storability of vegetables varies greatly and depends mostly on type, but also on vegetable quality. While some leafy vegetables, such as lettuce and spinach as well as beans, peas, cauliflower, cucumbers, asparagus and tomatoes have limited storage time, root and tuber vegetables, such as carrots, potatoes, kohlrabi, turnips, red table beets, celery, onions and late cabbage cultivars, can be stored for months. Cold storage at high air humidity is the most appropriate. Table 17.19 lists some common storage conditions. The relative air humidity has to be 80–95%. The weight loss experienced in these storage times is 2–10%. Ascorbic acid and carotene contents generally decrease with storage. Starch and protein degradation also occurs and there can be a rise in the free acid content of vegetables such as cauliflower, lettuce and spinach.

Table 17.19. Effect of cold storage temperature on vegetable shelf life

Vegetable	Temperature range (°C)	Shelf life (weeks)
Cauliflower	−1/0	4–6
Green beans	+3/+4	1–2
Green peas[a]	−1/0	4–6
Kale	−2/−1	12
Cucumber	+1/+2	2–3
Head lettuce	+0.5/+1	2–4
Carrot	−0.5/+0.5	8–10
Green bell pepper	−1/0	4
Leek	−1/0	8–12
Brussels sprouts	−3/−2	6–10
Red beet	−0.5/+0.5	16–26
Celery	−0.5/+1	26
Asparagus	+0.5/+1	2–4
Spinach	−1/0	2–4
Tomato	+1/+2	2–4
Onion	−2.5/−2	40

[a] Kept in pods.